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Original Article

A comprehensive review on monitoring and purification of water through tunable 2D nanomaterials

Uma revisão abrangente sobre monitoramento e purificação de água através de nanomateriais 2D sintonizáveis

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Abstract

Instead of typical household trash, the heavy metal complexes, organic chemicals, and other poisons produced by huge enterprises threaten water systems across the world. In order to protect our drinking water from pollution, we must keep a close eye on the situation. Nanotechnology, specifically two-dimensional (2D) nanomaterials, is used in certain wastewater treatment systems. Graphene, g-C_3N_4, MoS_2, and MXene are just a few examples of emerging 2D nanomaterials that exhibit an extraordinary ratio of surface (m^3), providing material consumption, time consumption, and treatment technique for cleaning and observing water. In this post, we'll talk about the ways in which 2D nanomaterials may be tuned to perform certain functions, namely how they can be used for water management. The following is a quick overview of nanostructured materials and its possible use in water management: Also discussed in length are the applications of 2D nanomaterials in water purification, including pollutant adsorption, filtration, disinfection, and photocatalysis. Fluorescence sensors, colorimetric, electrochemical, and field-effect transistors are only some of the devices being studied for their potential use in monitoring water quality using 2D nanomaterials. Utilizing 2D content has its benefits and pitfalls when used to water management. New developments in this fast-expanding business will boost water treatment quality and accessibility in response to rising awareness of the need of clean, fresh water among future generations.

Keywords: water purification, monitoring, nanomaterial, 2D nanomaterial.

Resumo

Em vez do lixo doméstico típico, os complexos de metais pesados, produtos químicos orgânicos e outros venenos produzidos por grandes empresas ameaçam os sistemas de água em todo o mundo. Para proteger nossa água potável da poluição, devemos ficar de olho na situação. A nanotecnologia, especificamente nanomateriais bidimensionais (2D), é usada em certos sistemas de tratamento de águas residuais. Grafeno, g-C3N4, MoS2 e MXene são apenas alguns exemplos de nanomateriais 2D emergentes que exibem uma extraordinária proporção de superfície (m^3), proporcionando consumo de material, consumo de tempo e técnica de tratamento para limpeza e observação da água. Neste trabalho, trataremos das maneiras pelas quais os nanomateriais 2D podem ser ajustados para desempenhar determinadas funções, ou seja, como eles podem ser usados para o gerenciamento de água. A seguir, uma breve visão geral dos materiais nanoestruturados e seu possível uso no gerenciamento de água. Serão também discutidas detalhadamente as aplicações de nanomateriais 2D na purificação de água, incluindo adsorção de poluentes, filtração, desinfecção e fotocatálise.

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Sensores de fluorescência, colorimétricos, eletroquímicos e transistores de efeito de campo são apenas alguns dos dispositivos que estão sendo estudados para uso potencial no monitoramento da qualidade da água usando nanomateriais 2D. A utilização de conteúdo 2D tem seus benefícios e armadilhas quando utilizada para gerenciamento de água. Novos desenvolvimentos neste negócio em rápida expansão visam aumentar a qualidade e a acessibilidade do tratamento de água em resposta à crescente conscientização sobre a necessidade de água limpa e fresca entre as gerações futuras.

Palavras-chave: purificação de água, monitoramento, nanomateriais, nanomaterial 2D.

1. Introduction

Water is an essential natural resource that may greatly alter the chances of human survival in a variety of settings. Services related to water are crucial not just for maintaining biodiversity but also for enhancing people's standard of living, creating economic opportunity, and ultimately ending poverty. The World Health Organization and the United Nations Children's Fund report that only 71% of the worldwide people has access to clean drinking water, despite the fact that this is a fundamental human right. But as the economy at national level and people expand, and problem of water pollution also, which is growing more serious. There is no known way to sustain life without water; moreover, water is vital to human civilization, social organization, and even scientific exploration of the cosmos (Chen et al., 2020). Only approximately 3 percent of Earth's water is drinkable, and it comes mostly from aquifers, ice caps, and glaciers; the rest is salty ocean (Van Engelenburg et al., 2019).

There is a growing demand for urbanization and industrialization, and with that comes water contamination. Substantial risks to the surroundings and health of human are posed by pollutants that enter water supplies via accidental or careless disposal of hazardous waste (Kyriakopoulos et al., 2022; Mukhopadhyay et al., 2022). To prevent aquatic habitats from being harmed by pollution events and frequent trash releases, proper disposal of pollutants is essential. Therefore, it is crucial to build accurate and efficient procedures for tracking pollutant geneses, identifying the causes of pollutants being discharged in watercourses, and quantifying quantity of effluence being discharged.

In order to improve the purification of contaminated water, it is crucial to use efficient sample creation methodologies, since various industries emit different toxins at different times of the hydrological cycle. A high level of clean-up and enrichment performance is only possible with the use of adsorbent materials, which are the primary focus of most sample building methods. This has led to a surge in interest in studying high-tech adsorbents during the last several ten years (Su et al., 2022). Water purification by use of nanotechnology is a viable option. Zero-dimensional nanoparticles by metals such as nanoparticles of Au (Priya et al., 2022), Ag (Li et al., 2022), Fe_3O_4 (Singh et al., 2022), and TiO_2 (Davarikia et al., 2022)

Low-dimensional nanomaterials have many potential applications, but they are constrained by a number of factors, including the fact that 1) They like to agglomerate or re-stabilize in solution, considerably lowering their surface area (Chen et al., 2022)). It is vital to fully recover depleted nanomaterials, because nanomaterials in water that are not recycled can cause considerable harm to persons and ecosystems (Manikandan et al., 2022). Their limited dimensionality prevents them from. Atomically thin structures ranging in size from tens of nanometers to micrometres on a side, 2D nanomaterials hold great promise due to their incredibly low consumption, control, and excellent action consistency (Xiao et al., 2022). surface area, made possible by 2D nanomaterials' huge lateral dimension and nanoscale thickness, this makes them appealing in a wide range of ecological remediation applications, including as adsorption, sensing, and catalysis (Li and Yang, 2022). Many water-treatment systems have been settled using 2D-nanomaterials, demonstrating remarkable adsorptive, catalytic, and parting capacity. These systems contain ultrathin atomic layer graphene membranes (Jatoi et al., 2023), highly efficient oil adsorbents.

