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An Overview of Titanium Oxide Nanoparticles, Chareacterisation, Synthesis and Potential Applications

Ayad Mohammed Nattah[1] **Ahmed Hashim Mohaisen**[2]

College of Materials Engineering, Babylon University[1]

College of Education of Pure Sciences, Babylon Universit[2]

ayadnatah@yahoo.com ahmed_taay@yahoo.com

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Abstract

The nanoparticles has given a serious concern due to its novel and attractive properties due to its small size and high specific surface area. These outstanding features has allow for nanoparticles to potentially utilized for many applications. Aconsiderable attention has recently fouced on Titanium oxide nanoparticles because of their outstanding applications including gas sensors, electronic devices, optical magnetic recording, catalysis, and potentially used in biomedical applications. Various methods have been employed in order to generate TiO_2 (NPs) of required size and morphology to potentially use in many field sectors. In this review, the importance, structure and properties of TiO_2 nanoparticles are summarised and demonstrated. Recently, a number of scientific researchers have been developed synthesis methods for obtaining titanium oxide nanoparticles are classified into basically methods: physical, chemical and biological synthesis. A detailed overiew of different applications for titanium oxide nanopartciles are presented.

Keywords: Nanoparticles, Small size, Titanium oxide, Applications , Properties, Structure, Chemical, Physical

1- Introduction

Nanotechnology has greatly contributed in several fields of research and is considered as a gate of the revolutionary technology in the 21st century. This technology has seen recently an emerging area of science and become a powerful for new nanosize particles and their applications [1]. The science of nanotechnology including the controlling of atoms and molecules for creating new materials with a diiferent of useful applications in various fields [2]. Nanomaterials have gaind a great deal of attention due to their excellent optical, electrical, magnetic, and catalytic properties. It is well-known that the nanomaterials properties and their potential applications have significantly influence by phases, sizes, and morphologies of nanomaterials. Thus, much attention has been paid to synthesis nanostructured materials with controlled and novel morphologies [3]. The TiO2 is found in different structures such as rutile, anatase and brookite which are efficiently used in many practical applications. TiO2 is unique

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functional materials due to its outstanding properties such as high refractive, superconductivity, low cost, index, and corrosion resistance [4] .

Nanosized material at a size range of 1–100 nm have gained a great deal of interesting due to its unique properties into the region of transition between the molecular and the bulk phases [5].

The titanium oxide at nanoscale have been widely applied to different potential applications such as solar cells [6], pigments and paints [7],bio- sensors [8] , photo catalyst [9], fuel cell [10], optical fibres and telecommunication [11] , future lithium batteries [12] , bio-sensors [13],photo-detectors [14], drug delivery [15]. Titanium dioxide (TiO2) is an ideal semiconductor for photocatalysis due to its high stability, low cost and safety toward both humans and the environment [16].

Basically, there are two main routes that emplyoed to produced titanium oxide nanoparticles which are classified ito bottom-up and top-down. Top–down route involves mainly physical methods wherase bottom–up routes mainly including chemical and biological methods for fabrication the nanoparticles[17]. The most common techniques in the top-down used for synthesizing nanoparticles and nanostructures are lithography, dry etching techniques and anodization. There are a number of bottom up techniques used to produce nanomaterials. The most common techniques are co-precipitation, sol-gel, hydrothermal, microwave etc. however, the limitations of the bottom up methods including high temperature and pressure, cost effectiveness, high energy , eco-toxicity and environmental sustainability. In addition, the limitation in term of mass production and potential applications in different fields[18].

In recent year, it has been proven that gas-phase processes can be considered as one of the most effective ways to generate nanoparticles. This approach possesses many advantages including large scale –production, single-step and contionous process, high puirity of products. Moreover, this does not involve all the extensive steps related to wet-chemistry methods To overcome the drawbacks of wet chemical route, it has been proven that the flame or combustion synthesis has enormous valuable as cost effective method. Thus, this method has become widly used for fabrication of the nanoparticle as a simplest route. Generally, wet chemical methods required multiple steps while, flame synthesis occurs as a single-step process. The combustion synthesis is considered as easily scalable process and therefore has proven efficiently achieve high product yields and large, continuous production quantity [19]. This review paper aim to give an overview of the importance of titanium nanoparticles and foucing on their unique properties and outstanding applications.

