Development of polyaniline for sensor applications: A review

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Abstract: This review is focusing on the uses of polyaniline as conductive sensors over the past decade and especially for biosensors to be within easy reach. The effort of conducting polymers has been on modern reviewing literature that addressing use as a sensor. In addition, the gradual development in the literature on the evolution of polyaniline as electrical conductivity methods and sensor in the chemical or biological field according to time sequence. Numbers of potential applications and different possible uses have shown promising application for polyaniline polymers.

Keywords: Polyaniline, biosensor, application, conducting polymers, dopin.

List of acronyms

| Acronym | Meaning |
|---------|---------|
| APS | ammonium peroxidisulphate |
| BSA | bovine serum albumin |
| CFU | Colony-forming unit |
| CNFs | functionalize carbon nanofibers |
| COC | chemical oxidation-casting |
| CPE | carbon paste electrode |
| CVD | chemical vapor deposition |
| dsDNA | double-strand DNA |
| GCE | glassy carbon electrode |
| GO | graphite oxide nanocomposite |
| GOD | glucose oxidase |
| IMB | Immuno-magnetic Bead |
| IO | impregnated oxidation |
| LB | Langmuir–Blodgett |
| NF | Nano fibers |
| MWCNT | Multi-walled carbon nanotubes |
| NMP | N-methyl pyrrolidone |
| NPs | nanoparticles |
| PLED | polymer light-emitting diode |
| PPY | polypyrrole |
| PVDF | polyvinylidene fluoride |
| RH | Relative Humidity |
| SA | stearic acid |
| SEM | scanning electron microscopy |
| SPCE | screen-printed carbon electrode |
| ssDNA | single-strand DNA |
1. Introduction:

1.1. History of polyaniline
The past of the revelation and starting points of polyaniline were made with the oxidation of aniline by F. Ferdinand Runge in 1834 and finishing up with the principal electrochemical oxidation of aniline by Henry Letheby in 1862. And then the exploration of its conductive abilities in the 1960s [1]. Polyaniline has “Good conductive properties” [2]. Either alone or interaction (doped) with other materials and/or elements according to the synthesis requirements, various types of applications have been produced in chemical or biochemical fields. In addition, the way to make polyaniline as a sensor is different depending upon how it is synthesized, either as a pole or as thin layer... etc. [1,2].

1.2. Synthesis of polyaniline (PANI) Polymer:
In 2014, S. M. Pethe and S. B. Kondawar were expressed that optical and electrical capacities of leading polyaniline nanofibers, which can be incorporated by various techniques, relied upon interfacial polymerization and rapidly blended responses. It has been developed that can promptly yield nanofibers by marginally altering the regular synthetic combination of polyaniline without the requirement for any format or auxiliary coordinating element [3]. In 2016 T. Sen and his research group have the combination and detecting the utilization of polyaniline Nano-composite. Presentations that the majority of the strategies that being used for Nanocomposite item are commonly founded on two different ways: (I) one-advance redox responses where synchronous polymerization of aniline and development of nanoparticle happens, or (II) in situ polymerization where pre-combined nanoparticles are blended into the monomer arrangement sought after by concoction or electrochemical polymerization. Delivering courses, Nanocomposites have structure by both ordinary and inventive recommendations. [4]. As well as in 2019, I. Rahayu et al., have explored the impact of HCl corrosive doped polyaniline to raise the conductivity, as appeared in the (Schemes 1 & 2). The orchestrated of Polyaniline by the oxidation of aniline with (NH₄)₂S₂O₈ ammonium peroxidisulphate, as an oxidant by the interfacial strategy in an immiscible natural/watery biphasic framework, with HCl hydrochloric as a dopant [5].
1.3. Conductivity of polyaniline

The polyaniline was identified as the conducting polymer. It was polycetylene, could be n-or p-doped either electrochemically or chemical. [2, 3] The advancement of the field of polymers has continued to stimulate at an unexpectedly rapid rate and a variety of other conducting polymers and their derivatives have been detected. Engineered polymers have been mainstream as electrically insulating materials for longer than 100 years. [4] The revelation of electrical olymers proclaimed another use in the area of polymer science. Shirakawa, and his groups awarded Nobel Prize in Chemistry in 2000 in the field of driving polymers; they discovered the impulse from the spearheading work. From that point forward, the field of directing polymers has assembled quality attributable to the huge scope major investigation given in this field of knowledge in science, incorporates a large group of conjugated polymers, for example, polycetylene (PA), polyaniline (PANI), polypyrrole (PPY), etc. [5,6,7,8]