Despite the advances reported in studies on 2D nanomaterials-based water treatment, the utility of composite material in the presence of water has not yet achieved its original goal technology (Thanigaivel et al., 2022). The primary goal of this overview is to reduce the burden of the obstacles blocking the use of 2D nanomaterials in water treatment by illuminating their positive attributes. This review will provide researchers a snapshot of the national of the art in 2D nanomaterials for aquatic treatment in light of the growing interest in this area. Also covered are the many kinds of 2D nanomaterials, how they are synthesized, and their conspicuous properties, as well as their uses in water action and intensive care, and the mechanical foundation of how the basic assemblies of 2D nanomaterials impact their accumulative nature.

2. Source and Forms of Water Contaminations

Harmful waste and unintentional spills posture hazards to both aquatic ecosystems and human health when pollutants enter waterways (Fang et al., 2018). Both natural and manmade contaminants contribute to water pollution, and their effects on human health vary widely depending on the specific species involved (Sweetman et al., 2017). Dangling sediments, chemical pollutants (both organic and inorganic), and biological pollution are all potential sources of water contamination.

3. Microorganisms and Other Biological Contaminants

There are many different types of microbes in water, containing Proteobacteria, Firmicutes Cyanobacteria, and Bacteroidetes. Microorganisms belonging to the Cyanobacteria, family Methylobacteriaceae genus Xanthomonadaceae, and the genus Sphingomonadaceae. Biofilms formed by microorganisms are widespread in drinking water distribution systems, especially in older infrastructure (Douterelo et al., 2017).

In addition to these microbes, worried pathogens may occasionally find their way into drinking water, increasing the consumer anxiety possibility. Among the pathogens that might set off sickness in persons with immune problems are enteric bacteria and opportunistic infections. Entamoeba histolytica and Giardia duodenalis are two protozoans that may live in water and cause illness. Hepatitis A and Norovirus are only two examples of viruses that are suspected in the development of a wide range of illnesses, including those spread by contact with water (Jenns et al., 2022). These pathogens are implicated in a wide spectrum of disorders, some of which are fatal. Kidney impurities, lung infections, diarrhoea, cholera, dysentery, fever, and urinary tract infections are all included.

4. Large-scale Pollutants

Macro-pollutants are the large, easily observable contaminants found in rivers and other bodies of water. Trash ends up in waterways whether it is thrown into water bodies on purpose or is just remain behind on the ground and washed into drains by runoff. As a consequence, the "major pacific rubbish field" has been modelled, and it's now the size of France. Macroscopic contaminants include things like nurdles (tiny plastic pellets), wood, and metal. This may be a quick and easy task, but time is of the importance. Large pollutants must be removed so that marine ecosystems are not destroyed by their chemical breakdown (Younas et al., 2023)

5. Pollution by Organic Substances

Insecticides, herbicides, petroleum, detergents, disinfectants, and pharmaceuticals are all specimens of potential carbon-based goods. Methyl tert-butyl ether (MTBE) is a very hazardous organic chemical that was once used as an aerosol gaseous air additive but is now prohibited. nonetheless, it will take a long time for MTBE to be completely eradicated from contaminated water sources. This chemical molecule, which is present in high amounts in contaminated water, has been related to tumors of the genitalia, kidneys, and gland, as well as leukaemia and lymphoma (Picetti et al., 2022; Furtak et al., 2022).

Toxicity from pesticides is widespread in water systems, where they bioaccumulate in fish and soil to threaten human health (Cabello et al., 2023). As the global pesticide industry has expanded rapidly, more and more pesticide formulations have been developed for use in both agricultural and non-agricultural settings. Runoff and infiltration may carry pesticides to surface and groundwater, contaminating these supplies and limiting their usefulness (Syafrudin et al., 2021). Due to their bioaccumulation capabilities, the persistent and widespread nature of certain pesticides used in agriculture has constituted a significant threat to the environment (Areche et al., 2022. About 2Mt of pesticides are used annually across the world, with 47.5%, 29.5%, 17.5% and 5.5%, herbicides, insecticides, fungicides and pesticides respectively (UNEP, 2001).

Exposure to pharmaceutical complexes (PCs), which are designed to trigger a certain living reaction in the body, may have the equivalent effect on non-target organisms after prolonged, low-dose exposure. Effluents from hospitals are thought to be the primary source of pharmaceutical compounds (PCs) in the aquatic environment, despite the fact that pharmaceuticals are extensively dispersed throughout the environment. Nonylphenol and bisphenol-A are the most studied of the many PCs that are harmful to the health of animals and people alike (Bilal et al., 2018). Pharmaceutical pollutants have also been discovered in a broad range of ecosystems, including water, rivers (ponds, streams, and lakes), seawater, sewage treatment plants (influents, industrial effluent), sediments, and slurries. As a result, finding them all over the biosphere has become an urgent matter of environmental concern, and better wastewater technology is crucial for combating pollution. Interestingly, the World Health Organization (WHO) also gave considerable thought to. They produced exclusive research demonstrating the prevalence of medicines in underground and potable water, as well as the accompanying potential hazards for human health and ecology (WHO, 2011). PCs have been eliminated from water systems because to their toxicity by procedures like as corrosion, photodegradation, UV deterioration, nano - filtration, deionized water, and absorption (Wang et al., 2022).

There is evidence that detergents may contaminate water treatment systems and reduce their effectiveness. Humans use detergents for a wide number of purposes, the most common of which is to maintain personal hygiene. Both point and non-point sources are potential entry points for detergent elements into soil and water. The sustainability of Earth's diverse flora and fauna is threatened by pollution from both point sources, such as sewage systems in cities and factories, and non-point sources, such as agricultural practices like contaminated irrigation water in soils, clothes wash near the streams in country, especially in developed countries, and run-off (Masocha et al., 2022). The removal of these compounds from water is crucial since they may be acutely and chronically hazardous to natural plant and animal.

6. Pollution by Inorganic Materials

Toxic wastes such as ammonium or nitrogen inorganic fertilizers, white phosphorus fertiliser, and toxic substances are examples of inorganic material pollution. Although lithium, copper, nickel, chromium, zinc, mercury and barium are all insignificant in small amounts, they become contaminants when existing in sufficient amounts in water (Claustre et al., 2022; Pramanik et al., 2023; Gondal et al., 2023). Significant pollution in water is caused by incompetent water removal methods, the leakage of dirty water, or the runoff into aquifers. Death and serious illness are also possible outcomes of this form of water poisoning, particularly at a high absorption level.

7. Contamination Due to Heat

Thermal pollution or contamination occurs when a hot liquid (such industry effluent) is released into cold water environments (Vallero 2019). Industrial equipment and power plant cooling systems are the most likely culprits in the rise in global temperatures (Raptis et al., 2016). Especially in riverine habitats, rising water high temperature, reduction in oxygen levels, that may change food chain assembly, eat fish, or reduce kinds of diversity (Miara et al., 2018). An additional effect of urban runoff is an increase in surface water.

