INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Nanotechnology In Cosmetics: A Comprehensive Review of Innovations, Applications, And Challenges

Ketan Sonawane*, Uday Satpute Shahid Jakir Shaikh

Student (Bachelor of Pharmacy) at Savitribai Phule Pune University Pune

ARTICLE INFO

Published: 18 Nov. 2024
Keywords:
Nanotechnology, Nanomaterials, Nano cosmetics, Skincare, Safety concerns, Formulations.
DOI:
10.5281/zenodo.14178566

ABSTRACT

Nanotechnology has revolutionized the cosmetics industry by introducing cutting-edge solutions that elevate the performance, stability, and delivery of active ingredients in skincare and beauty products. This technological advancement has enabled the creation of products with superior functionality, durability, and aesthetic appeal. The use of nanoparticles—such as liposomes, solid lipid particles, and Nano emulsions—has significantly enhanced the delivery and effectiveness of active ingredients, ensuring deeper skin penetration, targeted release, and improved bioavailability. Moreover, nanotechnology has paved the way for innovative cosmetic products, including nano-based sunscreens, anti-aging creams, and hair care solutions. The growing number of patents granted in this area, alongside ongoing research, reflects the rapid advancements in this field. While nanotechnology holds great promise for enhancing the performance, longevity, appearance, and safety of cosmetic formulations, it also presents challenges related to safety, health risks, and regulatory concerns. This necessitates continuous research, rigorous safety evaluations, and the development of robust regulatory frameworks. This review offers a thorough exploration of current trends and applications of nanotechnology in cosmetics, shedding light on both its benefits and associated challenges. Additionally, it delves into future prospects by reviewing scientific literature and patents, providing a comprehensive overview of nanotechnology's evolving role in the cosmetics industry.

INTRODUCTION

Nanotechnology, defined as the manipulation of matter on a nanoscale, typically between 1 to 100 nanometres, has been rapidly advancing across numerous industries, including the cosmetics sector. This emerging field involves the design, production, and application of materials and devices by controlling their size and shape at the molecular or atomic level. In the realm of cosmetics, which are products intended to be

***Corresponding Author:** Ketan Sonawane
Address: *Student (Bachelor of Pharmacy) at Savitribai Phule Pune University Pune.*
Email ✉: ketansonawane9011@gmail.com
Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

applied to the human body for beautification, cleansing, or protection, nanotechnology has brought about significant changes in the way products are formulated and how they perform. Nanoparticles, the central elements of this technological shift, are particles that measure less than 100 nanometres in at least one dimension. Due to their extremely small size, nanoparticles exhibit unique properties that differ from larger particles, such as increased surface area and enhanced reactivity, which can lead to better absorption, stability, and efficiency when incorporated into cosmetic products. Nanotechnology has enabled the development of "Nano cosmetics," a term used to describe cosmetic products that incorporate nanoparticles or are developed using nanotechnology. These products are designed to provide superior performance compared to traditional formulations, offering enhanced penetration, longer-lasting effects, and more targeted delivery of active ingredients. Nanoparticles such as liposomes, Nano emulsions, and niosomes have been widely utilized in various cosmetic products, including moisturizers, sunscreens, anti-aging creams, and hair care products. For instance, in sunscreens, nanoparticles like titanium dioxide and zinc oxide are used to provide effective protection against harmful ultraviolet (UV) radiation while maintaining a transparent appearance on the skin. These nanoparticles are much smaller than traditional sunscreen ingredients, which allows them to offer protection without leaving a white, chalky residue on the skin. This has been a game-changer in the sunscreen market, especially for consumers seeking non-greasy, aesthetically pleasing options. In addition to sun protection, nanotechnology has significantly impacted the formulation of anti-aging products. The use of nanoparticles in anti-aging creams allows for the deep delivery of active ingredients such as retinoid, peptides, and antioxidants into the skin, where they can stimulate collagen production, improve elasticity, and reduce the appearance of fine lines and wrinkles. Nanotechnology ensures that these ingredients penetrate the skin more effectively and remain active for a longer period, leading to enhanced results. Similarly, in moisturizers, nanoparticles help improve the retention of moisture in the skin by creating a barrier that reduces water loss, ensuring that the skin remains hydrated for longer periods. This has led to the development of lightweight, fast absorbing formulations that appeal to consumers looking for products that deliver visible results without leaving the skin feeling greasy or heavy. One of the major trends in the cosmetics industry today is the move towards sustainability and consumer safety, both of which are areas where nanotechnology can make a significant impact. As consumers become more conscious of the environmental and health implications of the products they use, there is a growing demand for cosmetics that are not only effective but also safe and eco-friendly. Nanotechnology allows manufacturers to reduce the amount of potentially harmful chemicals in their formulations by using smaller quantities of highly efficient nanoparticles. For instance, Nano encapsulation techniques can be used to create slow-release formulations, which deliver active ingredients gradually over time, minimizing irritation and improving overall product safety. These advancements align with the industry's push towards "green beauty," where environmentally friendly and ethically sourced ingredients are prioritized. Looking ahead, the future of nanotechnology in cosmetics is set to focus on further advancements in product personalization, improved safety protocols, and environmentally sustainable practices. Personalized skincare, which tailor’s products to the individual needs of consumers based on their unique skin type or condition, is becoming increasingly popular, and nanotechnology plays a

