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Applications of nanoscale silica (silicon dioxide) in the cosmetics industry

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Abstract: As nanotechnology gains growing interest and popularity from a wide range of industries, in this review special focus is given to the cosmetics industry, one of the first industries to implement nanomaterials. Among the different types of extensively utilized nanoparticles, silica stands out with its unique physicochemical characteristics and favorable benefits. This article presents several common synthetic methods for nanoscale silica. In addition, its distinctive features and numerous advantages are reviewed, followed by its varieties of uses in the cosmetics industry, in terms of skin care, make-up, hair care, and dental care products. However, considering the large-scale applications of silica nanoparticles, their potentially hazardous impacts on humans and the environment cannot be overlooked. Concerns over possible health risks and environmental harms that nanoparticles may cause arise among the general public and are becoming increasingly widespread. The potential toxicity of nanoscale silica to humans and its detrimental environmental effects are also discussed in this paper. Since further incorporation of nanomaterials into cosmetics has now been limited, more thorough and detailed regulations, safety assessments, as well as toxicological investigations and characterizations are encouraged and required to allow for the future development of nanotechnology.

Keywords: Nanomaterials; Nanoscale silica; Preparation methods; Cosmetics; Toxicity.

1. Introduction

Nanomaterials, defined as substances with a size in the range of 1 to 100 nanometers, are drawing increasing attention to their uses and applications in cosmetic products due to their unique physical and chemical properties [1]. The cosmetics industry was among the first industries to implement nano-sized materials, and in today's society, they have become more and more popular thanks to technological advancements [1]. Nanotechnology now serves as a technical strategy for the development of novel cosmetic formulations [2].

Generally, some distinctive characteristics of nanomaterials include size effect, quantum size effect, surface effect, quantum tunneling effect, etc. Properties can vary greatly depending on size. Nano-sized materials show some significant advantages when added to cosmetics, such as enhanced stability, more effective transport of the constituents through the skin, and more efficient skin penetration for improved delivery of the active ingredients to targeted areas of the human body [1].

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Silica nanoparticles have attracted great attention from the cosmetics industry because of their advantageous features, including biodegradability, high biocompatibility, strong chemical stability, high surface area, pleasant touch, and the ability to deliver lipophilic and hydrophilic compounds by encapsulation [1-3]. The low manufacturing costs and easy synthesis also make nanoscale silica stand out among a great variety of nanomaterials [2]. Nanoscale silica is typically utilized to improve the effectiveness, efficacy, texture, evenness, and shelf-life of cosmetics [1].

Despite the growing public interest in nanotechnology, an ever-increasing number of people are fretting about its side effects, including its potential harm to humans and detrimental impacts on the environment [2]. There are also concerns that some businesses may use nanomaterials improperly or excessively simply for enhanced performances. However, as this field was recently developed, many test results remain contentious or inconclusive, and the cytotoxicity of silica nanoparticles has not been fully determined [2,3]. Therefore, promoting the progress of test models that would allow for an accurate prediction of the toxicological effects of nanoparticles is necessarily required [2]. Moreover, efforts should be undertaken to lessen nanomaterials' damaging consequences on the environment without sacrificing their properties and effectiveness [2].

In this review, a non-exhaustive list of preparation methods for silica nanoparticles is provided, followed by their unique features, benefits, and applications in cosmetic products [1]. Additionally, the toxicological properties of nano-silica and widespread concerns regarding its possible health hazards and environmental damages are reviewed [1]. As an increase in the presence of silica nanoparticles in the cosmetics industry is anticipated, further and more detailed tests and risk assessments are required to meet the safety standards and overcome the limitations [1].

2. Preparation of silica nanoparticles

2.1. The sol-gel method

Colloidal nano-silica can be produced by employing the sol-gel method [3]. The controlled synthesis of silica nanoparticles resulting from a sequence of chemical reactions was reported by Stöber et al. in 1968, involving the hydrolysis of alkyl silicates and subsequent condensation of silicic acid, with the use of catalysts, such as ammonia, and alcohol solutions (see Figure 1) [3]. In this way, species comprising Si-OR and Si-OH are converted to siloxane (Si-O-Si) compounds [3]. Two significant advantages of this technique are the obtainment of high-purity products and the controllability of the reaction process [3,4]. By changing the reaction parameters, one can alter the particles' size, distribution, and shape [3].

