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Nanotechnology in Cosmetics: An Overview

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ABSTRACT

Nanotechnology is revolutionizing the treatment of skin diseases in cosmetics, offering safe and targeted delivery of active medications and cosmetic ingredients. The use of carrier systems in nanotechnology improves skin penetration and sustained drug action. Formulators are using technology exclusive to cosmetic products, such as vesicular, particulate systems, emulsions, nano capsules, nanotubes, nanocrystals, and dendrimers. Nanomaterials are also used in hair care products and nail formulations. Nanomaterials are used in modern cosmetic products, particularly in sunscreens due to their ability to protect the skin from harmful UV radiation which is carcinogenic. This review explores nanotechnologies in the cosmetic industry and their potential as next- generation smarter carrier systems. It highlights the advances in nano cosmeceuticals and the applications of nanotechnology in cosmetics. It also focuses on the regulations of nanotechnology in cosmetics and describes various routes of exposure to nano particles in the human body.

Keywords: Nanotechnology, cosmetics, nanoparticles, regulations, advances

INTRODUCTION

Innovative fields of study including nanotechnology and nano delivery systems involve the creation, analysis, production, and use of materials, apparatuses, and systems at the nanoscale (1–100 nm). As one of the technologies that is altering the cosmetics and skincare industry, nanotechnology is being investigated extensively (1). The word "Nano" was derived from Greek which means dwarf, consisting of manipulating materials at atomic and molecular levels. Nanoparticles contain unique and novel characteristics that differ from the original materials they are derived from. These particles possess one or more external dimensions or internal structures on a nanoscale and exhibit novel characteristics compared to the same materials without nanoscale features (2).

Nanotechnology in cosmetics

Cosmetics are topical preparations that are used externally and can be formulated from a single or acombination of substances either from natural or artificial sources (3). The Drugs and Cosmetics Act 1940 and Rules 1945 define cosmetics as "any substance intended to be rubbed, poured, sprinkled or sprayed on, or introduced into, or applied on the human body or part for beautifying, cleansing, enhancing appearance, promoting attractiveness (4). US Food and Drug Administration (USFDA) defines cosmetics as "a product intended to be applied to the human body for cleansing, beautifying, promoting appearance without affecting the body's structure or functions (5). The European Union Cosmetics Directive (EUCD) defines cosmetics as "any substance or preparation intended to be placed in contact with the various external parts of the human body (epidermis, hair system, nails, lips and external genital organs) or with the teeth and the mucous membranes of the oral cavity with a view exclusively or mainly of cleansing them, perfuming them, changing their appearance and/or protecting them or keeping them in good condition (6).

Cosmeceuticals are described as preparations containing traditionally used cosmetics that specifically have restorative effects on skin and hair. Serving as an intermediary between pharmaceuticals and cosmetics, they guarantee an enhancement in appearance (7), (8). The market for individual consideration is increasing at an exponential rate, and cosmeceuticals are currently one of the personal care segments with the quickest rate of growth(9). It is one of the fastest-growing industries and uses nano cosmeceuticals. Through the applicationof nanotechnology, materials can be manipulated at the atomic level, offering the cosmetics industry new opportunities in the field of cosmeceuticals.

Nano cosmetics and nano cosmeceuticals are the outcome of the creation of cosmetic and medicinal products, respectively, incorporating different nanomaterials. Among the benefits of using nanotechnology in cosmeceuticals include a longer duration of action, increased bioavailability, and enhanced visual appeal. These sizes and high surface-to-volume ratio, among other advantages over conventionally utilized cosmeceuticals. Furthermore, adding nanoparticles to cosmetic compositions enhances the cosmeceuticals' look, coverage, and skin adherence without altering their active ingredients. Nano ingredients are excellent adjuvants in cosmeceuticals because of their tiny lowed in cosmetics to enhance UV protection, color, release of fragrance, quality, anti-aging properties, and other properties like duration of action, site specificity, biocompatibility, drug-loading capacity. They are used in skincare, haircare, nailcareproducts, etc. (10).

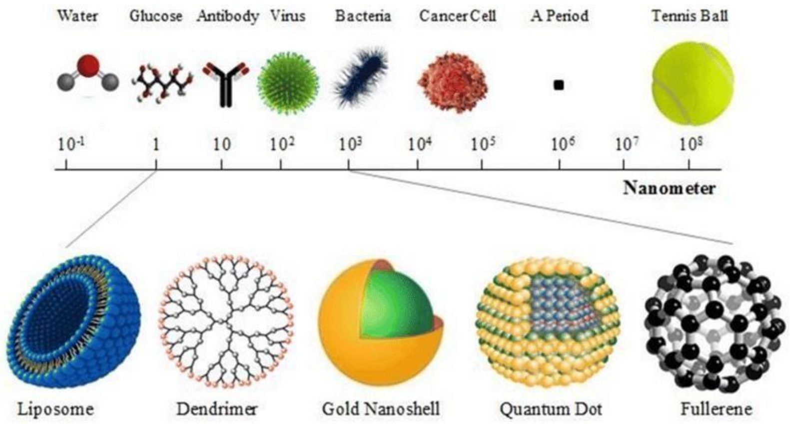

Figure 1: Nanoscale and nanostructure diagram (11)

Nanomaterials used in cosmetics: -

Nanomaterials are materials that have at least one dimension in the nano range and significantly distinct physiological properties. These materials have been commonly used in cosmetic products. Nanoscale cosmetics show more advantages than microscale cosmetics. The large surface area of thenanoparticles is responsible for the efficient transportation, absorption, bioavailability, transparency, and sustained effect of the product. However, necessary considerations are being taken to overcome the related toxicity of the product. A few examples of nanomaterials used in cosmetics are given below.