critical role in enabling this trend. By leveraging the precision and versatility of nanoparticles, companies can create targeted treatments that address specific skincare concerns, leading to more effective and customized beauty solutions. Moreover, as regulatory frameworks around the world evolves to address the potential risks associated with nanomaterials, we can expect to see stricter safety assessments, labeling requirements, and environmental considerations being incorporated into product development. Future research will likely focus on ensuring that nanoparticles are safe for both human health and the environment, with a particular emphasis on biodegradability and reducing environmental contamination. In conclusion, nanotechnology is revolutionizing the cosmetics industry by enhancing product efficacy, sustainability, and consumer satisfaction. With its ability to improve the performance of cosmetic products, nanotechnology is poised to continue driving innovation in beauty and personal care, shaping the future of the industry in ways that are both exciting and beneficial for consumers. As scientific research and technological development in Nano cosmetics continue to advance, we can anticipate even more sophisticated and personalized products entering the market, offering unprecedented levels of efficacy, safety, and environmental responsibility. [1] [2]

Brief Historical Background of Cosmetics and Nano cosmetics: The evolution of cosmetics, driven by humanity's enduring desire for beauty, dates back to ancient civilizations. Early evidence of cosmetic use can be traced to ancient Egypt around 4000 BCE, where Egyptians employed oils, creams, and ointments for hygiene and protection against harsh environmental conditions. Iconic depictions of heavily made-up eyes in Egyptian art highlight the cultural significance of cosmetics, reflecting their role in both religious and medicinal practices. The discovery of Pharaoh Tutankhamen's tomb underscored the historical importance of eyeliner, marking an early instance of global cosmetic trends. Similarly, ancient Chinese society around 3000 BCE used brightly colored nail polishes to signify social status, and the term "Heang" referred to the lavish use of perfumes and incense by the T'ang upper class. Greek cosmetic practices, influenced by Eastern traders, included facial powders and artificial eyebrows. Historical records reveal that Athenian women in the 5th century BCE used lead for face whitening, plant-based rouge for lip coloring, and kohl for darkening eyelids, despite the health risks posed by these toxic substances. Archaeological findings in ancient Greek sites uncovered various beauty tools, such as mirrors and miniature vases for perfumes and creams. Throughout history, cosmetics often involved harmful ingredients like lead, arsenic, and mercury, reflecting a longstanding disregard for health in the pursuit of beauty. In the 1800s, women used leeches and toxic substances to achieve a desired pale complexion, with tragic health consequences. However, the 20th and 21st centuries brought significant advancements in cosmetic science. The integration of safe, biologically active ingredients led to the development of cosmeceuticals—products designed to treat skin conditions like hyperpigmentation and wrinkles. This shift towards safer, more effective beauty solutions was further revolutionized by nanotechnology. Originating from Richard Feynman's 1959 lecture on manipulating materials at the atomic level, nanotechnology began to impact the cosmetics industry in the 1990s. Early innovations included the use of nanosized titanium dioxide and zinc oxide in sunscreens, which provided effective UV protection without leaving a white residue. This breakthrough spurred interest in Nano cosmetics, highlighting the benefits of enhanced ingredient penetration, stability, and efficacy. By the early 2000s, the industry explored liposomes, niosomes,

and solid lipid nanoparticles to deliver active compounds more effectively into the skin. Advances in Nano capsules and Nano emulsions improved the encapsulation of unstable ingredients, enhancing their stability and bioavailability. As nanotechnology advanced, Nano cosmetics evolved to include targeted delivery systems that release active ingredients at specific sites, optimizing their benefits while reducing side effects. Despite its rapid growth, the field of Nano cosmetics has faced scrutiny regarding the safety and environmental impact of nanoparticles, prompting ongoing research and regulation to ensure consumer safety. Today, Nano cosmetics represent a frontier in skincare and beauty, offering innovative solutions with enhanced performance and personalized care, while regulatory bodies and scientists continue to address the challenges of this emerging technology.
[4] [5] [6]