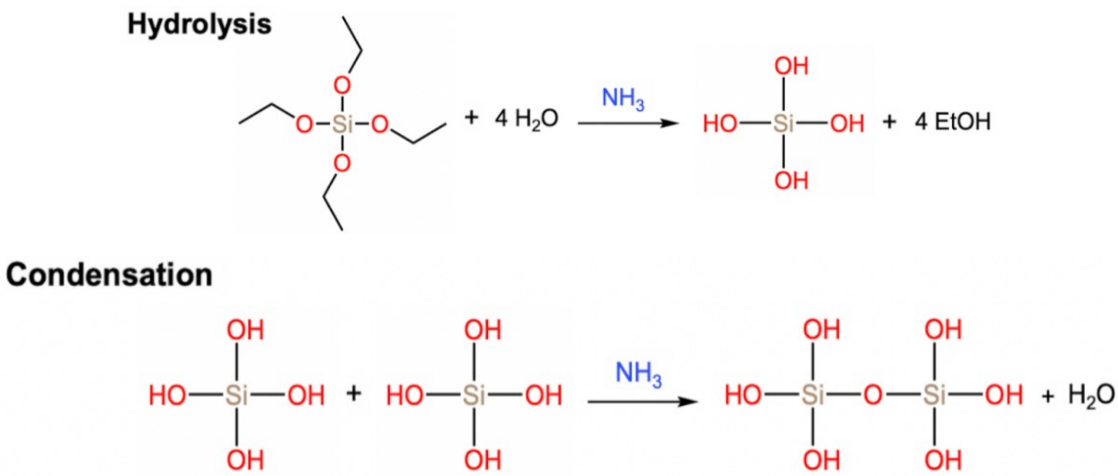

Figure 1. Schematic diagram of possible steps of the sol-gel approach [3].

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2.2. The microemulsion method

Among the commonly utilized approaches to synthesize nanomaterials is the microemulsion method [3]. Porous silica nanoparticles can be prepared using water-in-oil (W/O) microemulsions [3]. When the alkyl silicate compounds dissolved in the oil phase diffuse to the surfactant layer and enter into the water phase, the hydrolysis process occurs [3]. While this technique allows for easier reaction control in comparison to other one-phase reactions, one should not ignore the high costs of organic solvents and surfactants used as well as the requirement for purification and recycling of nanoparticles in order to achieve manufacture on a large scale [3].

2.3. Chemical precipitation method

As a conventional method for preparing nano-silica, the chemical precipitation approach uses sodium silicates and inorganic acid (hydrochloric or sulfuric acid) as raw ingredients [4]. Then, silica nanoparticles can be produced by adding proper stabilizers (surfactants) and maintaining a suitable pH value, followed by calcination of the precipitates at an appropriate temperature [4]. The principles are as follows: $2HCl+Na_2SiO_3 \rightarrow 2NaCl+H_2SiO_3$, $H_2SiO_3 \rightarrow SiO_2+H_2O$ [4]. Some major benefits of the chemical precipitation technique include its simplicity, little requirement for equipment, and low production costs [4].

3. Applications of nanoscale silica in cosmetic products

3.1. Skin care products

Presently, skin care products, especially sunscreens which employ nanoparticles as ultraviolet (UV) filters, are the most common application of nanomaterials in cosmetics [2]. Typically, nano-sunscreens are superior to conventional sunscreens, as they will not create a white layer on the skin surface [5]. In addition, they have little odor and are more aesthetically pleasing [5]. Also, a smaller amount of the product is supposed to be applied to the skin each time as the particles are nano-sized [5].

Silica nanoparticles, strongly UV-reflective and highly stable, are easily compatible with the other parts in the formulation without decomposing or reacting with them [4]. Thus, they can be added into cosmetic formulations together with titanium dioxide (TiO2) and zinc oxide (ZnO) to attain better sunblocking effects [4].