1. Inorganic particles

Compared to natural nanoparticles, these are safer, more biocompatible, hydrophilic, and remarkably more stable particles. They might differ greatly from one another as they are derived from inorganic materials (Ag, Au, Ti, etc.). The natural ones are manufactured from polymers. Some of the important inorganic nanoparticles used in cosmetic products are -

- Titanium Dioxide and Zinc Oxide
- Gold and Silver Nanoparticles
- Silica
- Carbon Black
- Nano-Hydroxyapatite

Titanium Dioxide and Zinc Oxide

Sunscreens are useful for shielding the skin from solar radiation i.e., UV radiation (UVA-1, UVA- 2, UVB). Prolonged exposure to this radiation leads to skin cancer and various dermatological problems. Sunscreen consists of zinc oxide (ZnO)and titanium dioxide (TiO2) as inorganic UV protectants. They prevent UV radiation from reaching the skin. Zinc oxide is more effective against UVA whereas titanium dioxide is effective against UVB radiation (12), (13), (14). Titanium dioxideis the most widely used inorganic nanoparticle used in sunscreen. At the nanoscale, it offers a higher sun protection factor (SPF), enhancing its effectiveness and providing a superior restorative effect due to its transparency, unlike its original color. These beneficial properties of TiO2 are due to its large surface area to volume ratio in the nano range (15).

They scatter more effectively and have a more potent restorative or protective impact. However, it has been demonstrated that inhaling a significant quantity of these nanoparticles can be hazardous (16). Because regular sunscreen components are safer and have not been shown to cause serious toxicity problems or infiltration into the epidermis, an alternative mode of administration (i.e., dermal application) focuses on them (17), (18). In a study, rats exposed to high concentrations of TiO2 nanoparticles and pigments experienced cellular disintegration in their lungs. This condition is analogous to working in dusty environments, where exposure to these substances can have detrimental effects on humans. Nonetheless, the USFDA views ZnO as safe to use as a UV filter in cosmeceuticals or cosmetics. Alternatively, naturally occurring nanoparticles are used for their UV-protective properties; one example of this is ivy nanoparticles, which are secreted from the roots of English ivy (Hedera helix) and are safer (19). Ivy nanoparticles' improved safety and optical transparency make them an attractive alternative replacing other toxic nanoparticles reducing the impact on health and the environment.

Gold and Silver nanoparticles

Nanoparticles made of gold and silver have both antibacterial and antifungal characteristics (20) and are frequently used in cosmetic formulations including face masks, anti-aging lotions, and antiperspirants. Egypt has a long history of using gold in cosmetics and skin health products. Gold was used there to preserve skin tone. Gold is currently used in a variety of skincare products, including lotions, salves, and treatments. Gold used in skincare products is referred to as colloidal gold or, more accurately, nanogold if its size falls between 5 and 400 nm. Depending on the size andoverall surface area, its hue can range from red to purple (9), (21). Gold nanoparticles have diverse shapes, such as nanospheres, nanorods, nanoclusters, nano stars, nano shells, nano cubes, and nano triangles, and the state of these particles determines their cell uptake and optical behavior. Properties such as stability and biocompatibility make them more appropriate for skincare and cosmetics (9). Furthermore, their antifungal, antibacterial, and anti-aging benefits are well established and are highly significant in cosmeceutical industries and wound healing applications (22). Gold nanoparticles play a substantial role in fixing skin damage and improving skin surface, grace, and flexibility. The soothing properties of gold make it an exceptional agent for treating skin

inflammation, sunburn, and hypersensitivity. Hence, it can be successfully used in face masks and other cosmetics.
Research indicates that the use of silver nanoparticles as an additive in cosmetics makes the formulation stable, without showing sedimentation, for more than a year. Additionally, silver nanoparticles demonstrated adequate protection against bacterial growth in various formulations. The use of silver in cosmetics can be problematic because silver readily precipitates in silver-based mixtures, which can be overcome using silver nanoparticles. In Europe, the safety of colloidal silver in nanostructures regarding its use in oral and Dermal cosmetic items is ambiguous (23). In the USA,due to the lack of FDA regulations, cosmetics items are thought to lack promising antibacterial properties (24).

Silica (SiO3)

Silica nanoparticles are present as nano dispersions with a size range of 5 to 100 nm and can deliver both hydrophilic and lipophilic entities to their respective targets by encapsulation. It has been demonstrated that silica nanoparticles may help to improve the appearance and appropriation of shades in lipsticks and keep colors in place (25). The majority of leave-on and wash-off cosmetic products for the hair, skin, lips, face, and nails contain these nanoparticles, and it is anticipated that the presence of silica nanoparticles in cosmetic products will continue to grow (26). Although the safety of silica-based nanoparticles is questioned due to their dubious practical applications, aspects like surface modifications and size should be considered when assessing their toxicity (26), (27). Long-term studies are necessary since the commercial application of silica nanoparticles in beautifying compounds is currently unclear (17).

Carbon black

Carbon black, or CI 77266, is widely used as a colorant in cosmetic treatments for the eyes and skin and is recognized as a key component of cosmetic formulas. The EU permits it to be used as a colorant up to a maximum amount of 10% and in its nanostructure form. In comparison to micro-sized nanoparticles, an assessment of carbon black nanoparticles revealed a greater propensity for cytotoxicity, aggravation, and alterations in phagocytosis in human monocytes (28). When there is no risk of inhalation, the EU states that it may be used in cosmetic products (17).

2. Nano-Hydroxyapatite

Hydroxyapatite Nanoparticles Cosmetic products designed especially for oral preparations that are used to cure excessive dental sensitivity and polish remineralization of the teeth contain nano-hydroxyapatite (29). The US Food and Drug Administration (USFDA) views it as a promising and secure choice for these reasons (30). Because these particles can remineralize and desensitize, they have been included in oral formulations including mouthwashes and dentifrices. These mixtures might offer a fluoride toothpaste substitute (17).

3. Nano organic (Tris-Biphenyl Triazine)

Nano-organic, a unique, potent, and photostable filter used only in sunscreen compositions is called tris-biphenyl triazine (31). Because of its broad-spectrum UV protection properties in nano form, it is often employed in sunscreen formulations. It is an authorized UV protectant in Europe and provides notable photostability. BASF SE uses it under the brand name TINOSORB® A2B. Another permitted UV protectant on the EU market is methylene bis-benzo triazolyl tetramethyl butylphenol (MBBT), which can be used in dermally applied cosmetic preparations at up to 10% w/w. The Scientific Committee on Consumer Safety's (SCCS) evaluation states that MBBT poses no risk to humans when applied to intact, solid skin. However, it has sparkedworries about potential.