Polyaniline (PANI) has particular properties, as huge concoction and warm steadiness, satisfactory electrical conductivity, and so on. Polyaniline (PANI) can be utilized in different capacities, comprising of medication, conveyance, photovoltaic cells, plastic batteries, show gadgets, microelectronics, artificially adjusted cathodes, consumption assurance, and polymer light-radiating diode (PLED) shows.
[9] So, the polyaniline can be utilized as a delicate material like a synthetic sensor by identifying or detecting a few gases, substances, or as a natural sensor. [9] In the undoped framework, polyaniline is a low conductor that comprises of arrangements of substituting benzenoid and quinoid rings (Scheme I). Uncovering dedoped polyaniline (which is not conducting) to an acid (e.g., hydrochloric, HCl) makes the polyaniline better in conductivity of current, in this way debilitating its resistance. [10]

The most distinctive characteristic of polyaniline is the good conductivity of electricity (when it's dopend), and the reason for this, that polyaniline has double bonds alternating with single bonds. In addition to what was mentioned above, making polyaniline a substance with multiple applications even for the future. It has been shown that polyaniline has low conductivity and may increase its conductivity with different substances used with it, like dopant, such as metals, hydrochloric acid, or with another polymer, etc. [9, 10].

2. Development of Polyaniline (PANI) for sensor applications

2.1. Development of Polyaniline for chemicals sensor applications

Polyaniline can be used as a gas (chemical vapors) sensor, as study of J. Huang, et al, 2004, the study of Nanostructured Polyaniline Sensors and found that Nanofibers of polyaniline have superior performance relative to conventional materials because of their more exposed to surface area [11]. A format free concoction union was depicted that outputs uniform polyaniline Nano-fibers with measurements underneath 100 nm. The outcome was the interfacial polymerization could be promptly scaled to make gram amounts. Resistive-type sensors produced using un-doped or doped polyaniline nanofibers beat customary polyaniline on introduction to corrosive or base fumes, separately. The nanofibers show basically, no thickness reliance on their sensitivity. [11]

While using the ammonia gas sensor, it was introduced by P. P. Sengupta, et al, 2006, Polyaniline orchestrated by oxidative polymerization of aniline utilizing ammonium persulfate in an acidic medium. The polyaniline salt altered to the base structure by responding with ammonium hydroxide. The polyaniline base was disintegrated in N-methyl pyrrolidone (NMP) as a film. The pour film was doping with HCl for acquiring more noteworthy conductivity. Alkali gas-detecting (like ammonia), qualities of the readied polyaniline film were inspected by assessing the change in electrical conductivity on presentation to smelling salts gas at various concentrations [12]. In addition, the polyaniline nanofibers can be used as a humidity sensor, it was investigated by F. W. Zeng, et al, in 2010, shows wetness sensors dependent upon polyaniline nano fibers. The sensor reacted to minimal relative dampness less than 50% ordinarily by lessening electrical obstruction with expanding mugginess. Regardless, at more noteworthy Relative Humidity, the sensor moved its answers by expanding the electrical opposition with wetness [13].

As well as the view of another study of ductile pH sensor with polyaniline coat set up on impedance assessment, by C. H. Chuang, et al, 2011, the pH sensor comprises an interdigital cathode exhibit on an adaptable printed circuit and slight film polyaniline as the detecting layer. To acquire a dependable and steady impedance estimation output, standard lead for pH esteem recognition, likewise created. As the research facility results appear, the impedance variety of the pH sensor is under 1% in a surrounding circumstance, and the ascertain impedance increments with pH esteems running from 2 to 12. Furthermore, the impedance changes between the unreacted sensor and the responded sensor show 3
sets of distinction; along these lines, the precision of the pH esteem location is extraordinary, making it conceivable to perceive the impedance by methods for a basic electronic gadget. [14]