8. Three New Perspectives on 2D Nanomaterials for Water Management

Most definitions of nanomaterials say that their structures have to be between 1 and 100 nm in size. Because of their smaller size and the potential for quantum effects, nanomaterials may exhibit unusual behaviour compared to their bulk counterparts (Ding et al., 2017). Due to their new shapes and properties, two-dimensional nanomaterials, have gained a considerable deal of media interest in recent years. Two-dimensional nanoparticles are now of attention for usage in water treatment and specialist care. 2D nanomaterials are being investigated as prospective replacements for existing water desalination and filtration barrier materials due to their atomically thin structure, large surface area, and physical properties. For example, it is widely accepted that thin films have a strong proclivity to cluster together (i.e., agglomerate), and that this clumping is frequently associated with poor material properties degradation, unpredictable morphological distortion, and diverse interfacial interaction.

9. Common 2D Nanoparticles in Water Treatment

Due to its novel structure and promising potential uses, 2D materials have attracted significant scientific interest in recent years. Consequently, a wide variety of 2D nanomaterials have been predicted and created utilizing a wide range of processes, with great examples of how these materials may be put to use having been shown. We'll go through several of the most prevalent nanostructured materials in this section, such as graphene and boron nitride nanomaterials (BNM), transition metal dichalcogenides (TMDs), transition metal oxides (TMOs), layered double hydroxides (LDHs), and metal oxymexanes (MXene) (Fatima et al., 2022).

Graphene, a carbon inert gas having a two-dimensional (2D) shape, is commonly assumed to be just one atomic layer thick. The structure is composed of a graphene sheet with a close hexagonal stacking. This material's lone element is covalently linked to its 3 near neighbors (carbon atoms). A carbon - carbon sheet has a spacing at all between the 2 adjacent carbon molecules of about 0.142 nm. When atom levels pack firmly together due to the effect of van der Waals, graphite is created, with an interlayer spacing of around 0.335 nm (Huang et al., 2020).

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In the chemical formula MX2, where M is a transition metal and X is a chalcogen, we can see that TMDs are layered materials. In TMD, monolayers stack with the assistance of van der Waals force. Each TMD monolayer is composed of three atomic layers: a transition metal layer, two chalcogen layers, and an intervening transition metal layer. One of the properties that sets TMDs apart is their capacity to form many kinds of crystal polytypes (Manzeli et al., 2017).

Because of their higher redox activity relative to carbon materials, transition metal oxides (TMOs) are employed as anode tools in electrochemical capacitors (ECs). However, TMO's limited ability to store energy, particularly at higher rates, stemmed from its reduced electrical conductivity. When used as electrode materials, the charge-storing capacity of ECs is greatly enhanced by the presence of 2D nanostructured TMOs due to their large superficial region, developed compatibility by electrolytes, and tiny method ion removal network (Tan et al., 2016). When raw MAX phases are lithographed in a certain way, the resulting MXenes are a type of layered metal carbide or nitride with the resulting formulae: Here, M is a TM, A is a member of group IIIA or IVA on the periodic table, and X is either carbon or nitrogen, where n is an integer from 1 to 3. In MAX phases, the M layers are packed into a hexagonal lattice, while the X atoms fill the empty octahedral spaces. A and M elements form metallic bonds and are stacked one on top of the other in Mn+1Xn layers. With the use of solid etching solutions like HF, the A layer can remove from the MAX stages, leading to MXenes with three different structures: M2X, M3X2, and M4X3 (Dhakal et al., 2015). Many additional MXenes are expected theoretically based on the existing MAX phase precursors, but only around 30 have been successfully synthesised so far (including Ti3C2Tx, Ti2CTx, Nb4C3Tx (Ghidiu et al., 2014), Ti3CNTx, Ta4C3Tx (Naguib et al., 2012), Nb2CTx, V2CTx (Lukatskaya et al., 2013). Because of their abundant elements and non-toxic breakdown products, MXenes based on titanium, such as Ti2CTx and Ti3C2Tx, hold the greatest promise for environmental applications. In particular, titanium carbide (Ti3C2Tx) is the most researched MXene to date. In addition, a variety of MXene compositions have been presented, some of which include two or more transition metals in the M layers, in both ordered and disordered structures (Mo2Ti2C3, (Ti0.5, Nb0.5)2C, (V0.5, Cr0.5)3C2) (Gogotsi and Anasori, 2019).

Positively charged layered materials called layered double hydroxides (LDH) typically have the formula [Mz+1-xM3+x (OH)2]m+ [An]m/n.yH2O and include water molecules in the interlayer voids to achieve charge neutrality through solvation. Mz+ and M3+ often represent divalent and trivalent metal ions, thus m = x. In the interlayer space, an is a replaceable anion. Lack of interlayer bonding in LDHs allows for a wide variety of interlayer anions to be accommodated by adjusting the interlayer gap. Therefore, an may be any anion (organic or inorganic) able to neutralize charges (Bukhtiyarova, 2019).

10. 2D Nanomaterial Synthesis

10.1. Top-down approach

The top-down synthesis (TDS) approach to nanomaterials includes the chemical or physical creation of ultrathin needlelike nano-sheets. Physical TDS relies on ultrasonic influences or mechanical energy to strip covered van der Waals articles into monolayer and multilayer 2D supplies, whereas chemical TDS relies on chemical processes generated by ion interchange, temperature, and other methods (Boncz et al., 2022; Mohammadtabar et al., 2019). The chemical top-down technique is predicated on chemical processes induced by chemical etchants or by applying heat, whereas the physical TDS approach makes use of photons, electrons, and ions (Saeed et al., 2020). Since the TDS method can be used to the fabrication of such a diverse set of devices without compromising on quality or dependability, it has found widespread usage in the semiconductor device sector. Nanowires, for example, are a novel structure that can be made using this method and might be used for the label-free detection of biological material. First, there is lithography, then there is laser ablation, then there is chemical etching, then there is milling, and finally there is thermal breakdown.