Nanoscale silica has the particularity of improving sun protection properties since it enhances the spreadability of sunscreen products and minimizes their phototoxicity or degradation [2]. Silica nanoparticles can be often utilized to lower the deleterious effects, such as cytotoxicity, allergic reactions, and skin damage, and reduce photocatalytic activity [5,6]. Moreover, it has been indicated that enzymes leading to skin dryness can be restrained by silica powder at the nano-order level [7]. Silica nanoparticles can be found in skin care products and present functions as emulsifiers, emollients, and water barriers [2].

Furthermore, the silica nanoparticles found in cosmetic anti-wrinkle formulations might induce the stratum corneum to retract, causing the skin to be smoother and tighter [6]. Steger once described a kind of silica nanoparticle-containing cosmetic product used for delaying the skin aging process. These particles function as water binders and help stabilize and regulate the skin's moisture content [6].

3.2. Make-up products

Lip and face cosmetics that are either rinse-off or leave-on often contain nano forms of silica [1]. It serves as an anti-caking agent and improves absorbency [1]. Research has shown that silica nanoparticles play a role in improving the looks and distribution of the pigments in lipsticks, while also inhibiting the pigment migration into fine lines of the lips [1].

Also, foundations and concealers use inorganic materials to cover blemishes and give the skin a natural appearance [7]. Absorbent fillers like silica are utilized to obtain a desired matte finish on the skin [7]. Silica spheres are another popular and widely used additive in many cosmetics, which can improve the “skin feel” of the product [7]. Silica nanoparticles in numbers of skin, nail, and face cosmetics are used for the efficiency of the product [8].

Moreover, according to research by Maitra et al., an aqueous cosmetic gel composed of a nanoparticle fractal network, preferably silica, can produce optical blurring effects and, by filling in the empty spaces on the skin surface, is said to make wrinkles, fine lines, pores, and other blemishes become invisible, while allowing the skin to appear flawless and natural [6].

3.3. Hair care products

A great many solutions for hair care contain silica [6]. Beate et al. described an organic chromophore-bound dye for human hair containing functionalized silica nanoparticles [6]. Less skin staining is achieved by this method’s deeper and lasting dyeing, which stays fast even after washing, gentle shampooing, and rubbing, demonstrating remarkable stability under both reducing and oxidizing circumstances [6].

In addition, according to Canham et al., a certain type of composition for hair care that contains mesoporous silica offers burst fragrance release, enhanced bioavailability of hydrophobic active constituents, and favorable degradation products [6]. Also, color, aroma, luster, volume, and manageability are claimed to be imparted [6].

3.4. Dental care products

A certain composition in a dental care product that can reduce color fading by encapsulating an organic dye in a silica shell nanoparticle matrix was described by Cummins et al. [6]. Thanks to it, the color of the oral care composition remains stable at temperatures as high as 49 degrees Celsius for three weeks at minimum [6].

Silica nanoparticles are also utilized in dental fillers and tooth polishing because of their being biocompatible and economical [9]. Cariogenic bacteria living in cavities are responsible for causing damage to tooth enamel by generating acids that harm the enamel and induce caries [9]. In order to “combat” the cariogenic bacteria and protect the enamel surfaces, teeth should be often polished [9]. It has been revealed that using silica nanoparticles for polishing results in a surface with reduced roughness, thereby helping prevent dental caries [9].

Moreover, modified silica nanoparticles can be used as desensitizing agents to treat dental hypersensitivity [9]. Enamel loss will result in the exposure of dentinal tubules and thus an increased risk of dental hypersensitivity [9]. Although a great many oral care products have been used to occlude the exposed dentinal tubules, these products, unfortunately, can only reach a very limited depth into the dentinal tubules, meaning that they cannot possibly achieve the intended results [9]. Under this circumstance, silica nanoparticles have been a promising material owing to their tiny size, well-defined structures, large surface area, biocompatibility, and high thermal stability, which enable them to penetrate deeper into the dentinal tubules without irritating the surrounding tissue and offer long-lasting tubule occlusion in dentin [9].