The research group f X. Du, 2012, was study of the utilization of effortless mechano chemical structure to functionalize carbon nanofibers and nanostructured polyaniline to deal with usefulness carbon nanofibers [CNFs]. The nanostructured polyaniline uniting on the CNF was basically in a manner of expanded nanofibers just as harsh nanolayers. [15]. Moreover, it was confirmed by M. T. S. Chani, et al in 2013 has study Polyaniline based impedance humidity sensors. PANI thin films with 30-70 μm thickness kept on glass substrates between pre-saved silver and gold cathodes. It found that the distinguishing framework relies upon the impedance and capacitance assortments. For the adjustment in Relative Humidity range 36- 90%, the modification in the sensor's capacity is 167 for multiple times, independently. The impedance-moistness is dynamically uniform when stood out from the capacitance-soddenness for this scope of stickiness. It additionally saw that toughening improved the affectability of the sensor by multiple times. The result of estimating the recurrence and assimilation desorption conduct of the wetness sensor. Reaction (τres) and recuperation (τrec) times are 8 and 27s separately. Results analyzed by reenactment and found a decent concurrence with exploratory information. [16]. In addition, polyaniline enabled used to monitor the level of (CH$_3$)$_2$CO in the gas phase as J. S. Do and S. H. Wang in 2013, the affectability of conductimetric (CH$_3$)$_2$CO gas sensor dependent on polypyrrole and polyaniline directing polymers. Polypyrrole (PPy) and polyaniline (PANI)/Au/Al$_2$O$_3$ by substance, like chemical oxidation-casting (COC), chemical vapor deposition (CVD), and impregnated oxidation (IO) methods are applied to check the degree of (CH$_3$)$_2$CO in the gas stage. PPy made by CVD (PPy (CVD)) as the detecting segment, the affectability of the (CH$_3$)$_2$CO gas sensor is gotten the chance to be 5.20 × 10$^{-7}$ ppm$^{-1}$. The affectability of the (CH$_3$)$_2$CO gas sensor set up on PANI is more grounded than that of PPy. The most extreme affectability and least reaction time are won for PANI delivered by the IO procedure. PANI (IO)/Au/Al$_2$O$_3$ as the detecting terminal, the affectability, answer, and recuperation times of (CH$_3$)$_2$CO gas sensor: (5.908 ×10$^{-4}$) ppm$^{-1}$, 1.0 - 3.0 and 3.0 - 10.0 min, individually. The recognition furthest reaches of the (CH$_3$)$_2$CO gas sensor set up on PANI (IO) is 29 ppm. [17].

In 2013, A solid-state form was synthesized polyaniline (PANI)/noble metal hybrid materials with the existence of (H$_2$PtCl$_6$•6H$_2$O) or (HAuCl$_4$•4H$_2$O ) in the reaction mechanism. The enzyme-less H$_2$O$_2$ sensor formed with PANI/Au composite from the existence of HAuCl$_4$•4H$_2$O displayed a low response time (within 5 s) and exhibited a great act in the wide linear range. [18]. There is another investigation confirmed by S. P. Basak, B. Kanjilal, et al in 2013, about utilization of electrical impedance spectroscopy and amperometry in polyaniline adjusted smelling salts gas sensor. The sensor was set up on polyaniline (PANI) nanofibers applying the procedures of electrical impedance spectroscopy with recurrence answer examination and amperometry. PANI is surely understands for its connection with alkali gas. The leading polymer (PANI) of the semi-adaptable of calamitic (pole like) polymer group, is interesting because of its straightforward made plan, natural dependability, and simple doping/dedoping science. The nondestructive synthetic gas sensor was portrayed by incredible affectability, an extensive range to compute fixations (0 to 20 ppm) if there should arise an occurrence of (Electrical impedance spectroscopy) and (2.5-20 ppm) in the event of amperometry, precision, and reproducibility of the detecting information. [19].

The polyaniline introduced by K. Crowley, et al, in 2013 has investigated the Printing polyaniline for sensor applications. Featuring the level of thoroughness is doable by inkjet printing. Using these nanomaterials as inkjet-printable inks open novel, effortless, and modest probabilities for leading polymer-printed electronic applications in the fields of sensors, yet additionally numerous other
application fields, for example, vitality stockpiling, shows, natural light-emanating diodes. Given that inkjet-printing is an adaptable produce method, and it gives access to the huge scope creation of mechanical assemblies, for example, sensors for a scope of capacities. [7].