2. Potential application of nanoparticles

Titanium dioxide is one of the most important materials and therefore has been paid a great interest due to its distinctive optical and electronic features . Nanomaterials at nanoscale size ranging from 1 to 100 nm are exhibit unique properties of materials. Nanoparticles have become most important in many technological fields and they are highly promising for a wide range of applications such as solar cell, catalysis, electronics, energy storage, gas sensor, and biomedical applications[20]. Titanium oxide (TiO_2) has been used for cleaning contaminated air and water due to its their photocatalytic activity . Also, rutile Titanium oxide is more preferred in and suitable for the materials that exposing to outdoor conditions like paints [9]. In Photovoltaic application the TiO_2 nanoparticles have been widely used as semiconductor in solar cell due to its low price and non-toxic as shown in Figure 1.

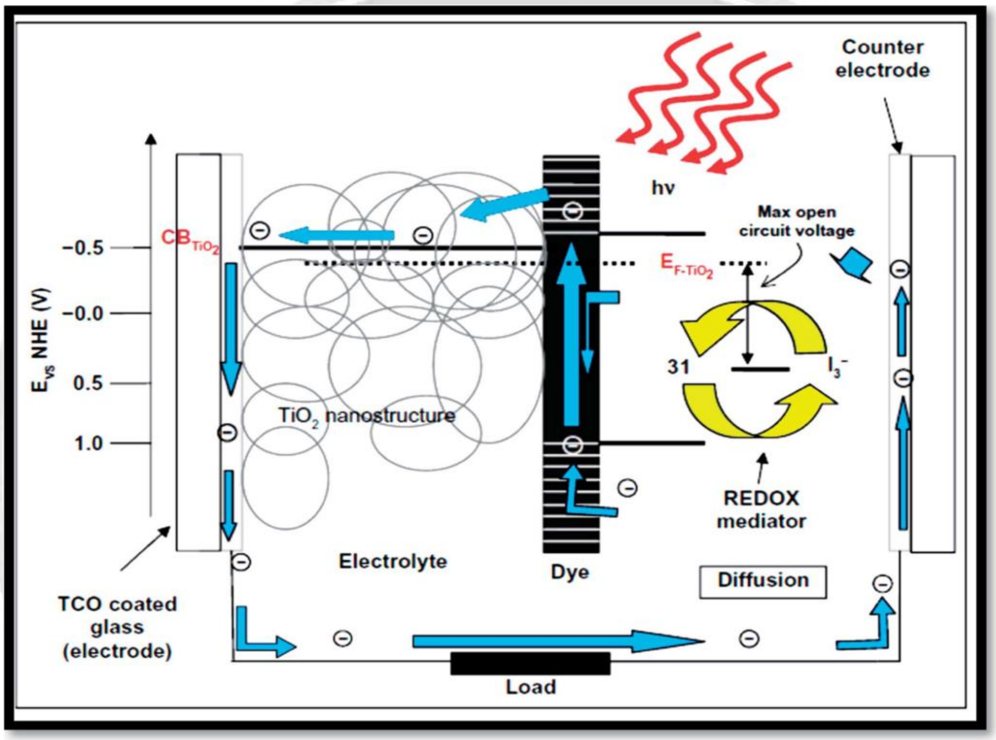

Figure 1 : Titanium oxide role in solar cell [21].

TiO_2 nanoparticles play important role in waste water treatment because of the high ability of the removal toxic from water as shown in Figure 2.