4. Bucky Balls (Buck minster fullerene/c60)

Because of its antioxidant qualities, carbon fullerene is widely employed in cosmeceuticals and cosmetics. Because of their strong ability to scavenge free radical oxygen species, fullerenes are frequently employed in skin-rejuvenating cosmeceutical formulations, which help to lessen the consequences of UV damage, such as wrinkles and hyperpigmentation (32). Fullerene, often knownas "buckyballs" or buckminsterfullerene, is a three-dimensional spherical compound that consists ofa carbon ring with an odd number of carbon atoms (33). Because fullerenes are hydrophobic, their utility in pharmaceutical applications is limited. However, their aqueous solubility has been successfully boosted through the introduction of surface-active chemicals at the right concentration (20), (34).

5. Miscellaneous

The two main types of nanoparticles used in cosmeceuticals and cosmetics are biodegradable (composed of lipids, chitosan, etc.) and non-biodegradable (composed of ZnO, silica-based nanoparticles, etc.) (35). Because of their unique organic and mechanical qualities, chitin and its deacetylated derivative chitosan represent another class of materials that the cosmeceutical sector is very interested in (36). After carbonate and protein fractions are removed from the shellfish exoskeleton, chitin nanofibrils can be extracted (35). Emulsions containing chitin nanofibrils can form a hygroscopic subatomic coating that increases skin hydration and prevents water loss (17), (37).

Advances in nanotechnology in cosmetics

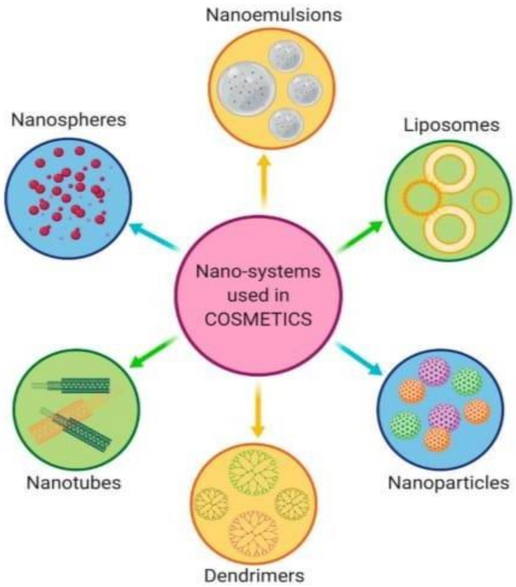

Figure 2: Advancements in nanotechnology in cosmetics (38)

Liposomes:

These are membrane-bound, spherical, double-phospholipid molecules. These liposomes can function as delivery systems for encapsulated substances that are intended to enter or pass through the skin. The targeted actives are kept in reserve by these nanomaterials. Liposomes are used in cosmetics because they are flexible, biodegradable, and non-toxic. It is possible to encapsulate active ingredients in these liposomes for simple and secure distribution. The liposomes can be used to deliver both hydrophilic and hydrophobic compounds. The skin's ability to remain smooth and supple is facilitated by the phospholipids found in liposomes. Lipids included in liposomes shield the active components from ultraviolet light, extending the shelf life of the items (39). Sonication and micro fluidization are two techniques that can be used to create liposomes and nanoliposomes. Extrusion was the first technique used to synthesize liposomes.

During that process, liposomes are structurally transformed to become large unilamellar vesicles (LUV) or nanoliposomes, depending on the pore size of the filters used (40), (41), (42). Liposomes provide UV protection for the skin and hair as well. Liposomes may facilitate the release of the active substances at the location. Liposomes can be used to transport a variety of components, including vitamins, antioxidants, and other lipid compounds. Dior introduced "Capture," their first liposomal anti-aging cream, in 1986 (43). These liposomes are used in cosmetic items like cream, shaving creams, sunscreens, and shampoos. Liposomes, which include phosphatidylcholine, a form of phospholipid that helps soften and condition, make them suitable for usage in a variety of shampoos and conditioners. Liposome quality could be brought on by oxidation.

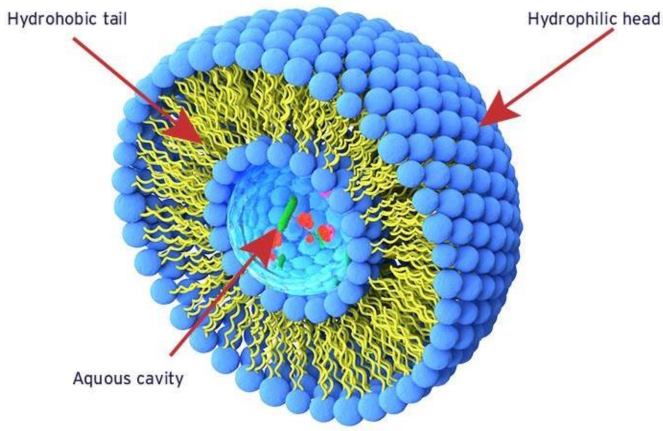

Figure 3: Structure of Liposome (44)

Niosome:

Niosomes are referred to as nano-vesicles composed of self-assembly of essentially non-ionic surfactants, with/without the integration of cholesterol/lipids. These unilamellar or multilamellar vesicles comprise an aqueous solution of solute and lipophilic components enclosed by a membrane generated from the organization of surfactant macromolecules as a bilayer. From the size range perspective, small unilamellar vesicles range from 0.025–0.05 µm, large unilamellar vesicles range up to 0.10 µm, and multilamellar vesicles range >0.05 µm. Cholesterol and non-ionic surfactants, including alkyl amides, brigs, tweens, spans, crown ester, sorbitan ester, steroid-linked surfactants, and polyoxymethylene alkyl ether, are the major noisome components that are widely used for its preparation. Researchers from L'Oréal (Clichy, France) were the first to report the application of noisome in cosmetic products in the 1970s and 1980s.

Since then, they have been inspected for numerous applications, including cosmetic, pharmaceutical, and food sectors. Niosome is used in cosmetic products and skincare applications since it exhibits the potential for reversible reduction of the barrier resistance of the horny layer. Thus, this increases the bioavailability of active constituentsin living tissues at a faster rate. Niosome is thought to improve drug delivery across the skin barrier. Many factors, such as the structure and nature of surfactants, the composition of the membrane, structural and functional attributes of the encapsulated drug, and hydration temperature, can affect the formation of niosome. Apart from conventional niosomes, proteasomes are also employed to improve targeted drug delivery. Numerous niosome-based cosmeceutical formulations are available in the market, such as moisturizing and skin-whitening creams, anti-wrinkle creams, conditioners, and hair-repairing shampoos.