11. Bottom-up Approach

Needle-like high-quality nano-sheets with large transverse dimensions may be successfully fabricated using a top-down technique. Additionally, it is important to highlight that the aforementioned exfoliation methods are only applicable to bulk materials having stacked crystals. Using the aforementioned strategies, the price per unit of output is often rather cheap, making mass manufacturing a realistic possibility. Materials at nonorange are fabricated via a bottom-up approach, beginning with reactive molecular or atomic precursors that grow in size or self-assemble into increasingly complex structures. This allows for simple extension of 2D materials (Karfa et al., 2020). Assembling atoms and molecules in this way allows for the construction of efficient multicomponent devices without any unnecessary waste or elimination of system mechanisms (Anastas and Zimmerman, 2019). The association of the fundamental components is typically manipulated by physical aggregation, chemical interactions, or the use of templates (Liu and Bashir, 2015). Nanotubes, nanoribbons, and quantum dots are all examples of nanostructures that may be formed by the controlled chemical reactions of their constituent building components. When the top-down method of creating nanostructured materials fails, this bottom-up method may be used to construct the desired material (Abid et al., 2022).

12. Key Characteristics of 2D Nanomaterials

Two-dimensional 2D nanomaterials are sheets of atoms or less thick. Many more atoms may be found on the surface of these nanomaterials than on the bulk version of the same substance. Increasing the amount of surface atoms modifies the behaviour of 2D nanomaterials since they are more versatile than the interior atoms. In comparison to other nanomaterials, 2D nanomaterials are expected to be somewhat weak due to their thickness and macroscale or nanoscale dimensions. These nanoparticles form strong in-plane connections with one another, and weak van der Waals bonds between layers (Hwangbo et al., 2021). Below is a quick rundown of these amenities:

13. In Plane Electronic Confinement

The electronic band arrangement of a material determines its electrical and optical characteristics. It's produced by the periodicity of the mineral assembly and describes how electrons (es) move through the material. When a factual is transformed after three dimensions into two, its uniformity in the perpendicular to the plane direction is lost, which may cause major changes to the band structure. Graphene's very high conductivity and monolayer MoS_2's fluorescence are attributed to the material's rearranged band structures.

Another effect of dimensional confinement on semiconductors is a reduction in the screening effect of the dielectric between the holes and electrons. When just a thin layer of material is available, the electric field cannot be filtered. As the strength of the Coulomb contact grows, the stability of the highly bounded excitons surpasses that of the bulk form. As has occurred in many 2D semiconductors, if 2D structure are confined in a plane thinner than their radius, then quantum term begins cumulative their energy compared to bulk excitons, causing them to consume and emit light of longer wavelengths (Zheng and Zhang, 2019). Altering the layered thickness of the 2D material might control their energy output. However, this may alter the band composition and cause other characteristics to shift (for instance, bi-layer MoS_2 loses its emissiveness when compared to mono-layer MoS_2).

14. Higher Surface to Volume Ratio

Materials in the 2D dimension have a larger surface area relative to their volume than their 0D, 1D, and 3D counterparts. Due to their greater surface area in comparison to their volume, 2D materials are further right for device uses.

Thus, such sensors can detect analytes even at low concentrations. The extent to which a material is permeable to its surroundings is proportional to the relation of its surface area (A) to its volume(m^3). The bigger element that derives into contact with the example will carry out the return more quickly, hence 2D complexes are more volatile than in substance form counterparts. In addition to being employed in 2D material sensors, it makes such materials more sensitive to their surroundings (Buckley et al., 2020).

15. Exceptional Pulling Power

Using the aid of weak van der Waals exchanges, a layered substance material may hold together several covalently bonded surfaces. These Van der Waals forces are swiftly determined when a force is applied to an object, resulting in cracking and the appearance of fragility. The atomic layers are held together by covalent bonds, which are much stronger than the weaker ionic connections. Bonds in a monolayer can only be covalent. When the "weak links" in a material are removed and replaced, the substance often becomes even more durable. Although a graphite pencil may be broken with relative ease, graphene has a tensile strength 1,000 times that of graphite and is around 100 times tougher than steel (Sundqvist, 2021).

16. Two-dimensional Nanomaterials and Their Possible Use in Water Management

16.1. Purifying water: a practical application of reverse osmosis

Since two-dimensional nanomaterials are atomically thin, have a large surface area, and are mechanically robust, they are being considered as potential alternatives for more traditional detoxification and water distillation membrane supplies. The notoriously great clumping propensity of 2D materials (i.e., agglomerates) is a good illustration of this phenomenon. Agglomerates are often linked to undesirable material characteristics deterioration, arbitrary mechanical distortion, and diverse interlayer interference (Jeong et al., 2020). Here, we've briefly covered the ways by which various 2D nanomaterials may be used to purify water and how they work to do so.

17. Two-dimensional Nanomaterials: Superior Sorbents

Because of its cheap cost, high removal effectiveness, abundance of available adsorbents, simplicity of operation, and regeneration potential, adsorption is one of the most popular methods for purifying water (Momina et al., 2018; Crini et al, 2019). Many hazardous contaminants in water have been removed using adsorption techniques that make use of nanomaterials including graphene (Wang et al., 2013), carbon nanotubes (Shulaker et al., 2013), metal oxide (Gondal, 2023) and MXenes (Monastyreckis et al., 2021). In this part, we've skimmed the surface of the method that gives 2D nanomaterials their function as sorption in water purification.

Graphene is a 2D nanomaterial consisting of sheets of a single layer of graphite. Graphene is an appealing material for use in water purification due to its great surface area for adsorbing pollutant species, its likely for unusual biochemical alterations and complex construction. Graphene is often transformed into graphene oxide by an acid action process, namely the Hummers or enhanced Hummer's techniques, for use in water purification applications. A great deal of hydrophilic oxygen-containing groups, such as hydroxyls and epoxides, are introduced throughout the graphene sheet during the conversion to GO (Liu et al., 2013). Most significantly, the biochemical alteration dramatically increases the hydrophilicity of GO materials, allowing for the development of films with high water penetrability and flux (Sweetman et al., 2017). Graphene and GO facilitate water distillation via a number of processes, including electrostatic, hydrogen bonding, and - interactions between contaminating molecules and the graphene (Baig et al., 2019). Graphene's outstanding adsorption capacity is made possible by its large particular surface area (about 1,000 m2/g), nano-perforated membranes and laminar structures. Key mechanistic approaches for graphene-controlled water purification include the use of graphene for inactivating the feature of microorganisms by interrupting their biological function, componization of the bacteria membrane, production of reactive oxygen species (ROS), and encirclement of microorganisms (Chen et al., 2014).

Noncovalent bonding between the cationic host layers and the anionic interlayers assembles LDHs into a hydrotalcite-like anionic lamellar assembly (Zou et al., 2016). With their high ion-exchange capacity, wide chemical diversity, and large interlayer spacing, LDHs are ideal 2D materials for application as catalysts or sorption in the area of water treatment (Karim et al., 2022). Graphene-LDH compost (G-LDH) has been extensively accepted for water remediation because to the many improvements made to LDH materials over the last decade, including surface decorating, calcination, intercalation, and diverse composition processes (Pang et al., 2019).