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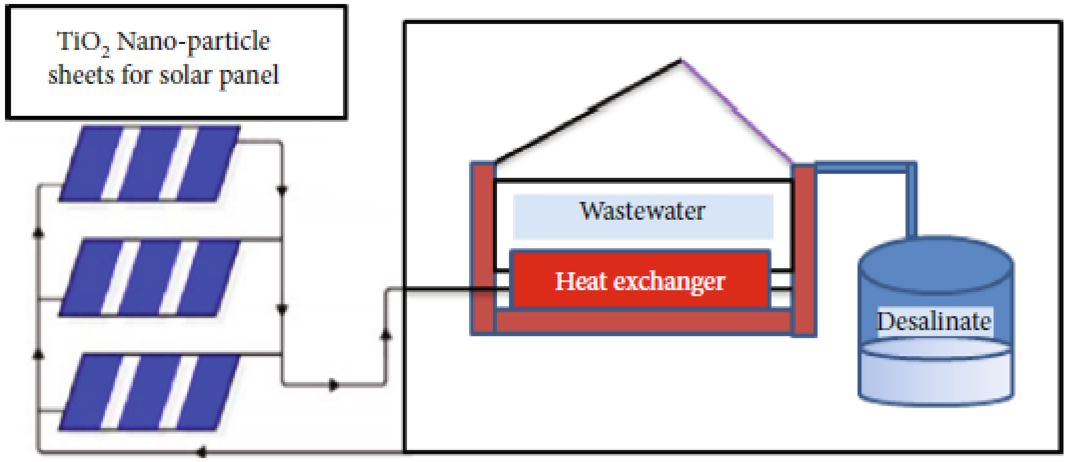

Figure 2: The schematic diagram of application of TiO_2 nanoparticles in water treatment [22]

Titanium NPs have been used perfectly for loading various types drugs as nanocarrier .Thus, titanium nanoparticles are effective carrier and deliver a drug with enhanced efficacy [17]. A schematic shows the drug delivery system using TiO2 nanoparticles is shown in Figure 3.

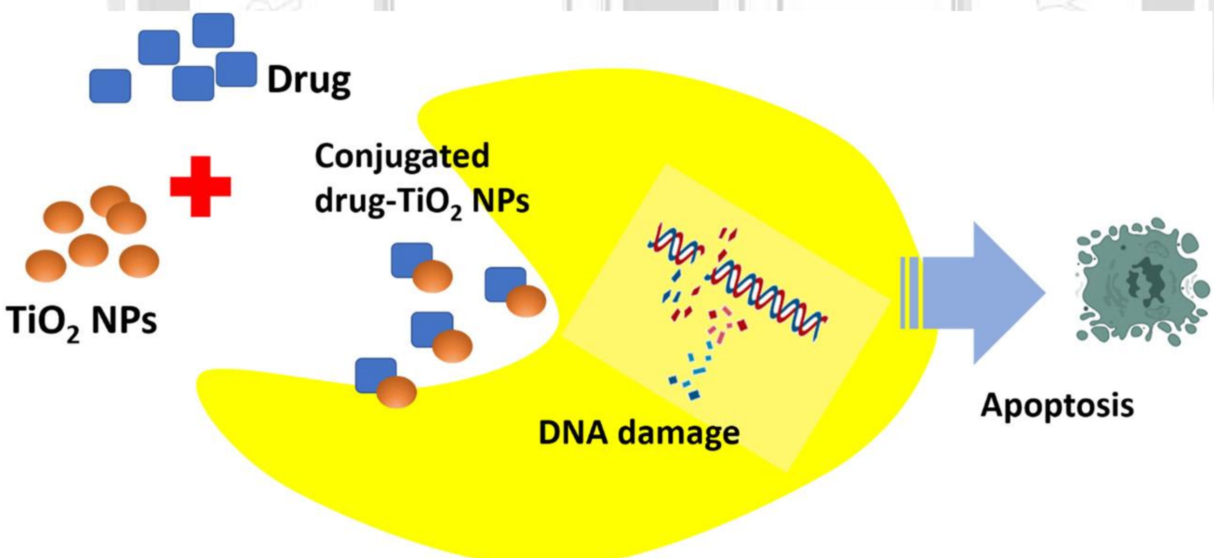

Figure 3: Schematic sketch the drug delivery system by using TiO_2 nanoparticles[17]

The different fields and wide range of nanoparticles applications are shown in Figure 4.