The sensing mechanism, of the PANI/sponge-based flexible sensor has been discussed by, X. X. He et al., in 2017. They used commercial type of sponge as a template platform to install PANI via in situ polymerization. As shown in the (figures 1& 2). [20]

**Figure 1.** The preparing of polyaniline/sponge. [20] a: A commercial polyurethane sponge. b: Insitu polymerization of PANI on the sponge. c: Washed with distilled water and dried at room temperature.

**Figure 2:** Preparation of PANI/sponge sensor. [20]
After that time, another study by H. J. Park, J. H. Yoon in 2019, was investigated the potentiometric work of elastic pH sensor set up on polyaniline nanofiber arrays, as shown in Figures 3. Reported potentiometric work of a polyaniline nanofiber cluster-based pH sensor planned by weaken blending, synthetic polymerization and ease the basic screen-printing technique. [21]. The pH sensor had two-electrical tips comprising of polyaniline nanofiber cluster detecting cathode and Ag/AgCl reference terminal. The assessment of electromotive power among detecting and reference cathodes gave different electrochemical properties of pH sensors as shown in figure 4.

**Figite 3.** [21]. a : The construction of pH sensors using screen printing. b : The device of pH sensor. c : Images of pH sensors under normal states, mechanical bent and cross section SEM images of pH sensors
Figure 4. Determine damage by pH sensor and pH meter [21]. a: for milk, b: for apple

Table 1 shows the some sensors that were previously described.

Table 1: Different categories of PANI for chemical application

| The application name                  | Application          | The result and source                                                                 |
|---------------------------------------|----------------------|--------------------------------------------------------------------------------------|
| PANI nanofibres                       | humidity sensors     | Low relative humidity (<50% RH) normally at higher RH the sensor reversed its responses by increasing the electrical resistance with humidity [13] |
| PANI layer                            | Flexible pH sensor   | pH sensor is less than 1%, and measured impedance increases with pH values varying from 2 to 12 [14] |
| PANI thin films (30-70 μm) thickness  | humidity sensors     | Response (τres) and recovery (τrec) times are 8 and 27s [16]                           |
| on glass                              |                      |                                                                                      |
2.2. Development of Polyanieline for biomedical sensor applications

T. Sen, S. Mishra, and N. G. Shimpi, 2016 Showed a complete review of an amalgamation of PANI nanocomposites and their capacities as gas sensors and biosensors had given. The multi-utilization of PANI nanocomposites had comprehensively utilized in thrill results. The agreeable impacts for the constituents have made segments abnormally intriguing as detecting things for gases and natural specialists. Unexclusively PANI nanocomposites permit ambient temperature detecting numerous combustibles or poisonous gases and contaminations in high affectability and selectivity, likewise grant stoppage of bio-receptors, for example, compounds, antigen-antibodies, and nucleic acids onto their surfaces for the location of natural specialists over a merger of electrochemical and biochemical responses [4]. Biosensors are varied class of analytical devices with the common theme of using biological elements such as proteins, nucleic acids, glucose or whole cells for detection of the target analytic. [8] The first biosensors developed in the 1950s. But these days there is an array of types that rely on different combinations of detection and transduction elements. [22].

To manufacture sensors from materials with comparative properties to those of the organic framework. The potentiometric results acquired demonstrate unmistakable examples of conduct for arrangements with various taste properties; for example, salt arrangements have a comparable example; however, that contrasts from sharp or sweet materials. The sensor additionally recognizes various brands of brew, espresso, mineral water, purified milk, and wine, distinguishing likewise concealment impacts and the nearness of poisons in the water. For instance, polyaniline utilized as a gas specific film since, it has an alternate porosity and particle selectivity in its doped and undoped states. [23] The average life span in most countries has been widening regularly over the few decades, by procedures of significant developments in medication, public health, as well as personal and environmental hygiene. [24] In the biochemical or biological field, it has been clarified by, H. Sangodkar, et al., in 1996, the construction of polyanieline-based micro-sensors and micro-sensor arrays for the evaluation of biomedical application. Microelectronics innovation has been utilized to shape gold interdigitated microelectrodes on oxidized silicon wafers. [25] Electrochemical conceivable control was used to lead catalyst immobilization to the picked microelectrodes and restrict it at different microelectrodes regarding the protein arrangement. The empowered of the limitation of three unique catalysts on three firmly divided microelectrodes, created in a sensor cluster that consider an example including a blend of glucose, urea, and triolein in a solitary examination utilizing a couple of microliters for example. The