Many research has been conducted to investigate the possible advantages of two-dimensional BNMs, namely hexagonal BNM (also known as "white graphene"), which is a material that is structurally analogous to graphite (Fang et al., 2016). The adsorption of water pollutants can be conceptualized in terms of electrostatic attractions, physisorption, pep stacking interactions, surface complexation, hydrogen bonding, van der Waals forces, and chemical adsorption; however, the actual sorption mechanism is entirely determined by the particulars of the pollutants as well as the structure and the surface characteristics of the BN materials (Gonzalez-Ortiz et al., 2020). In addition to p-p interactions, the sorption of pollutants also makes use of the hydrophobic contact that exists between aromatic ring molecules and the hydrophobic surface of BNMs (Ihsanullah, 2021).

The sorption ability of MXenes may successfully compete with or outperform with other nanomaterials, making them a viable contender for water purification owing to their large specific surface area, plentiful functional -OH and -O groups with variable surface chemistry.

In addition to facilitating direct ion exchange, the MXene surface's functional groups may also be used to decrease the size of certain organic molecules and cations. This novel reductive-adsorptive removal of contaminants using MXenes' in-situ reduction capacity is exciting since it opens up a new potential use for these nanomaterials. The strong negative surface charge (zeta-potential between 30 and 80 mV) of MXenes makes them good adsorbents for a widespread diversity of compounds, including polar organic molecules like hydrazine, urea, and DMSO (Rasool et al., 2019). As an added bonus, MXenes' outer surface groups not only serve as sites for ion exchange, but help to neutralize the oxidation of certain organic compounds and cations like copper (Cu2+) and chromium (Cr6+) (Lazarova et al., 2014). A novel, favorable function of MXenes for pollution elimination is also shown by their in-situ reducing ability. For instance, DL-Ti3C2Tx nanosheets showed effective reductive removal of Cr6+, with a extreme elimination size of 250 mg 1 and a residual concentration of less than 5 ppb following treatment (Ying et al., 2015). Hydrophilic and weak bonding forces in MXene, as well as the small interlayer spacing (2) between MXene nanosheets, set MXenes apart from other 2D nanomaterials in their superior ability to adsorb contaminants (Ren et al., 2015).

18. Desalination Water Filtration Using Membranes Mediated by 2D Nanomaterials

The basic aim of water handling is to separate undesirable items existing in water based on their mass or maybe penetrability, and membranes offer a physical barrier to do this. It is challenging to build workable membranes with both high permeability and excellent selectivity using standard membrane materials due to the frequent trade-off between water permeability and selectivity. It is generally accepted that a membrane's permeability decreases as its thickness increases. 2D nanomaterials with atomic thicknesses of 1 to a few nm have so emerged as promising building blocks for developing next-generation lipid bilayer membranes. Practical membrane design that incorporates 2D nanomaterials, for instance, enables the creation of an atomically thin separating structure that allows for the selective passage of water molecules. Depending on whether the water utilised to create these membranes was in a gaseous or liquid condition, we may classify them as either membranes that filter water or solar membranes that distil it. The desalination process is a classic application of membrane filtration mediated by 2D nanomaterials. Multistage flash distillation and reverse osmosis (RO) are the two most common methods now used to desalinate saltwater. The desalination facilities use a process called reverse RO, which involves pumping water across a semipermeable membrane using an external, positive hydrostatic pressure. That's why it's easier for water to permeate a membrane than it is for dissolved salts or organic molecules. Although RO is currently the most energy-efficient method of desalinating saltwater, it still has certain drawbacks, including a limited desalination capacity and membrane fouling during treatment, which lowers treatment efficiency and yields difficult-to-manage concentrate. High capital expenditures and poor ammonium separation during reverse osmosis limit its widespread use in most emerging areas (Nicolaï et al., 2014). Reverse osmosis relies on a semipermeable membrane to isolate fresh water from saltwater (Mian et al., 2022). Three decades after its inception, the semipermeable RO membrane's traditional polyamide thin-film composite design remains unchanged (Cohen-Tanugi and Grossman, 2015). Thin-film composite membranes have increased in permeability by only 1.5-2 times in the last 20 years, and they continue to be affected by chlorine exposure, making disinfection difficult and increasing the fouling propensity (Lee, 2011). The water problems of the twenty-first century can only be solved by making significant advances in RO membrane technology, hence enhanced desalination is essential. The generated TFC-PE membrane has more mechanical robustness and resistance to organic solvents than regular RO membranes, mostly owing to the PE support's remarkable high mechanical and chemical stability. However, polyamide thin film composites membranes have a few drawbacks that make them less desirable. These include their susceptibility to chlorine and fouling, as well as their limited operating temperature range (0-45°C (Ibrahim et al., 2015).

Graphene has the potential to be the best RO membrane ever made due to its superior mechanical properties and chemical resistance compared to the polyamide active layers typically used in thin-film composite RO membranes (Cohen-Tanugi and Grossman, 2015). Water permeability via graphene (d = 0.34 nm) may be increased to a greater extent than through the polyamide active layer in thin-film composite membranes (d = 100 nm) due to graphene's atomic thinness. Graphene also has a higher chlorine tolerance than polyamide, which is a significant benefit in preventing membrane fouling without degrading the membrane (Cohen-Tanugi and Grossman, 2015). Antimicrobial characteristics of GOs reduce membrane biofouling, extending the membrane's useful life and decreasing the amount of energy needed to purify water (Mahmoud et al., 2015). Grain boundaries, one kind of defect in graphene sheets, have been shown to be significant in evaluating their reliability in actual desalination plants. Graphene membranes' mechanical and selectivity properties may be impacted by this type of defect (Gondal and Tayyiba, 2022). Mxenes Ti3C2Tx, thanks to its large specific surface area and strong electrical conductivity, has been shown to remove salt at a rate of 9.4 mg g^{-1} min^{-1} in research.