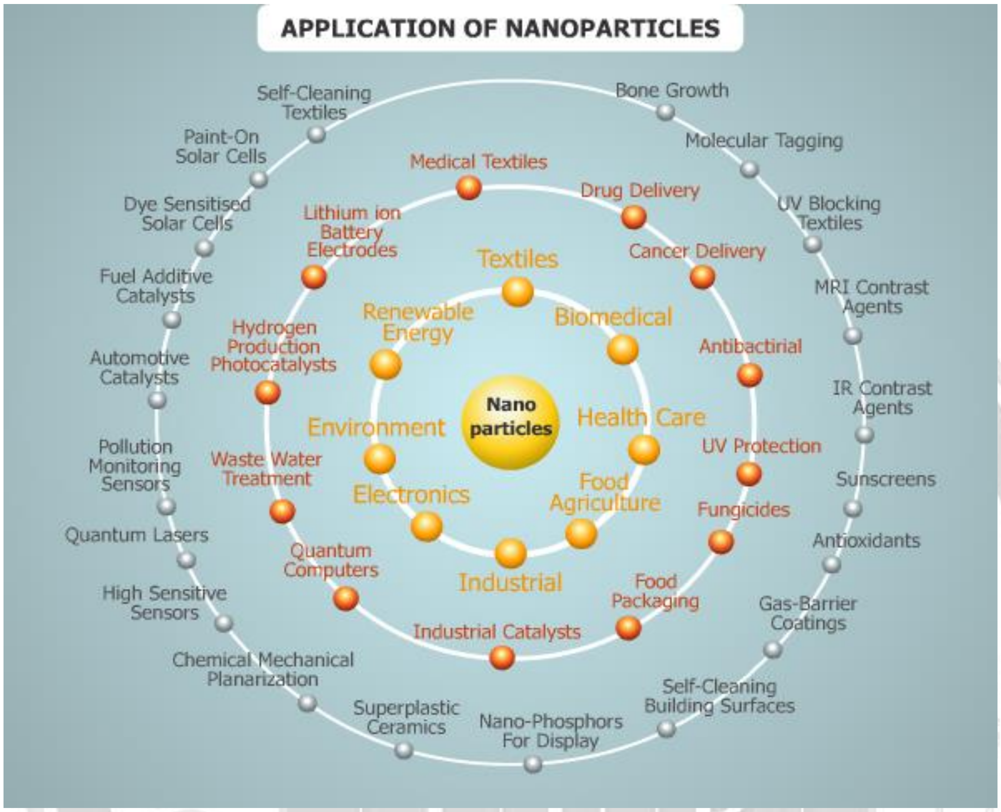

Figure 4 : Application of nanoparticles [23]

3. Synthesis methods of titanium oxide nanoparticles

The most common approaches for producing titanium oxide nanoparticles including physical, chemical and biological. The selection of each method of synthesis has significant influence on producing titanium oxide with a desired size, shape, structure and magnetic properties. The main approaches to synthetize titanium oxide nanoparticles, highlighting advantages and limitations of each technique are as follows [18].

3.1 Sol-gel

Sol-gel processing, a wet chemical synthesis approach is widly used to synthesize magnetic nanoparticles. In this method, the process starts with a chemical solution as precursor undertake different forms of hydrolysis and polycondensation reactions. The solution is then stirried to make a (sol). The sol is then dried to form a (gel) by using chemical reaction. The basic catalysis leads to produce a colloidal gel while, a polymeric form of the gel is produced by acid catalysis. The particles produced in this method are significantly influence on the rate of condensation and hydrolysis. The following parameters solvent, concentration, pH, and

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temperature also have impact on the size of the particles. However, sol-gel process is considered as cost intensive due to its costly raw materials and drying process. The organic material removal which also leads to cracking and volume reduction of prepared TiO_2 [18,24].