| Material | Sensor Type | Sensitivity/Performance |
|----------|-------------|-------------------------|
| PANI (IO)/Au/Al₂O₃ | acetone gas sensor | 5.908 × 10⁴ ppm-1, 1.0-3.0 and 3.0-10.0 min respectively [17] |
| PANI/HAuCl₄·4H₂O | H₂O₂ sensor | Response time (5s) [18] |
| (PANI) semi-flexible | ammonia-gas sensor | High sensitivity concentrations (2.5-20ppm). [19] |
| PANI/sponge sensor | Pressure sensor/gas sensor | High performance in pressure detection with fast response. [20] |
| PANI /Ag/AgCl | pH sensor | Sensitivity: (62.4mV/pH), repeatability (97.9%) retention, response time (12.8s), and durability (3.0 mV/h). [21] |
task is very broad and can be created to other protein substrate frameworks to in the long run produce an "electronic tongue". [25]

In 2003 made A. Riul, et al, a sensor using the polymers as conducting materials are commonly constructed by saving a polymeric film onto interdigitated anodes of pre-decided creation. An electronic tongue set up leading polymers and lipid-like material. It is worked of six diverse detecting units: (I) exposed interdigitated terminals, (II) interdigitated cathodes secured with (SA), (III) a polyaniline oligomer (16-mer), (IV) polypyrrole (PPy), and mixes (1 to 1, w/w) of (V) 16-mer/SA and (VI) PPy/SA. The films were gathered utilizing the Langmuir–Blodgett (LB) method attributable to the plausibility of storing different leading polymers, and blended movies of them in with stearic acid (SA), just as the high control of film thickness. [23]. In 2008 the investigation by, C. Dhand, et al, about Biosensor of Cholesterol oxidase/ Polyaniline/multi-walled carbon nanotubes (PANI/MWCNT)/indium tin oxide with results of direct scope, voltammetric assessments uncover that bioelectrode can recognize cholesterol in the scope of 1.29 to 12.93 mM with a high affectability of 6800 nA mM⁻¹ and a quick reaction time of 10s. Photometric examination for cholesterol oxidase/PANI/multi-walled carbon nanotubes/indium tin oxide bioelectrode demonstrates that it is thermally steady up to 45 °C and has a time span of usability of for the most part 12 weeks when saved at 4 °C. [26].

Another biosensor utilized by E. B. Setterington and E. C. Alocilja, 2011, Rapid electrochemical revelation of polyaniline-named Escherichia coli O157:H7 to recognize the cyclic voltammetry and to distinguish polyaniline and signal significance exhibits the proximity or nonappearance of E. coli O157:H7 on the screen-printed carbon cathode (SPCE) sensor. As relatively few as 7. CFU of E. coli O157:H7 (contrasting with a novel centralization of 70. CFU/ml) were viably recognized cyclic voltammetry is used to distinguish polyaniline and signal degree exhibits the proximity or nonattendance of E. coli O157:H7. On the screen-printed carbon cathode (SPCE) sensor as shown in figure 5. The evaluation need a 70 minutes from inspecting to recognizing, giving it a significant benefit, over standard culture techniques in multi applications demanding high-throughput screening of example and very quick outputs. [27].
Polyaniline hydrochloride, were tested by P. Humpolicek, et al, 2012, they used both conducting form and non-conducting polyaniline, emeraldine base, were examined for their biocompatibility as far as skin touchiness, sharpening, and cytotoxicity performed on human deified non-tumorigenic keratinocyte and human hepatocellular carcinoma cell lines. The test was done on concentrates of polyaniline powders in simultaneousness with capabilities of worldwide guidelines appropriate for testing of clinical gadgets. [28]. Likewise, in 2012, D. Saini, et al, studies the ability of Biosensor Cholesterol made of (polyaniline/Au/graphene). Coupled enzyme reactions Sensitivity: 0.42 mA mM^{-1}. [29]