The use of niosome as a carrier system has gained increasing importance for cosmetic actives due to bioavailability, improved skin penetration, enhanced stability of encapsulated active substances, high surface adhesion, and constant release attributes. In contrast to conventional formulations, noisome exhibits less toxicity and allows controlled transfer of the loaded active ingredients, which in turn Cosmetics 2020, 7, 24 6 of 16 show beneficial effects for skin soothing and tanning products. Many plant-derived biologically active substances are of high interest in cosmetics because of their beneficial activities such as anti-aging and antioxidants. A vast number of bioactive substances extracted from plants have been probed using niosomes to augment their beneficial effects on the skin. The liposome-incorporated cosmeceutical formulations offer better skin penetration and help to protect the skin from harmful radiation. Skin cancer issues are caused by unprotected skin health, intrinsic pathway of cell death via apoptosis upon uncontrolled exposure to harmful radiations.

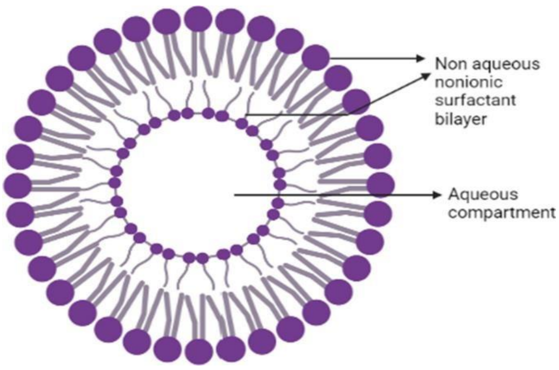

Figure 4: Structure of Niosome (38)

Carbon nanotubules:

Various hair coloring solutions have incorporated nanoparticles based on graphene. Carbon nanotubes, often known as CNTs, are cylindrical hollow fibers comprised of rolled graphene walls that are composed of graphene. CNTs have lengths of around 10 s of microns and diameters ranging from 0.7 to 50 nm (45). They are also incredibly light in weight. CNTs come in a variety of forms, including single-, double-, and multi-walled varieties. Whereas double-walled CNTs have two concentric single-walled CNTs, single-walled CNTs only have one sheet of graphene. Multi-walled

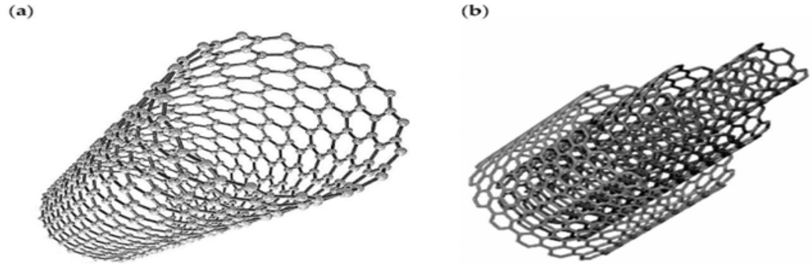

Figure 5: Structure of Carbon nanotubes (a) single-walled nanotube (b) multi wall nanotube (46)

CNTs are formed by several layers of graphene tubes (47). Cosmetic preparations employ carbon nanoparticles, carbon nanotubes, and peptide-based carbon nanotubes (48), (45). CNTs that have undergone chemical modification are used to color eyebrows, eyelashes, and hair. CNTs are based on peptides that are created by combining by creating a covalent link, a hair-binding peptide on the nanotube's surface increases its affinity for hair (47). Additionally, used in hair care formulations include boron-nitride, nickel vanadate, and halloysite clay nanotubes. Carbon nanotubes have also been produced using widely utilized techniques such as chemical vapor deposition (CVD) and electrochemical anodization (49), (50). Because of their high natural abundance, low toxicity, and affordability, nano clay nanotubes are in high demand in hair care products (51), (52).

Nano emulsion:

Nano emulsions allow ingredients in cosmeceutical cosmetics to quickly permeate the skin. A high degree of fluidity without creaming, a strong occlusive effect that keeps skin moisturized, enhanced infiltration in narrow gaps like hair scale spacings and pilosebaceous follicles, and a clear, slightly turbid appearance and glossy coating on the skin are just a few of the potential benefits of using nanoemulsions in cosmetic products because of their small droplet size. Oil-in-water nano emulsions can be prepared with a combination of emulsifiers called Nano cream, which is made by Synergia. It is intended that this product be used in sprayable emulsions, hyper-fluid emulsions, and wet wipes (53).

Nanoparticles:

Nanoparticles Particles with a solid lipid matrix that are nanometers in size are known as solid lipid nanoparticles (SLNs). These are greasy lipid droplets stabilized by surfactants that are solid at body temperature. Silver nanoparticles are currently found in toothpaste, face creams, soaps, food packaging, clothes, household appliances, wound dressings, and disinfectants. The power of silver nanoparticles to kill germs is strong. Additional instances of nano-compounded cosmetic products on Earth include deodorant, body firming lotion, bronzer, exfoliating scrub, eyeliner, and styling gel. According to their research, nanoparticles are present in nearly every personal care product available. Friends face powder, lipstick, blush, eye shadow, nail polish, hair conditioner, anti-aging cream, moisturizer, soap, toothpaste, and shampoo (54).

Nanocrystals:

Smaller than one-micrometer crystals are known as nanocrystals. They are aggregates that make up a "cluster" and range in size from a few hundred to tens of thousands of atoms. These aggregates typically have diameters ranging from 10 to 400 nm. It is also possible to add poorly soluble medication nanocrystals to cosmetic items, where they can be applied topically and have a strong penetration capability. The first cosmetics hit the market in 2007 with Juvena (rutin) and La Prairie (oil-in-water concentration) in 2008. These products were designed to minimize trans-epidermal water loss and improve skin protection as well as the penetration of active ingredients. It would be helpful for moisturizing, anti-aging, and suncare products. Giving skin care compositions a positive skin feel is beneficial (55), (56).