3.2 Hydrothermal Synthesis

The hydrothermal synthesis methods can be described as any heterogeneous reactions for synthesizing inorganic materials. This method is commonly carried out in steel vessels with aqueous solutions at controlled temperature and pressure which called autoclaves. The aqueous solutions at a high temperature and high vapor pressure are employed to be carried out the experiment. The depicted is commonly as crystal growth from substances which are insoluble in customary temperature at 100°C and pressure less than 1 atm. In this method, the experimental can be occurs under controlled temperature and pressure in autoclaves The hydrothermal method is affected by alkaline concentration, temperature and reaction time. Temperature is important for promoting growth of crystals and nucleation of nanoparticles[24]. The hydrothermal method is considered as easy method for obtaining nanotube morphology. However, the disadvantage including the high cost of equipment and the inability to monitor crystals in the process of their growth. The important factors that influence on the hydrothermal method are alkaline concentration, temperature and reaction time. The tempreture is significantly effected on the crystals growth and nucleation of nanoparticles [25].

3.3 Microwave method

Microwave method has gained interest due to simpler , low cost , a shorter crystallization time and more energy efficient technique to synthesis new improved nanostructures materials and short crystallization time comparing with the conventional heating methods. Therefore, microwave method is a convenient technique for preparing nanocrystalline oxides with possible formation of new meta-stable phases and rapid heating to reach the required temperature. In this method the experimental reaction happens by mixing titanium slags and Na_2CO_3 by using magnetic stirrer. The leaching and washing process for three times with water the residue was collected. Then the residue is placed in a corundum crucible in a microwave at high-temperature 900 °C for 60 minutes and 1 kw of a microwave heating power [24].

3.4 Chemical Vapor Deposition

Vapor deposition is define as coating process which allows thin coating a solid-phase form which stands for physical vapour deposition. These processes are potentially used coatings techniques which lead to improve the properties of different substrate. These properties such as mechanical, optical, electrical, corrosion resistance, and wear resistance. In Chemical Vapor Deposition (CVD) process occurs when the gases in the coating chamber are heated by the thermal energy heats resulting in the deposition reaction. In CVD, the most important parameters that influence on deposition controlling. These parametetrs including deposition temperature, flow rate, gas composition, pressure and deposition chamber geometry. However, the most important challeng with gas-phase deposition technique is the risk of contamination[20]. Djerdja et al. [26] stated synthesis nanocrystalline TiO_2 films by using CVD on different substrates. The experiment is carrioud out at relatively low temperature of 320 ◦C

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and $TiCl_4$ used as precursor. The results obtained that the size and distribution of nanograins in the films are influenced by the nature of substrates.

3.5 Combustion

Combustion synthesis has become most important route for synthesis inexpensive metal oxide nanoparticles. This method has many advantages in term of ingle step process, high purity, simplest and continuous production. This method is more effective route and is widely used over wet chemical approaches. Thus, flame synthesis has been successfully applied in the synthesis of iron oxide nanoparticles. In this method, the flames produce high temperatures that are important to activate precursor pyrolysis. The final product obtained has outstanding characteristics including controlled particle size distribution, phase and composition. The nanoparticles propreties are highly affected by the altering flame operating conditions such as temperature, reactant concentration, stoichometry, pressure, burner configuration, precursor injection location [27]. Flame based synthesis is more commercially successful due to the advantages of it being simple, scalable, low-cost and continuous operating mode to give high production yield [28].