19. Photocatalysis by Two-dimensional Nanomaterials

The use of solar energy in a process called photocatalysis to purify water has been the subject of much research and is now widely recognised as one of the most reliable methods of dealing with environmental issues in the face of constrained energy resources. In general, photocatalysis is comprised of one or more photochemical reactions that are catalyzed by the photocatalyst. During these processes, accessible unbound electrons (e's) are excited to the conduction band, whilst holes remain in the same state, which is the valence band. Hence, these electron-hole pairs are necessary for photocatalytic reactions such as the oxidation of pollutants and the lowering of CO2 levels. The excited charge carriers that are produced by light are unstable and may quickly recombine with one another, which results in a reduction in the effectiveness of the photocatalytic conversion. These 2D material-dependent photocatalysts have the potential to provide indication characteristics such as a high number of host-guest species, a large specific surface area, an abundance of surface energetic sites, and a porous structure due to the one-of-a-kind properties of 2D nanomaterials and their nanocomposites. These characteristics include: a high number of host-guest species; a large specific surface area; an abundance of surface energetic sites; and a porous structure. Recently, black phosphorus, also known as BP, has been identified as a possible photocatalyst for the synthesis of hydrogen from solar energy. Despite this, the bandgap of the bulk crystal, which is 0.3 eV, limits the driving power that is required for effective photocatalytic activity. Recent studies have concentrated on the photocatalytic capabilities of two-dimensional materials, such as graphene, carbon nano-sheets, metal oxide, as well as BNM and MXene, to name a few.

In particular, photocatalysts based on graphene nanocomposites have showed tremendous potential as heterogeneous photocatalysis systems for the purification of water. Another well-liked strategy for enhancing the photoactivity of nanocomposites is to include graphene into the semiconductors. In most cases, the production of graphene nanocomposites may be simplified down to one of three basic processes.

The fabrication of hybrids with a 2D-2D material enhances the contact area between the semiconductor and graphene. This makes it possible for a more efficient charge transfer as well as the formation of electron trapping channels, which reduces the recombination rate. Take, for instance, a model of the electron transport in a graphene/titanate nanotubes (TNTs) photocatalyst when it is exposed to visible light. This model is based on the topologies of their energy bands. It is possible for graphene to perform the function of a sensitizer, which would increase the photocatalyst's reactivity to visible light and cause TNTs to form a metal-semiconductor junction. Xiang et al. (2012) created 2D-2D materials that consisted of TiO2/graphene and graphene/g-C3N4 composites. When these composites were subjected to visible light, both of these composites demonstrated enhanced photo-efficiency. For example, in the production of Cu2O/Pd/RGO (reduced graphene oxide) composites, a noble metal is often used in the role of an interfacial mediator (Bai et al., 2014). Pd nanoparticles play a crucial function in this scenario, as they are responsible for the collection of holes from Cu2O and the subsequent transfer of those holes onto the graphene surface. This helps to avoid electron-hole pair recombination. The solvent-exfoliated graphene (SEG) method, for example, may be used to improve graphene's electrical conductivity. For instance, (Yuan et al., 2014) manufactured SEG/TiO2, which was of greater photo-activity than RGO/TiO2 for aerobic oxidation. This study demonstrated that SEG/TiO2 is superior to RGO/TiO2 in terms of aerobic oxidation (3D).

BNMs, which belong to another promising family of 2D nanomaterials, speed up the process of photocatalytically filtering water. Both the filtering of water and the sorption of pollutants like oil and organic solvents from heavy industries are areas in which BNMs excel. BNMs also show promise in the sorption of pollutants (Gonzalez-Ortiz et al., 2020). BNMs interact with other metal oxides to considerably increase the photocatalytic activity of the latter, and they do this by facilitating the separation of electrons and holes on TiO2/P-BNMs. The abundance of photoreaction species on the surfaces of TiO2, such as HB and OH, as well as the enormous surface area of BNMs, both contribute to the fast adsorption of LR2B onto porous TiO2/TiO2 nanoparticles (Ihsanullah, 2021). In addition, it was shown that the hybrid nanocomposite of BNM-doped polyaniline (PANI) was effective in the photodegradation of pollutants (Shahabuddin et al., 2018) PANI that has been doped with BN produces more photoelectrons and holes, which contributes to an increase in the photocatalytic efficiency of the nanocomposite. They are able to degrade biological molecules because to the conductive polymeric chains that PANI has (Shahabuddin et al., 2018). It is possible to add BNM to the mixture in order to further boost the photocatalytic activity of TiO2 for the purpose of removing water pollution. Ibuprofen was not the only pollutant that BNMs/TiO2 nanocomposites were tested to see whether they could catalytically oxidize, as additional contaminants were also tested. When BNNS were present, there was a reduction in the recombination of electrons and holes, and there was an increase in the absorption of light. In addition, the presence of more BNMs resulted in a bigger nanocomposite photocatalytic oxidation rate.

The density of electrons is very near to the Fermi level and very high in MXenes, which gives the material the behavior of a metallic substance. Because of its high and anisotropic carrier mobility, MXene is an intriguing candidate for use in photocatalytic applications. This property helps with the movement and separation of photogenerated electron-hole pairs (Rasool et al., 2019). The photocatalytic performance of the TiO2/Ti3C2Tx nanocomposite is superior to that of TiO2 or Ti3C2Tx by itself. This is because the TiO2/Ti3C2Tx nanocomposite exhibits enhanced electron-hole separation as well as the development of a heterojunction between TiO2 and Ti3C2Tx during irradiation with UV light. TiO2/Ti3C2Tx nanocomposites also have use in photocatalytic water splitting, which may be used to produce hydrogen. This is another purpose for the materials (Liu et al., 2015a). Ti3C2Tx acted as an electron sink in this nanocomposite, which facilitated the separation of photo-generated charge carriers and provided a 2D platform for intimate interactions with TiO2 NPs. This nanocomposite was able to do this because Ti3C2Tx acted as an electron sink (Rasool et al., 2019). Guo et al. (2016) examined 48 2D transition metal carbides, commonly known as MXenes, in order to get a better understanding of the photocatalytic characteristics of these compounds via the use of ab initio calculations. According to the findings, the most promising single photocatalysts for obtaining high efficiency in photocatalytic water splitting were 2D Zr2CO2 and Hf2CO2. It is possible that the unexpectedly high and directionally anisotropic carrier mobility of 2D Zr2CO2 and Hf2CO2, which may effectively help in the migration and separation of photogenerated electron-hole pairs, is one of the most remarkable properties of these two materials (Guo et al., 2016). MXenes have a variety of potential uses, one of which is as a photocatalytic agent.

20. Antibacterial Effects of 2D Nanomaterials

To protect ecosystems and human health, the last and most crucial step in water and wastewater treatment is disinfection, or the killing, inactivation, or annihilation of harmful bacteria. Cl2, NH2Cl, O3, and ClO2 are only few of the disinfectants utilised in modern water treatment. These disinfectants don't kill all they're supposed to and they leave behind harmful waste (DBPs). There is an urgent demand for novel disinfectants in the water treatment industry. That's why 2D nanomaterials are so crucial in this field. In recent years, MXenes (Ti3C2Tx) have shown to be very efficient against a wide range of bacteria, including Escherichia coli and Bacillus subtilis. MXenes are well-suited for membrane applications because to their exceptional resistance to biofouling. MXenes' antibacterial properties stem from their anionic surface, the immediate death of bacteria upon contact with their hydrophilic surface high, and the disruption of nutrition uptake by the cell owing to hydrogen bonding between the cell membrane and oxygenate groups of MXene (Ihsanullah, 2020). MXenes' antimicrobial effects are in part determined by their atomic structure.