Alternative the study of a Biosensor Cholesterol PANI/Au/chitosan from N. Ruecha, et al, in 2014 they found that the Sensitivity of this sensor was: 34.77 mA mM^{-1} cm^{-2}, with detection limit: 1 mM [30]. In the same time rather a novel by Q. Xu et al. in 2014 for glucose biosensor was advanced remained on the prompt electrochemistry of glucose oxidase (GOD) adsorbed in graphene/polyaniline/gold nanoparticles (AuNPs) nanocomposite changed sparkly carbon anode (GCE). The amperometric response of the adjusted cathode was legitimately comparing to the combination of glucose in the extent of 4.0μM to 1.12mM with a low revelation cutoff of 0.6 μM at signal-to-upheaval of 3. [31]. In addition, the J. Zhu, et al, in 2015, they are studied about The significant and novel aspect preparation of a polyaniline (PANI)-TiO2 nanotube as biosensor polyaniline doped PANI/TiO2 sensor for Glucose they found it has a good sensitivity was 11.4 mA mM^{-1}, the limited detection was 0.5 mM.[32] . In the other hand in 2016, M. Zhybak, et al, they shows the biosensor of creatinine, urea Cu/PANI Ammonium ion-specific biosensor; affectability: 95 mA M-1 cm-2 and 91 mA M-1 cm-2 for creatinine and urea respectivlty . [33] In 2018 offer Y. Fu et al., their study showed for possible diagnostics application exhaled, the breath test is a non-prominent and important definite method to raise the fix pace of patients, as showed in the (figure 6). In this testing, groups have been created for the feasible revelation of a couple inside ailments. [34].
The material works by changing inhaled out breath imperativeness into piezoelectric gas-distinguishing signals with no external power sources. The five identifying packs in the device have various sensitivities to different gas markers with obsessions stretching out in the range of (0 - 600 ppm) as shown in table 2:

**Table 2:** Types of breath gases show types of disease by breath sensor

| Breath gas       | Type of disease                                           |
|------------------|----------------------------------------------------------|
| Ethanol          | in exhaled breath is recognized as a gas marker of fatty liver |
| Oxynitride (NOx) | is a gas marker of airway inflammation                     |
Acetone is a gas marker of diabetes
Methane (CH4) is a gas marker of liver cirrhosis
Carbon monoxide (CO) and is a gas marker of asthma

Nonetheless, breathe out analyzers are narrowed in any case, inhale out analyzers are limited by potential confinements, similar to significant expense, the unpredictability of structure, requirement for great materials, and dependence on outside force sources. Self-controlled frameworks planned for driving compact and wearable hardware with human development have been advanced relied upon piezoelectric or triboelectric Nano-generators [34]. Below is a summary (table 3) that shows the sensors that were previously described.

### Table 3: Summary of different types of PANI for biological applications

| The application name                      | Application                          | The result and source                                                                 |
|-------------------------------------------|--------------------------------------|---------------------------------------------------------------------------------------|
| An electronic tongue                      | six different sensing                | Impedance studies were performed over the frequency range 20-105Hz. The sensor is able to distinguish between different brands of mineral water, tea and coffee and can also differentiate tastants below the human detection threshold. [23] |
| biosensor array based on PANI             | biosensor array                       | Can analyze a sample containing a mixture of glucose, urea, and triolein in a single measurement. [25] |
| PANI/MWCNT                                | Cholesterol sensor                   | Sensitivity: 6800 nA mM⁻¹, with Detection range: 1.29—12.93 mM. [26]                  |
| PANI-labeled Escherichia coli             | Escherichia coli O157:H7             | Indicates the presence or absence of E. coli O157:H7. [27]                             |
| PANI/hydrochloride                        | Biocompatibility biosensor           | Skin irritation, sensitization and cytotoxicity performed on human immortalized non-tumorigenic keratinocyte and human hepatocellular carcinoma cell lines. [28] |
| PANI/Au/graphene                          | Cholesterol sensor                   | Coupled enzyme reactions Sensitivity: 0.42 mA mM⁻¹. [29]                               |
| PANI/Au/chitosan                          | Cholesterol sensor                   | Sensitivity of this sensor was: 34.77 mA mM⁻¹ cm⁻², with Detection limit: 1 mM. [30]   |
| graphene/PANI/Au NPs                     | concentration of glucose            | In the range of 4.0 μM to 1.12 mM with a low detection limit of 0.6 μM at signal-to-noise of 3. [31] |
| PANI/TiO₂                                 | Glucose sensor                       | Good Sensitivity was 11.4 mA mM⁻¹, the Detection limit: 0.5 mM. [32]                  |
Cu/PANI Ammonium