4. Biological methods

This method is cnsiderad as green nanotechnolog approach for TiO_2 NPs synthesis. This method is based on biological sources such as bacteria, fungi. plant extracts and protein-mediated. This technique has many advantahes in term of eco-friendly, simple, cost effective. However, this method required high pressure and temperature which have negatively impacted on the mass production of TiO_2. There are various parts of plants that can be used to generate the nanoparticles such as leaf, stem, root, and fruit. In addition, bacteria has excellent ability to reduce the metal ions and therefore utiliized for producing metalic and other novel nanoparticles. Furthermore, fungi is consideread as very efficient method to produce metal oxide nanoparticles [19]. The synthesis of TiO_2 NPs by biological routes is a green method which is and important for production nanoparticles in appropriate sized with low energy consumption [18].

The table below is summarized the advantages and disadvantages of the above methods and demonstrated in Table 1.

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Table 1. Comparative assessment of titanium oxide nanoparticles from different wet chemistry methods

Method	Authors	Advantages	Disadvantages
Sol-gel	Mironyuk et al. [24]	considered as cost intensive due to its costly raw materials and drying process.	Required long process
Hydrothermal	Nyamukamba et al. [25]	widely used for the production of fine particle in the ceramic industry. An easy method to obtain nanotube morphology	high cost of equipment and the inability to monitor crystals in the process of their growth. consuming time long time processing .
Microwave	Mironyuk et al. [24]	simplicity, low erenergy costs, minimal impact on the environment,	Generally do not give samples with nanometer-sized particles
Chemical Vapor Deposition	Byranvand et al. [20]	potentially used coatings techniques improve the properties of different substrate. These properties such as mechanical, optical, electrical, corrosion resistance, and wear resistance	Carried out at high pressures and temperatures in vacuum chamber.
Combustion	Kwon-Jai et al. [27]	synthesis in expensive metal oxide nanoparticles. single step process, high purity, simplest and continuous production effective route and widely used over wet chemical approaches.	It is a great challenge to obtain nanoparticles with contrlooled size and shape.
Biological	Li et al. [19]	Eco-friendly, simple, cost effective.	required high pressure and temperature which have negatively impacted on the mass production of TiO_2

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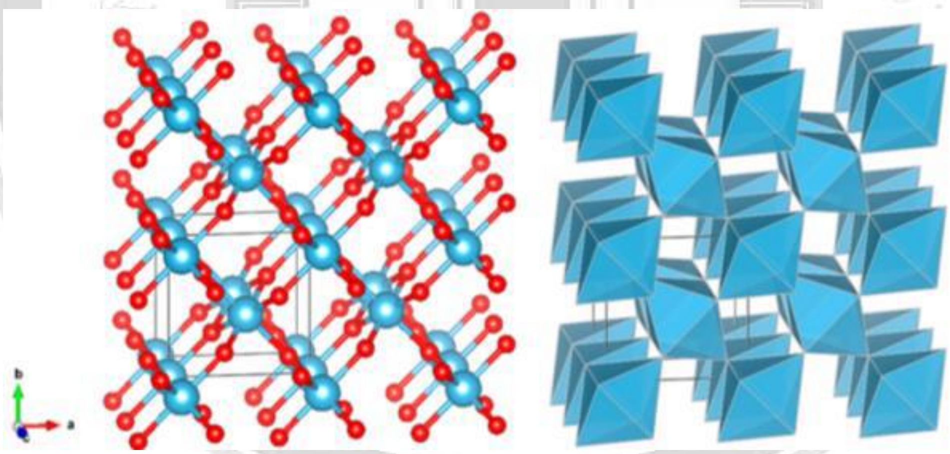
5. Nanoparticles- types, structure and applications