Graphene and graphene oxide (GO) are also potent antibacterial agents in their own right, even in the absence of functional groups (Younas et al., 2022). GO and RGO nanosheets, both of which are dispersible in water, have been shown to inhibit the development of E. coli with high efficiency and low cytotoxicity. Inhibiting their metabolism, GO has a negative effect on microorganisms (Ahmed and Rodrigues, 2013). Cells die as a result of a decrease in their oxygen consumption, which in turn reduces the value of their biological oxygen demand (BOD). The sharp edge of graphene nanosheets is one of the factors that contributes to graphene's bactericidal activity. Its sharp edge induces a physical breach of the cell membrane, which in turn leads to a loss of membrane integrity, the release of cellular content, and finally cell death. Materials based on graphene have been shown to oxidize a wide variety of biological components and thiols, including proteins, lipids, DNA, and more. Both membrane and oxidative stress contribute to GO and rGO's cytotoxicity against bacteria (Singh et al., 2020).

21. Water Pollutant Detection and Reporting

Accurate, accurate, and quick pollutant detection is crucial in water treatment systems because it provides a quantitative measure of the success of water disinfection. Research into a wide variety of nanomaterials has been conducted for the purpose of detecting and following poisons in water. Important features for monitoring water and detecting properties for pollution may be explained by the ability of 2D Nanomaterials to respond to external stimuli with increased surface reactivity. The recent finding of 2D nanomaterials that have exceptional electrical or optical capabilities has lately ignited concerns over the creation of high-volume sensing devices for contaminants. These concerns have been fanned as a result of the discovery. Analyzing contaminants may include using either noncovalent interactions, such as electrostatic force, or covalent bonds, such as amide bonding. The method used will depend on the kind of analytes being investigated. Here we discuss the current state of the art of 2D material-dependent sensors for the detection of water contaminants through either optical (Zhou et al., 2016). The following are some of the most important ways in which 2D nanomaterials are being used to help manage and track water pollution.

22. Fluorescent Sensors Based on 2D Nanomaterials

Photo-luminescent sensors (also known as fluorescent sensors) measure changes in environmental pollution by monitoring changes in fluorescent light (intensity, wavelength, and lifespan). Light or wavelength shifts may occur when pollutants attach to a sensor and cause structural or chemical change. The fundamental principle of fluorescence-based sensors rests on the observation that the presence of a target analyte (Pb) causes a variety of changes in the fluorescence properties of the recognition component (nanomaterial), including quenching, enhancement/recovery, radiometric fluorescence output, wavelength shifts, and anisotropy. In recent years, efforts have been made to improve the sensitivity and selectivity of fluorescence sensors by using techniques such as the fabrication of nanocomposites and/or functionalization with organic linkers. In order to create fluorescent (bright) sensors, it is essential to design the electrical band gaps of 2D nanomaterials. This is because photoluminescence is connected to processes that involve the transfer of energy. Two-dimensional nanomaterials, such as graphene with zero band gap, have ushered in a new era of huge sensing possibilities thanks to the broad variety of band gaps that are conceivable for these materials (Zeng and Zhang, 2019). There are several different 2D nanomaterials with UV-Vis band-gaps that may be used either on their own as brilliant fluorescent sensors or coupled with other materials to make useful composites (Rong et al., 2015).

23. Colorimetric Sensors Based on 2D Nanomaterials

Different from fluorescent sensors, which need ultraviolet light for laser activation, colorimetric sensors may exhibit colour changes in response to the presence of pollutants (Nirala et al., 2015; Gondal et al., 2021). Using a surface plasmon resonance (SPR) technique, enzyme-based catalysis, a fluorescent switch, and ligand-receptor binding, a colorimetric sensor may detect contaminants in water. The SPR process causes a change in coloration of 2D nanoparticle colorimetric sensors when they come into contact with various contaminants.

The colour of the fluid containing the nanoparticles will change as they aggregate, making their presence or absence visible to the human eye. Nanoparticles aggregate due to electrostatic contact or hydrogen bonding with their environment, which is affected by the solution's composition or the particles' surface features. For instance, in order to detect low concentrations of Cu^{2+} in water samples, an automated colorimetric sensor based on AgNPs was utilised during a flow batch operation. Some organic dyes, fluorescent nanomaterials and fluorescent polymers such as carbon dots, quantum dots and metal nanoclusters are used for pollution detection in 2D colorimetric sensors because of their fluorescence qualities. Colorimetric sensors based on enzymatic catalysis used both natural and artificial enzymes. However, although the catalytic processes of these two kinds of enzymes are quite similar, natural enzymes outperform in terms of stability and catalytic activity. Biomimetic enzyme and enzyme catalysis of 3,3,5,5-tetramethylbenzidine (TMB) is often employed as the basis for colorimetric sensors that mediate enzyme and biomimetic enzyme catalysis (Liu et al., 2019). The interaction of receptors and ligands as indicators (chromophore and fluorophore) and analytes (anion/cation) may cause the emission spectra of the indicator to change, which, in ligand-receptor based colorimetric sensors, results in a colorimetric response that is proportional to the quantity of analyte present (Zhu et al., 2021). The manufacturing of colorimetric chemical sensors for the detection of metal cations and other anions often makes use of Schiff bases, which are the most frequent form of ligand or receptor employed in this process. For instance, in the colorimetric detection of Fe^{2+}, Zn^{2+}, and Cu^{2+} (Tang et al., 2017), multifunctional Schiff bases have been used. The changes in fluorescence gating, surface plasmon resonance (SPR), catalysis by enzymes and mimic enzymes, ligand binding, and receptor binding are totaled up.

24. Electrochemical Sensors Based on 2D Nanomaterials

Standard practice demands for the employment of detecting electrodes capable of providing a detectable electrical signal concerning electrochemical adsorption or reactivity with analytes in the electrochemical identification of water contaminants. In addition to the anode, cathode, and cathode ion pairs, electrochemical sensing additionally makes use of a reference electrode, working electrode and counter electrode. Resistance, potential, capacitance, and current will all fluctuate as a result of pollution, and these variations may be measured and evaluated. Electrochemical sensors based on 2D nanomaterials can detect a broad range of toxins in addition to heavy metals (Tiwari et al., 2016). Hazardous pollutants in water, such as NH3 or toluene, may be monitored using gas sensors. A new review study will offer a more in-depth look into gas sensing utilizing 2D nanomaterials, and we will briefly discuss some recent improvements in water for gas sensing of common contaminants (Anichini et al., 2018). Changing the surface chemistry of 2D nanomaterials might lead to the creation of gas sensors.