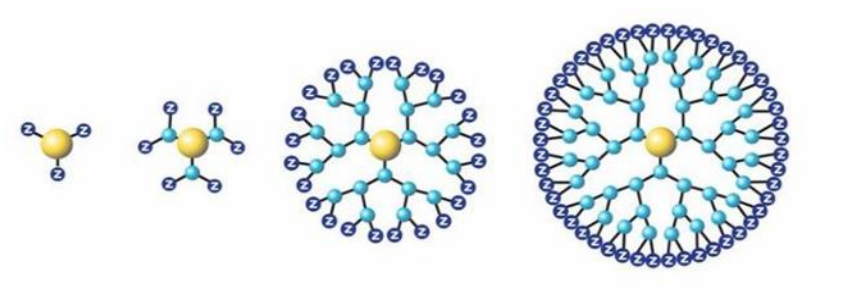

Figure 6: Structure of Dendrimer (57)

Dendrimers:

Dendrimers are microscopic, unimolecular, monodisperse nanostructures that measure around 20 nm in diameter. They have a symmetrical, well-defined, regularly branching structure with a high density of functional end groups surrounding them. In addition to being symmetrical around the core, dendrimers frequently take on a spherical, three-dimensional morphology. In 1985, the new kome dendrimer - one of the earliest dendrimers ever - was created. Additionally, the cosmetics sector has been considering the usage of dendrimers. Several cosmetic businesses have patented the uses of dendrimers in a variety of skin care, hair, and nail products. Because of these features, dendrimers can contain both hydrophilic and hydrophobic molecules. These nano structures have been employedin a variety of cosmetic goods, including sunscreen, shampoo, acne treatment and hair styling materials.

Nano capsules:

These are nanoparticles made of polymers that contain an aqueous or oily phase. They are used in cosmetics to preserve materials, cover offensive smells, and lessen incompatibilities between variousparts of the formulations. Polymeric nano capsule suspensions can be employed as carriers by fusing them into semisolid systems or by applying them directly to the skin. The formulation's usage of polymers and surfactants can control the degree of skin penetration (58). In one study, durable poly-lactic acid nano capsules measuring around 115 nm were created via nanoprecipitation, and odorous atoms were successfully encapsulated in a polymeric nano-transporter to produce a continuous fragrance release (59). This type of atom encapsulation in biocompatible nano capsules may play a crucial part in antiperspirant formulas to increase their efficacy (60).

To deliver vitamins and extracts, researchers have created unique stimuli-responsive nano capsules, which were then added to semisolid formulations like creams. The application of these formulations to the skin caused the nano capsules to release their active components at a specific site on the skin due to stimuli created by injured skin, including pH changes and the presence of enzymes (61). The dimensions of the solid lipid nanoparticles (SLN) are sub-micrometer. These nanoparticles consist of a distinct outer shell with a core composed of lipid or oily components. These are polymeric substances that include a variety of fatty acids, including stearic acid or a combination of fatty acids (62), (63).

When the skin's structure is considered, it is made up of the outer layer of epidermis covering the layer of dermis that contains blood and lymph vessels. Since the nanoparticles include lipid particles that facilitate their easy absorption through topical applications, the use of SLN for skin applications becomes acceptable. Due to the hydrophobic nature of SLN, the particles can prevent dryness and preserve skin moisture. As a result, these nanoparticles are more effective carriers, have less toxicity, and have improved skin penetration. The active ingredients can be released by these nanoparticles rather than penetrating the skin more deeply. Sunscreens, anti-acne, and anti-aging ingredients are frequently carried by SLN and NLC (Nanostructured Lipid Carrier) (64), (65).

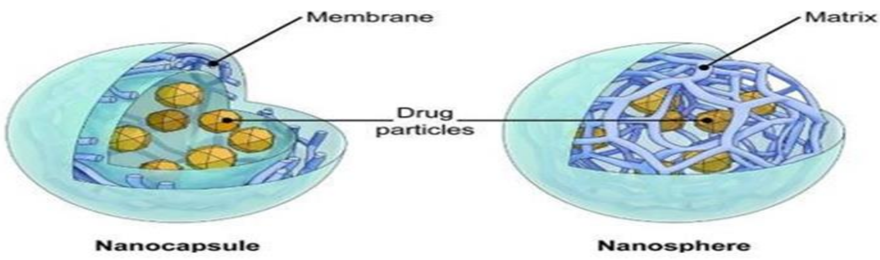

Figure 7: Structure of nano capsule and nano sphere (66)

Regulations of Nanotechnology: -

The growing demand from consumers for better products has made the research and commercialization of nanotechnologies a significant supplement for established companies. Cosmetics makers will have to disclose any nanoparticles in their products that are sold within the European Union according to new European legislation. The Council of the European Union, which consists of ministers from every member state and is the primary decision-making body of the EU, passed a new 397-page cosmetics rule on November 20, 2009, which includes the nanoparticle edict. The cosmetic law specifies that the word "nano" must be inserted in brackets after the ingredient listing to identify all chemicals that are contained in the product as nanomaterials. The legislation further mandates that all sunscreens and cosmetics that are sold and contain nanoparticles undergo individual safety testing by July 2013 (67).

Following the Scientific Committee on Consumer Products (SCCP) of the European Commission (EC) voicing their concerns on the use of insoluble nanoparticles in cosmetic products used topically. Since the nanoparticles pierce both healthy and unhealthy skin, concerns have also been raised about the particles' toxicity. In its view, the SCCP states that "it is necessary to review the safety of nanosized TiO2 in light of recent information and to take into account the impact that mechanical action may have on skin penetration as well as the influence of physiologically abnormal skin." (68). Safe Nano-Cosmetics must adhere to Soft Particle rules, as stipulated by the Scientific Committee on Consumer Products (SCCP) and the Royal Society & Royal Academy of Engineering in the United Kingdom. A new research strategy has been releasedby the US Environmental Protection Agency (EPA) to investigate the effects of manmade nanomaterials on the environment and human health in a more proactive manner.