4. Potential toxicity & risks

4.1. Environmental harms

The environment will be exposed to nanoparticles through both intentional and unintentional means, including air emissions and wastes from manufacturing plants [10]. Furthermore, nanoparticles in paints, textiles, and cosmetic products may also contribute to environmental pollution [10]. Nanomaterials released will eventually accumulate on the surfaces of land and water [10]. It is possible that nanomaterials may cause pollution to the soil and waters by flowing to the surface and ground water after they come into contact with the land [10]. Wind or rainwater runoff may make possible the transport of nanoparticles from solid wastes, wastewater, direct releases, or inadvertent spills to aquatic systems as well [10]. The biggest releases of nanomaterials into the environment may be caused by spills

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resulting from the transportation from production factories to other industrial sites, intentional environmental applications, and spillages related to daily wear and erosion [10].

4.2. *Health hazards*

Intentional and nonintentional skin exposure to nanoscale particles are both possible [10]. Using lotions, creams, and wound dressings may result in intentional dermal exposure to nanomaterials [10]. It is yet unknown if certain kinds of nanoparticles may have the ability to penetrate the skin and cause cytotoxicity to the skin and other organs by breaking down into even smaller particles and depositing or because of the photoactivated properties [10].

Inhalation exposure can occur because of nanomaterials’ tiny size [10]. Their potential to accumulate in the human body and have toxicity affected by their nanostructure is made possible by their high surface area and activity, peculiar morphology, and subsequent breakdown into smaller parts [10]. The smaller particles formed may also present concerns if they show biological activity that is dependent on the nanostructure [10].

In addition, nanoparticles pose a serious threat to humans’ lives considering their high accumulation efficiencies in people’s lungs, especially those suffering from chronic pulmonary illnesses [10]. Some studies have shown that silica nanoparticles have the potential to cause cytotoxicity, silicosis, and lung cancer [9]. Moreover, some experiments have also reported nano-silica’s genotoxic effects such as DNA damage and regulation of genes involved in apoptosis and autophagy as well as immunotoxicity [9].

Furthermore, silica nanoparticles' ability to pass through the skin barrier may give rise to a variety of harmful symptoms [11]. They may interact with the viable keratinocytes in the stratum granulosum to cause inflammatory reactions, or they may interact with a kind of immune cells, Langerhans cells, in the stratum spinosum to trigger allergic reactions that result in, for example, dermatitis [11]. Dermal exposure may induce skin cancer as well [11]. All these effects could be classified as dermal toxicity [11].

Even worse, if a compound crosses the epidermis successfully, it might potentially harm distal organs by translocation through the bloodstream or by inducing systemic reactions [11]. These can result in numerous detrimental consequences and diseases, including melanoma, organ damage, systemic inflammation, and even cancer [11].

5. Conclusion

Nanotechnology is playing a growingly significant role in the cosmetics industry, particularly in developing novel and more efficient cosmetic formulations, and people have reasons to believe that it will continue to be popular. Among varieties of nanomaterials, the unique and favorable characteristics and benefits of nanoscale silica have made it an excellent and commonly used additive in many cosmetic products, ranging from skin care products and make-ups to dental care and hair care products.

Gradually, the general public has shifted their intense attention from the extensive applications of nanoscale silica to its potential toxicity. Nevertheless, the information currently available is still insufficient to make any conclusive statements. Clearly identifying and characterizing the health hazards silica nanoparticles may pose as well as defining the appropriate conditions for their safe use has not been made possible. Despite some studies suggesting that they are safe, these data are inadequate and sometimes controversial.

Under this circumstance, more and further long-exposure tests are needed. There is an urgent requirement to research nanomaterials’ health and environmental impacts, the nanoparticle life cycle, human exposure routes, and the behaviors of nanomaterials in the body. Understanding the behavior of nanoparticles when they enter the human body and their interactions would help people design better and more goal-oriented tests and experiments.

Meanwhile, it is worth noting that silica nanoparticles' cytotoxic properties also depend on their size, charge, and concentration, and those with high specific surface areas tend to be more cytotoxic. Therefore, future research can focus on the toxicological characterization of particles of different sizes and types, including mesoporous silica, hollow silica, amorphous silica, etc. Potential exposure risks associated with silica nanoparticles via different routes of entry should also be taken into consideration. Furthermore, many other features and applications of nanoscale silica can be explored. For example, in the biomedical field, silica nanoparticles can be added to cosmeceutical products. They may be used as the drug delivery vehicle or to improve different therapies to treat skin disorders, such as skin cancer and wound healing.

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