| Creatinine, urea sensor | Sensitivity: 95 mA M^{-1} cm^{-2} (creatinine) and 91 mA M^{-1} cm^{-2} (urea). |
|------------------------|--------------------------------------------------------------------------------|
| PANI/polyvinylidene fluoride (PVDF) | breath analysis | For potential detection of several internal diseases. |

2.3. Development of Polyaniiline for DNA sensor applications

In 2005, J. Wu, et al, used polyaniline to search the interaction between DNA and PANI/graphite oxide nanocomposite (GO). The subsequent nanocomposite encased in the carbon paste electrode presentations electrochemical action. Also, show that solitary strand DNA (ssDNA) and twofold strand DNA (dsDNA) can turn redox attributes of PANI/GO on the PANI/GO adjusted carbon glue cathode (CPE) and the adjusted anode affects the redox of ssDNA and dsDNA. Also, found that the Biosensor DNA hybridization PANI/graphite oxide nanocomposite (GO) Linear reaction extend: 275 to 551 g mL^{-1} (ssDNA immobilized anode) Detection limit: 29.34 g mL^{-1}. [35]. In 2006, D. Wei and A. Ivaska, were reported and studied the Electrochemical biosensors depended upon the conductivity of poly\(\text{mers}\) to give many benefits and new chances to distinguish biologically significant compounds. Various biosensors, such as immunity sensors enzyme sensors, and DNA sensors, set up on polyaniline. [36]. In 2011, E. Spain et al. produced a study about Polyaniline nanofibres (PANI-NF), which have been adjusted with artificially developed gold nanoparticles, to give a nanocomposite segment (PANI-NF-AuNPs) and introduced on gold cathodes. Single-abandoned catch DNA, at that point bound to the gold nanoparticles and the fundamental gold terminal and permitted to hybridize with an integral objective strand that is interestingly joined with the pathogen, Staphylococcus aureus, that makes mastitis. Essentially, the affectability of DNA identification is right around 40-overlap more prominent for the PANI-NF altered anodes contrasted with the uncovered cathode surface. It's magnificent even at little DNA fixations, at 150 pM the (S/N) proportion is around 10. Nanomolar groupings of (Staphylococcus aureus) DNA are effectively detectable in entire milk utilizing the PANI-NF-Au sensor. [37]. It has also developed A novel DNA biosensor by, Y. Bo, H. et al 2011, An original DNA biosensor relied upon oxidized graphene and polyaniline nanowires (PANIws) adjusted lustrous carbon anode was developed. The subsequent graphite/PANIw layers saw great (differential pulse voltammetry) current reaction for the basic DNA arrangements. The immobilization of the test DNA on the outer piece of the cathode was broadly improved because of the remarkable synergetic impact of graphene and PANIw. Under ideal conditions, the biosensor displayed a fast amperometric reaction, high affectability, and great stockpiling dependability for examining DNA. [38]. Reinforce ideas in 2012, the investigation of J. Wilson, et al, for the biopolymer of 500 nm-sized nanotubes involve polypyrrole and polyaniline were surrounded by fundamental substance way onto the Au surface. Likewise, the gold nanoparticles were moreover electrodeposited to outline PPy-PANI-Au composite layer. DNA portrays at 5′ end using 6-mercapto-1-hexane (HS-ssDNA).This Biosensor with discovery limit: 10-13 M. [39] A new way of the discovery of another method of the revelation of anthracycline arrangements intercalating local DNA has been planned and acknowledged in the get together of an electrochemical sensor, in 2015 by R. Shamagsumova, et al. In ideal conditions, the identification furthest reaches of 0.01 nM doxorubicin, 0.1 nM daunorubicin, and 0.2 nM idarubicin were accomplished. The selectivity of DNA collaboration identification was incredible in feebly acidic media for impedimetric estimations and in 4-(2-hydroxyethyl) piperazine-1-ethane sulfonic corrosive, pH 7.0, for voltammetric location. The electrochemical sensor advanced was look at in the assurance of doxorubicin in business readiness with 91-93% recuperation. [40] Another study in 2015, by Q. Zheng et al,.figured by the statement of
polyaniline and unadulterated graphene nanosheet (PANI/Gratios) blend in different mass proportions, DNA test and cow-like serum egg whites (BSA) layer by layer on the outside of a smooth carbon cathode (GCE). High productively perceive basic with DNA from 0.01 pm to 1 µm and observe single-nucleotide polymorphisms. [41] DNA sensor made in 2019, by T. Kulikova, offered the stage of glassy carbon electrode adapted with natural DNA implemented from two electro polymerize layers of polyaniline. The charge transfer resistance of the inner layer interface weakened with the doxorubicin concentration variety with 1.0 pM to 0.1 µM (limit of detection 0.6 pM). The result of DNA sensor was confirmed for the test of spiked artificial urine test and exhibited satisfactory recovery in the concentration extent of 0.05–10 µM. [42]. The DNA sensors are described in (table 4)