Nanomaterials, which typically have a size of one to 100 nanometers, are being utilized more often in everyday consumer goods like paint, sunscreen, cosmetics, and athletic gear. The EPA is concentrating its research on seven types of manmade nanomaterials under its new plan, which was unveiled on September 29. These are single-walled carbon nanotubes, multi-walled carbon nanotubes, fullerenes, cerium oxide, silver, titanium dioxide, and zero-valent iron. The OECD (Organization for Economic Cooperation and Development) working party on manufactured nanomaterials, which was established in March 2007 to offer guidance on the responsible development of nanotechnology, recommended that the materials be scrutinized in addition to their current use in products, EPA's near-term needs, and ongoing research at other US government agencies (69), (70).

Figure 8: Routes of Exposures of nanoparticles (71)

Routes of exposure: -

Dermal absorption:

Three pathways of penetration across the skin have been identified: intercellular, trans follicular, and transcellular. The passive transport of nanomaterials through intact stratum corneum is considered highly unlikely because of the matrix of corneocytes, lipid bilayers within the intercellular spaces, and the physiological environment below the stratum corneum containing high levels of proteins. Ifthe skin is damaged, and the normal barrier is disrupted, then the probability of entry of particles may be substantially increased. Follicular openings are compatible with particulate dimensions.

- **Respiratory tract:**

The alveolar macrophages reside as free cells within the alveolar air spaces, from where they may migrate to the bronchioles and then, via the mucociliary escalator, to the lumen of the conducting airways. The alveolar macrophage plays an important role in the response of the lung to inhaled dust and the development of Inflammatory lung disorders. Their essential function is phagocytosis and clearance of particulates and micro-organisms. The type II cell is a secretary cell and is the progenitor cell for type I cells.

- **Intestinal tract:**

Particulate uptake occurs not only in the gut-associated lymphoid tissue (GALT) but also in the normal intestinal enterocytes.

- **Eye:**

The eye only provides only a small surface area for potential exposure but indirect exposure to nanomaterial may occur through it by cosmetics intended for use in the vicinity of the eye or from other types of cosmetic products.

Applications of nanotechnology in cosmetics: -

- **Beauty products:**

A variety of cosmetic products, including fairness creams, concealers, foundations, makeup bases, lipsticks, and others, have reportedly incorporated different nanoparticles due to their physical-chemical, electrical, and optical properties (72). For instance, due to their optical qualities, gold and silver nanoparticles have been used in a variety of cosmetic formulations. Red or blue coloring has been achieved using gold nanoparticles; yellowish coloration has been achieved with silver nanoparticles; and orange coloration has been achieved with gold-silver nanocomposites (10). Furthermore, the color of skin has been successfully altered using nanoparticles. This method uses mixing procedures with formulations that contain nanoparticles that first establish the desired skin color and then the natural skin color.

To achieve brighter shade, silver nanoparticles that produce blue coloration are employed to set the original skin tone. Gold nanoparticles that complement the blue color of the silver nanoparticles are then added to create a green hue. The kind and color of skin have been taken into consideration when choosing the nanoparticles (73). The topical delivery of active ingredients such as 6-methyl-3-phenethyl-3,4-dihydro-1H-quinazoline-2-thione (JSH18), which is effective in skin lightening due to the property of tyrosinase inhibition crucial for melanin production, has been achieved by solid lipid nanoparticles in skin whitening formulations. Applying JSH18-containing SLN formulations to hairless rats exposed to UV light for seven days resulted in an excellent recovery of skin coloring after four days, indicating the product's potential utility for skin whitening (74).

Owing to their antioxidant and hyperpigmentation qualities, arbutin (α- and β- arbutin) has found widespread application in cosmetic goods. α- and β-arbutin have been entrapped using chitosan nanoparticles. When compared to their free forms, these chitosan NPs-entrapped α and β-arbutin have been shown to exhibit improved stability and greater bioavailability, indicating that chitosan NPs are a viable carrier for topical delivery in skin-whitening formulations (75), (76). Nanoparticles have been utilized in nail and lip care products in addition to skincare items. Various nanoparticles have been integrated into lip balms, lip gloss, and lipstick to keep the moisture and suppleness of the lips. For example, varying ratios of silver and gold nanoparticles have been utilized to achieve long-lasting color retention (77) Moreover, silica nanoparticles have been used in lip care products to provide uniform dispersion and good coverage (78). Furthermore, compared to their conventional counterparts, nail care solutions incorporating nanoparticles offer advantages such as increased durability and resistance to blemishes (79). The Nano Labs Corp.-developed nail color that contains nanoparticles has been linked to several benefits, including quick application, stress resistance, easy drying, and the removal of cracks and scratches. In the future, nail care products containing antimicrobial nanoparticles may be utilized to treat microbial infections, fulfilling both therapeutic and cosmetic goals (80).

- **Hair products:**

A vast range of hair care products, including shampoos, conditioners, colors, serums, sprays, and other styling tools, have been made using nanotechnology-based technologies. Nanoparticles have been utilized to help with hair loss prevention, hair-related disorders treatment, hair growth improvement, hair quality enrichment, and more. When compared to traditional hair care products, many nanoparticles have demonstrated potential outcomes in hair care, including nanospheres, nanoliposomes, and nano-emulsions (81). In a different study, hair care products containing sericin nanoparticles—which are made from sericin protein derived from silkworm cocoons, Bombyx mori—were functionalized with quaternary ammonium salts to create sericin cationic nanoparticles.

These nanoparticles have demonstrated encouraging results in restoring hair health and color retention by enhancing hair tangibility, gloss, and softness (82). They were designed to be employedin the repair of damaged colored hair. It has been claimed that polymeric nanoparticles can be utilized to deliver follicular drugs, which can be used to treat hair disorders. Because of its ability to restore hair, Pluronic lecithin Organo gel (PLO) loaded with roxithromycin (ROX) has been utilized to treat hair loss issues. Fluorescence tracking has demonstrated that ROX-loaded PLO penetrates hair follicles effectively, which raises the effectiveness of these nanoparticle-based hair formulations in treating hair loss (83). To increase the manageability and longevity of hair color, various metal nanoparticles, metal oxide nanoparticles, carbon-based nanoparticles, and quantum dots have been included in hair color.