5.1 Types

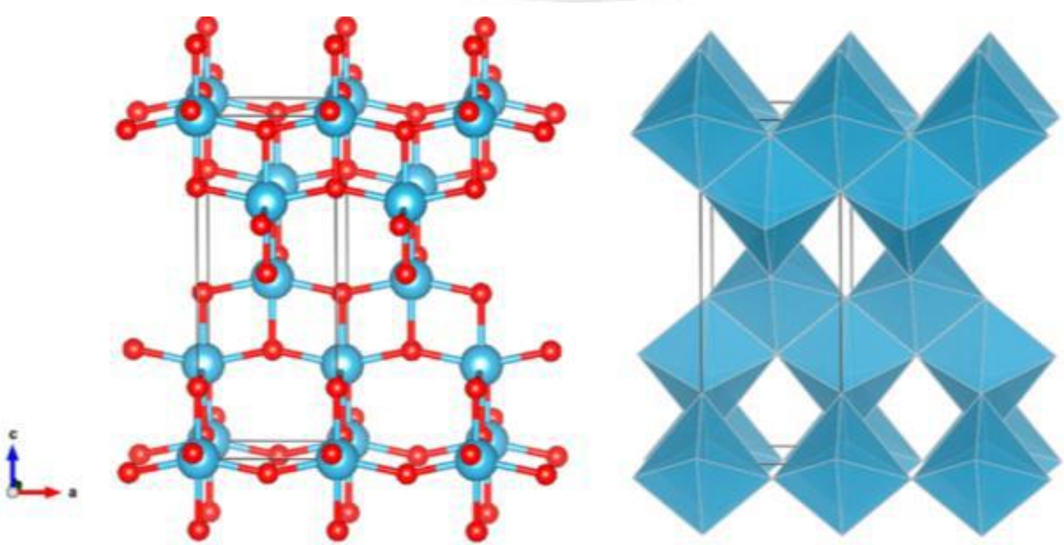
Titanium oxide nanoparticles can be found in the three main types such as polymorphic modifications: anatase, rutile, and brookite. TiO_2 has become much important nanomaterial and gain a great deal of attention because of outstanding properties. It has huge advantages in the transmission of solar energy [24] .

5.2 structure

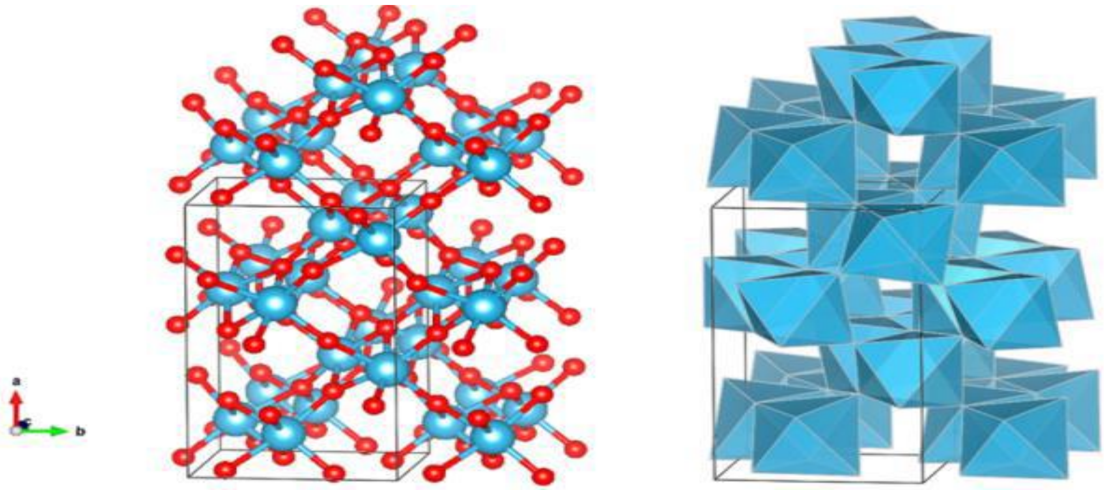
Titanium oxide (TiO_2) is a transition metal oxide with very good properties to address environmental and energy challenges. The properties of TiO_2 are highly influenced by the size, morphology and phase. TiO_2 nanoparticles have low surface energy and hence become more stable than their bulk material. The other important effect of the size of the TiO_2 nanoparticle is related to significant changes in solid state electronic properties compared to the bulk materia. Structural and electronic properties drive the physical and chemical properties of the solid. The other important effect of the size of the TiO_2 nanoparticle is related to significant changes in solid state electronic properties compared to the bulk material. Structural and electronic properties drive the physical and chemical properties of the solids [24]. Figure 4 shows the crystal structure of the three kinds of titanium oxide.