Table 4: Summary of different types of PANI for DNA application

| The application name | Application                                      | The result and source                                                                 |
|----------------------|--------------------------------------------------|---------------------------------------------------------------------------------------|
| PANI/GO              | DNA sensor                                       | Linear response range (275-551) g mL\(^{-1}\) (ssDNA immobilized electrode)            |
|                      |                                                  | Detection limit: 29.34 g mL\(^{-1}\). [35]                                             |
| PANI-NF-AuNPs        | Staphylococcus aureus DNA in milk                | signal over noise ratio=10                                                            |
|                      |                                                  | [37]                                                                                  |
| graphene/PANIw       | DNA sensors                                      | Fast amperometric response, high sensitivity and good storage stability.                |
|                      |                                                  | [38]                                                                                  |
| PPy-PANI-Au          | DNA sensors                                      | Detection limit: 10_13 M.                                                              |
|                      |                                                  | [39]                                                                                  |
| Polyaniline/DNA      | DNA sensors                                      | the detection limits of 0.01 nM doxorubicin, 0.1 nM daunorubicin, and 0.2 nM idarubicin were achieved. [40] |
| PANI/Gratios         | DNA and bovine serum albumin sensor              | Highly efficiently detect complementary DNA from 0.01 pm to 1 µm and discriminate single-nucleotide polymorphisms. [41] |
| Polyaniline/DNA      | DNA sensor                                       | Concentration in the range from 1.0 pM to 0.1 µM (limit of detection 0.6 pM). [42]   |

3. Conclusion
The most important thing in polyaniline is the conductivity that, can be obtained and strengthened in more than one way. The synthesis polyaniline as a sensor in a number of different ways, one being a slide or a film, and another being a pole, depending on the use. So the polyaniline used either alone or doped with the anther dopant materials. Each of them depends on a set of characteristics such as the amount of conductivity and the speed or response time as well as the stability of the sensor's structural morphology, in addition to high and accurate sensitivity and detection methods. As well as, the types of material to be sensitized, sensitive, or disclosed.
A comprehensive overview of the sensor of polyaniline have been explored. It was found that polyaniline possessed electromagnetism, and pH sensitivity, that give advantages for using polyaniline and significant for biosensing. Many researchers have focused on a number of aspects such as ease of tuning, cheap price, and ease of use. As addition that among important things to pay attention to that must mention when creating any sensor are:

First: the acceptable error rate of the sensor or limitation.

Second: the default or standard climates used upon detection.

Third: the number of times the detector can be repeated.

Fourth: the shelf life of the sensor or its instant synthesis before detection.

Fifth: the atmosphere that must be provide when conducting the sensor.

The importance of sensors has increased rapidly in recent years. The most important aspect, which is human health in general, through vital sensors, through which disease or disorder is identified without surgical intervention, in an easy and quick manner.

4. References

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