Hair coloring products have included metallic nanoparticles in the form of silver, gold, copper, palladium, platinum, selenium, cadmium, and their alloys. These coated layers of metallic nanoparticles have been noted that organosulfur compounds increase the quality of hair, aid in hairdressing, improve conditioning and provide heat and UV protection x (84). Chemically and physically altered carbon nanotubes have also been utilized in hair coloring. It has been noted that applying carbon nanotubes to human hair can give it a black hue without causing damage. Because of its tiny size, this CNT-based hair color creates a thin coating on human hair, giving it a smooth texture and adding volume. When compared to traditional hair dyes, the large surface area to volumeratio of CNT-based hair color enhances retention (85), (86).

- **Skin products:**

Because of their anti-aging qualities, biomolecules like proteins, vitamins, and antioxidants are usedin a variety of skincare products, including moisturizers, sunscreens, skin cleansers, and anti-aging formulations. By improving other cosmetic advantages and raising the bioavailability of the active components, the usage of solid lipid nanoparticles, nano emulsions, and nanoparticles offers a higher advantage over conventional skincare solutions. Due to their antioxidant qualities, metal-based nanoparticles have been used to counteract the anti-aging effects of free radicals. For instance, to reduce the negative effects of free radical production and increase tissue lifetime, cerium oxide nanoparticle-loaded liposomes have been incorporated into anti-aging lotions (87).

Transdermal medication delivery has made extensive use of both nanostructured lipid carriers (NLCs) and solid lipid nanoparticles (SLNs). It has been noted that SLNs packed with various antioxidants, such as resveratrol, vitamin E (VE), and epigallocatechin gallate (EGCG), offer superior skin protection. For resveratrol, SLNs guaranteed a controlled release profile that increased its bioavailability by up to 70% over 24 hours. Furthermore, because of their long-lasting antioxidant qualities, resveratrol- encapsulated SLNs demonstrated more effective penetration into the stratum corneum, indicating that they could be a viable substitute for current skincare products (88).

- **Oral products:**

Dental floss, mouthwashes, toothpaste, toothbrushes, and other oral hygiene products have all benefited from the application of nanotechnology-based techniques, which have increased the product's effectiveness over conventional alternatives. For this, a variety of nanocarrier forms have been employed, including liposomes, polymers, hydrogels, nanoparticles, quantum dots, and dendrimers. By promoting remineralization, reducing tooth sensitivity, and assisting in the fight against bacterial infections, toothpaste incorporating nanomaterials helps to improve tooth healing and enamel rebuilding. It has been documented that several nanoparticles, including hydroxyapatite, silver, gold, zinc oxide, titania, calcium carbonate, and others, are used in dental treatment (89).

There have been reports on the use of carbonate-substituted bioactive non-stoichiometric hydroxyapatite nanoparticles in dental formulations. These nanoparticles have a crystalline nature of less than 40% and dimensions of 20–200 nm in length and 5–30 nm in width, with an aspect ratio between 2 and 40. Dental formulations that incorporate hydroxyapatite nanoparticles enable effective desensitization and remineralization of teeth within a time frame that is suitable for daily oral hygiene practices. Because hydroxyapatite nanoparticles are stable, using them also extends the shelf life by two to three months (90). Non-aggregated zinc nanoparticles have been shown to exhibit anti-plaque and anti-malodor properties when utilized in oral compositions. By using zinc ions in the form of nanoparticles, the composition's overall zinc content is further decreased, which enhances the composition's negative organoleptic qualities and improves the oral formulation's clarity (91).

A notable rise in microbial load is linked to the most prevalent oral disorders, such as dental caries and periodontal diseases (92). Using dental care products that contain antimicrobial nanoparticles can help address these issues in the short term. According to reports, silver nanoparticles exhibit excellent antimicrobial activity in a size-dependent manner against a variety of aerobic and anaerobic oral pathogens, including Fusobacterium nuceatum, Aggregatibacter actinomycetemcomitans, Escherichia coli, Streptococcus mitis, Streptococcus mutans, and Streptococcus sanguinis.

Because silver has a strong antibacterial effect, using it in dental formulations can help treat microbial infections in a targeted manner in addition to biocompatibility with human cells (93). When gutta- percha (GP) is utilized as a dental filler during root canal therapy, it can lead to subpar mechanical characteristics, leakage, and dental reinfection. These drawbacks can be overcome by employing GP- embedded nanodiamonds, which exhibit superior mechanical qualities and great biocompatibility, making them appropriate for use in dental applications. Additionally, these GP-implanted nanodiamonds' functionality with conventional antibiotics tailored to treat oral infections, including amoxicillin, improves their suitability for dental treatments with outstanding outcomes (94).

- **Sunscreens:**

Insoluble microparticles like ZnO and TiO2 are present in sunscreens. These physical sunscreens are effective at blocking UVA and UVB rays. Benefits: They look invisible due to texture alterations, which makes them more aesthetically acceptable. To increase stability and tolerance, nanoparticles like liposomes or SLNs are used as penetration enhancers. Its drawbacks include thick, "dense" texture, chalky white deposits on skin, and the need for a greasy carrier for disintegration. UV light is reflected, adsorbed, or dispersed by ZnO and TiO2 nanoparticles.

- **Moisturizers:**

These are used to treat several skin conditions, such as psoriasis, dryness, and atopic dermatitis. The primary disadvantage of these traditional emollients is their failure to adequately transport ingredients, including ceramides, to the active site. On the skin, they are applied externally. Because they have long-lasting therapeutic benefits, liposomes, SLNs, and nano emulsions are frequently used to make moisturizers. Because of their lipophilic interior, nano emulsions are an effective delivery mechanism for hydrophobic compounds in aqueous conditions. Gamma amino butyl acid (GABA), an inhibitory neurotransmitter with the ability to relax muscles, is being used in wrinkle reduction formulations using this approach.

- **Phototherapy:**

To cure specific medical diseases, phototherapy is a sort of medical treatment that involves exposingpatients to fluorescent light bulbs or other light sources, such as halogen lights, sunlight, and light- emitting diodes (LEDs). Dermatologists have been using brief laser pulses to target melanosomes to treat skin hyperpigmentation conditions such as melasma. Iron oxide microparticles and gold nanoparticle immune conjugates are being researched as light absorbers for cell targeting. These particles absorb light in the event of a laser pulse and release the radiation that has been absorbed, raising the tissue's temperature to the point where tiny tissue rupture and cell damage occur. Photothermal treatment (PTT) is another area of application. It includes preventing the growth of tumor cells by using stirred gold nanoparticles. Using nanoparticles is also becoming more common in photodynamic therapy, whose method relies on the optical activation of a photosensitizer to create oxygen-free gradients in the local tissue that injure the tissue similarly to tumor cells.