25. Application of 2D Nanomaterials to FETs

Field-effect transistors (FETs) made from two-dimensional nanomaterials have attracted a lot of interest because of their potential use in pollution detection. The adsorption of certain contaminants on 2D nano-sheets alters one or more of the most essential properties of a conventional FETs-based sensor, such as the threshold voltage, field-effect mobility, and Ioff/Ion ratio. Nano-sheets of semiconducting materials are very enticing because to their great charge transporter mobility and agreeable band-gaps. And because of their huge lateral scale, 2D nanomaterials may interact conformally with metal electrodes, lowering contact resistance in field-effect transistor-based sensors. Comparatively, fluorescence sensors are noted for their slow detection time compared to fast-acting devices like FETs. In particular, FET sensors based on 2D nanomaterials tend to have small footprints and low power requirements, making them well-suited for applications such as embedded and wearable sensors (Mao et al., 2017). Sensors based on field-effect transistors have been developed using 2D nanomaterials for application in the management and detection of common water pollutants. Graphene's enhanced surface area, high carrier mobility, and flexible chemical functionalization have made it a paradigm 2D nanomaterial for GFET-dependent sensors. Protective layers, such as metal oxide, are required for 2D nanomaterials that rapidly disintegrate in water. The formation of an electrostatic double layer on the surface of the adsorbed target analytes is unfavorable to FETs sensors while monitoring water contaminants. Fields caused by charged impurities or gate potential are suppressed by an electrostatic double layer (such as a shorter Debye length) that is firmly in place (Gao et al., 2015).

26. Difficulties and Restrictions

There are several obstacles that need to be cleared out before we can fully grasp the potential of 2D nanomaterials for water filtration on a massive scale. The high expense of implementing 2D nanomaterials into industrial processes and their limited applicability to large-scale structures are both consequences of the fact that this technology is still in its infancy and the difficulties inherent in producing them. Many 2D nanomaterials still have a high production cost when compared to more conventional materials and products; hence, significant reductions in this area are highly sought. It is also important to think about the 2D nanomaterial's future potential (in terms of both production and use). Since water purification is essentially a decontamination process, it is important to prioritise ecologically friendly 2D nanomaterials with reduced toxicity (such as LDHs) and to consider the biocompatibility of these materials to avoid recontamination. Methods for preserving the reliable operation of targeted nanochannels over extended periods of time are urgently needed. Making channels with higher throughput is essential for high-performance solar desalination and energetic water transport. Hence, modern self-assembly and directed aggregation techniques that shape sequence structures via high-throughput channels may prove to be highly helpful.

Systematically modulating material pollutant interaction is important for the development of innovative types of creative nanostructures that are programmable, adaptive, multifunctional, and selective for sensing, photocatalysis, and adsorption processes. Poor and non-specific contacts with pollutants are common in many pristine ecosystems (Mounet et al., 2018). Too far, the majority of MXenes have been synthesised using a top-down strategy, and research on the production cost of bottom-up MXene synthesis is sparse at best (Ihsanullah, 2021). The innovative bottom-up techniques of MXene synthesis that allow for more control over product features need substantial attention in this field of study. The fact that MXene must be kept in a cryogenic state is still another challenge for scientists. For MXene solution to be stable for extended periods of time without oxidizing, an effective technique for doing so must be developed. It is crucial to achieve mass commercialization, which necessitates the creation of high throughput fabrication of stable 2D nanomaterials of appropriate quality at reduced cost. Considerations for large-scale deployment of 2D materials include their manufacturing cost, processability, scalability, stability, and consistency.

27. Final Thoughts

In conclusion, the world does not currently have access to an affordable and reliable source of water, despite the widespread use of various water purification techniques such as chemical disinfection, solar, distillation, sedimentation, oxidation and boiling. Thus, a more efficient technique must be developed to ensure that people have access to clean drinking water and water purification and integrated membrane operations are two areas where 2D nanomaterials can be put to use because of their distinct properties. The use of low-cost 2D material techniques with an emphasis on processability and high scalability may be useful. Due to the use of inexpensive and multi-layered crystals, solution-based top-down exfoliation will allow for the scalable synthesis of 2D materials at low cost. In contrast to the bottom-up techniques used to create 1D nanomaterials from molecular precursors, such as chemical vapour deposition growth, top-down exfoliation methodology for 2D nanomaterials is nearly developed and easily processed in an industrial setting by exfoliating bulk layered precursors with the aid of sonication or shear force. Since most 2D nanomaterials are made from Earth-abundant elements including Ti, sulphur, boron, Mo, nitrogen and carbon. Biodiversity and the problem of material shortages should both benefit from the implementation of appropriate solutions, such as materials recovery. From an operational aspect, 2D materials do not degrade via repeated use, do not corrode, do not cause harm, and do not introduce secondary pollution. Therefore, the longevity of the equipment is also an important factor to think about. When 2D nanomaterials assemble themselves, many different kinds of organised nano-architectures may emerge. Nano-sheets of transition metal dichalcogenides (such as $MoSe_2$ and MoS_2) have soft dangling groups like as Se and S, which react strongly with soft acids such as Hg^{2+} and Pb^{2+}, whereas MXene surface groups comprising -F and -OH contribute to greater adsorption on hard acids. Chemical programmability may be used to achieve a wide range of functionalities, such as the simultaneous removal of many contaminants in a single material system via the use of superlattices of nanomaterials and multi-component assemblies. Organic foulants may be reduced by using membranes in conjunction with photocatalysts to undergo photo-catalytic degradation, therefore lowering organic fouling during membrane separation. As an added bonus, many nanomaterials, like MXenes, are composed of components that are plentiful in nature, which might be useful in environmentally conscious applications on a budget. For adsorbents made from 2D nanomaterials to maintain their effectiveness after being reused, further research is needed to increase their stability. To find candidate materials with enhanced catalytic, electrical and thermal characteristics that are better suited for environmental remediation and water treatment, further study is needed to bridge the gap between newly predicted and experimentally achievable 2D nanomaterials. In order to create novel materials with improved electrocatalytic, photocatalytic, and other useful properties, it is essential to confirm theoretical predictions in the lab.

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