Rutile (**a**)



Anatase (b)



Brookite(c)

Figure 4: The crystal structures of (a) Rutile , (b) Anatase and (c) Brookite [24]

5.3 applications

It has unique photocatalytic properties which are highly useful for solar-energy conversion processes. In the past decade, significant research has been conducted on the potential of TiO_2 nanomaterials for their applications in practical systems such as photovoltaic devices, water splitting devices, photocatalyst, batteries, photonic crystals, sensors, ultraviolet blockers, smart surface coatings, pigments and paints[24].

The nanoparticles properties such as magnetic, physical, and optical are demonstrated in Table 2.

Table 2. The main properties of the anatase , rutile and brookite phase of titanium [29]

Properties	Rutile	Anatase	Brookite
Crystal structure	Tetragonal	Tetragonal	Orthorhombic
Lattice constant	a= 4.5936 c= 2.9587	a= 3.784 c= 9.515	a=9.184, b=5.44 c= 5.154
Space Group	P4/mnm	I4/amd	Pbca
Molecular (cell)	2	2	4

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Volume/molecule	31.2160	34.061	32.172
Density	4.13	3.79	3.99
Ti-O bond length	1.949(4) 1.98(2)	1.937(4) 1.965(2)	1.87-2.04
O-Ti-O Bond angle	90^o	92.6^o	77^o-105^o

5. Conclusion

1. Titanium oxide nanoparticles are potentially employed in many industrial sector that enable technology for a variety of practical applications.
2. The nanoparticles properties and their diverse applications are significantly influenced by nanomaterilas sizes, shape and structure.
3. This review provides an updated and critical focusing on nanoparticles, classification, synthesis, providing examples of different practical applications.
4. The nanoparticles have different applications of science such in electronics, solar cell, biomedical field.
5. A summary review of nanoparticles synthesis including chemical and physical route is presented .

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اياد محمد نطاح **احمد هاشم محيسن**

كلية هندسة المواد، جامعة بابل *كلية التربية للعلوم الصرفة، جامعة بابل*

ahmed_taay@yahoo.com ayadnatah@yahoo.com

الخلاصة

النانوباركتل حظي باهتمام كبير لخواصة المميزة نتيجة حجمة الصغير ومساحتة السطحية العالية ولذلك يستخدم بشكل فعال في مختلف المجالات. في الاونة الاخيرة اوكسيد التيتانيوم قد تم تسليط الضوء عليه ونال قدر كبير من الاهتمام وذلك للاستخدامات المميزة له بمختلف التطبيقات على سبيل المثال متحسسات الغازات والاجهزة الالكترونية والمسجل المغناطيسي الضوئي واستخدمت بشكل اكثر فعالية في التطبيقات مثل الطب الحياتي . هناك طرق مختلفة قد استخدمت لانتاج اوكسيد التيتانيوم النانوي بالحجم والشكل المطلوب تصنيعه كي يتم استخدامه بشكل امثل في محتلف القطاعات. في هذة الورقة المعدة هي مراجعة لاهمية اوكسيد التيتانيوم وتركيبته البلورية وخواصه قد عرضت بشكل مختصر. مؤخرا مجموعة من العلماء قد ساهموا بتطوير طرق الانتاج للحصول على اوكسيد التيتانيوم النانوي وهذة الطرق يمكن تصنيفها بشكل ريئسي الى طرق فيزيائية وكيميائية وطرق بايولوجية .ا لمراجعة المفصلة تناولت الاستخدامات المختلفة لاوكسيد التيتانيوم.

الكلمات الدالة:- النانوبارتكل، الحجم الصغير، اوكسيد التيتانيوم، التطبيقات، الخواص، الكيمياوية، الفيزياوية، التركيب

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