- **Antiseptics:**

Applying antiseptics, or antimicrobial compounds, to living tissue or skin lowers the risk of infection or sepsis. The field of antiseptics has been introduced to nanoparticles. In nano-formulations, a variety of materials, including silver, bare TiO2, and chlorhexidine gluconate, have been used as antiseptics. Because chlorhexidine gluconate absorbs quickly from the capsular wall, its nanoformulation has both immediate and long-lasting antibacterial properties.

- **Lip cosmetics:**

Lipstick is a type of cosmetic that gives the lips color, texture, and protection. It is made of pigments, oils, waxes, and emollients. Lipstick and lip gloss containing nanoparticles keep the lips supple and velvety by stopping the loss of water via the epidermis. For example, silica nanoparticles provide a uniform distribution of pigment in the formulation, preventing pigment migration into the delicate lip lines and improving the appearance of the makeup.

- **Hair formulations:**

When treating conditions like androgenic alopecia and alopecia areata, formulations containing nanoparticles are superior to those including water or alcohol. Compared to aqueous solutions, encapsulated hair growth medications have a 2.0–2.5 times longer permanence in hair follicular areas. For instance, minoxidil Within the hair follicle area, polyethylene glycol nanoparticles encapsulated in 40–130 nm particles have demonstrated enhanced permanency.

- **Toothpaste:**

The use of nanotechnology in toothpaste is very beneficial in avoiding dental enamel deterioration. As nanocrystals, hydroxyapatite is a crucial part of dental enamel. It is also the primary building block of teeth and bones. The hydroxyapatite nano form is utilized in toothpaste to create a barrier that shields dental enamel, repairs surface damage, and lessens discomfort. The first toothpaste in history to be remineralized is this one.

- **Nail formulations:**

For nail care, cosmeceuticals based on nanotechnology are being developed. Nanoparticle-based nail polishes strengthen and resist damage to the nails. They resist chipping, cracking, and scratching, and they dry to a highly hard condition, among their numerous benefits. In addition, it can be used therapeutically to treat onychomycosis.

Table 1: Manufacturing companies employing nanomaterials in their marketed products

Nanomaterials	Marketed products	Manufacturer
Zinc oxide and titanium dioxide	Sunforgettable corrector colores SPF 20, sunforgettable SPF 30 brush range, wild to mild skin bronzer.	ColoreScience
	Moisturizing dermatone lips 'n' face protection crème	Dermatone
	Solar defence organic moisturizer	Image skincare
	Olay complete UV protective moisture lotion	Proctor and gamble
	Soltan facial sun defence cream	Boots
Fullerenes and fullersomes	Defy: age management exfoliator, EGF complex cocktail, nourish	Bellapelle skin studio
	Dr. Brandt new lineless cream	Dr. Brandt
	Revitalizing night cream	MyChelle dermaceuticals LLC
	White out / daily under eye care	Sircuit cosmeceuticals
	Zelens fullerene C-60 day cream, zelens fullerene C-60 night cream	Zelens
Nanoemulsions	Coco mademoiselle fresh moisture mist	Chanel
	Calming alcohol-free nanoemulsion	Chanel precision
	Skin caviar ampoules	La prairie
	Pureology COLOURMAX	Pureology
Nanocapsules	Double dose in a box, laser relief, laser tight	Dr. Brandt
	Hydra flash bronzer	Lancome
	Super aqua skin cream range	Enprani
Novasomes	Renutriv range, resilience range	Estee lauder
	Neutrogena line	Johnson and johnson
Nanosomes	Revitalift double lifting, revitalift intense lift treatment mask	L'Oreal
Nano aluminium	Revlon colorstay stay natural powder, revlon new complexion concealer	Revlon
Nano silicon dioxide	Leorex hypoallergenic wrinkle nano remover range	GlobalMed technologies
	Renergie microlift eye, renergie lift makeup	Lancome
	Elixir skin range, pureness matifying compact	Shiseido
Lyphazome nanospheres	Moisturizing sunscreen MAX SPF 29, moisturizing sunscreen spf 30	Dermazone solutions

Advantages

1. The goal of using nanotechnology in cosmetics is to create anti-aging lotions, sunscreens that work better, and perfumes that linger longer.
2. To optimize the multi-component system's production conditions for skin care formulation.
3. To stop hair from going gray and hair loss in treatment; also used to maintain the lightness and transparency of active components, like vitamins and antioxidants.
4. To enhance UV protection when used with organic sunscreens like 2-hydroxy-4-methoxy benzophenone, the concentration of the UV absorber can be lowered.
5. It is necessary to conduct an independent assessment of nanomaterials utilized as UV filters in sunscreen products. However, we discovered that nano zinc oxide is in use, even if its assessment isnot yet complete (95).

Disadvantages

1. Particles that are smaller in size exhibit higher reactivity, chemical reactivity, and reactiveoxygen species production.
2. It might lead to inflammation and oxidative stress, which would harm proteins, membranes, andDNA.
3. It has been demonstrated that nanomaterials are harmful to human tissue and cell cultures, increasing oxidative stress and causing cell death.
4. Titanium dioxide nanoparticles that were triggered by light exhibited toxicity towards human colon cancer cells, skin fibroblasts, and nucleic acids.
5. When quartz, minerals, dust, coal, silicate, and asbestos are inhaled, it can lead to lunginflammation.
6. These have the potential to cause cancer, cytotoxicity, and lung fibrosis (96), (97).

CONCLUSION

Nanotechnology is a rapidly expanding and potentially beneficial field with tremendous implicationsfor Society, Industry, Medicine, and Cosmeceuticals. Nanomaterials have been incorporated into several skin care products to take advantage of the unique properties of matter on a nanoscale. It is critical for dermatologists intimately involved with the health of the skin to be aware of this new technology, to educate our colleagues about it, and to play an active role in evaluating this new technology and setting policies and guidelines for its safe and fruitful use.

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