Indian Nano Cosmeceuticals Market: Nanotechnology has emerged as a transformative force in the global cosmetics and pharmaceutical industries, with India being no exception. The integration of nanotechnology into these sectors within India has been propelled by a blend of pioneering research, growing market demand, and evolving regulatory frameworks. The Indian cosmetics market has experienced significant growth, largely driven by increasing consumer awareness and demand for advanced skincare solutions, with nanotechnology playing a crucial role. Both Indian companies and multinational corporations, such as Lakmé and Himalaya, have heavily invested in research and development to integrate nanotechnology into their product offerings. The pharmaceutical industry in India has similarly undergone a revolution in drug delivery systems thanks to nanotechnology. Targeted drug delivery has become more effective with the use of Nano carriers like liposomes, dendrimers, and polymeric nanoparticles, which enable drugs to be delivered directly to targeted areas, reducing side effects and improving therapeutic outcomes. In cancer treatment, nanotechnology is employed to deliver chemotherapy drugs specifically to cancer cells, minimizing damage to healthy cells and enhancing treatment efficacy. The COVID-19 pandemic further accelerated the adoption of nanotechnology in vaccine development, with nanoparticles playing a pivotal role in the creation of mRNA vaccines and other innovative vaccine delivery platforms. As one of the largest pharmaceutical markets globally, India is increasingly incorporating nanotechnology into its drug development pipelines, allowing Indian pharmaceutical companies to compete on an international scale by offering advanced drug formulations. The Indian government, through initiatives like the National Nanotechnology Initiative, has supported research in this area, fostering collaborations between academia and industry, leading to the emergence of startups and research centers focused on nanotechnology in drug delivery. India's regulatory landscape is also evolving to keep pace with advancements in nanotechnology. The Central Drugs Standard Control Organization (CDSCO) is actively working to develop guidelines and regulations specific to nanotechnology-based products in both the cosmetics and pharmaceutical sectors. However, challenges persist in terms of standardization, safety assessments, and consumer awareness, as regulatory bodies continue to catch up with the rapid pace of technological advancements, occasionally delaying the market introduction of innovative nanotech products. Despite the vast opportunities, certain challenges remain, particularly regarding safety concerns and cost. The safety of nanoparticles, especially in cosmetics, continues to be a concern, with ongoing research aimed at ensuring that nanomaterials do

not pose long-term health risks—a crucial factor for consumer acceptance. Furthermore, the higher cost of nanotechnology-based products can limit their accessibility to a broader population in India. Nevertheless, the potential benefits of nanotechnology in these industries continue to drive innovation and foster market growth. Several Indian cosmetics companies have integrated nanotechnology into their products to enhance the delivery and efficacy of active ingredients, offering advanced skincare solutions to consumers. Following table shows the Indian Cosmecuetical Companies which use Nanotechnology in their products with its advantages:

Company	Product	Nanotechnology Application	Benefits
Lakmé	Absolute Skin Gloss Gel Crème	Microcrystals	Boosts hydration and provides a glossy finish to the skin
Himalaya Herbals	Youth Eternity Day Cream	Nano-emulsion technology	Delivers anti-aging ingredients deep into the skin for better absorption and efficacy
VLCC	Anti-Tan Facial Kit	Nano-sized particles	Effectively delivers active ingredients, aiding in tan removal and rejuvenation
Boutique	Bio Dandelion Visibly Ageless Serum	Nanotechnology	Improves penetration of ingredients like dandelion and nutmeg, reduces dark spots and brightens skin
Lotus Herbals	YouthRx Anti-Aging Transforming Crème	Nano-emulsions (Gineplex Youth Compound)	Enhances the delivery of anti-aging benefits
Jovees	Anti-Acne and Pimple Cream	Nanoparticles	Deeper penetration of anti-acne ingredients, increasing effectiveness
Shahnaz Husain	Gold Facial Kit	Gold nanoparticles	Improves skin texture and provides a youthful glow

❖ **Table No. 1:** Commercially available Cosmetics products in Indian market with their Nanotechnology Applications and Benefits

Nano carriers Used in Cosmetics: Nano carriers in cosmetics represent a revolutionary advancement in delivering active ingredients effectively and efficiently. These nanostructured systems, which include nanoparticles, liposomes, and Nano spheres, enhance the stability, solubility, and bioavailability of cosmetic agents, allowing for deeper penetration into the skin. By encapsulating compounds such as vitamins, peptides, and antioxidants, Nano carriers not only improve the performance of cosmetic formulations but also extend their shelf life and reduce potential side effects. As the cosmetics industry increasingly embraces nanotechnology, these innovative carriers are paving the way for more effective skincare solutions, anti-aging treatments, and targeted therapies, ultimately transforming the way consumers experience beauty products. Following are some's major types of Nano carriers explained which used generally act as important aspect in cosmetics development.

Liposomes: These are widely used in Cosmeceutical products due to their ability to encapsulate and gradually release both hydrophilic and hydrophobic substances. These spherical vesicles consist of a hydrophobic lipid bilayer, primarily made of phospholipids, which is nontoxic and reduces the risk of adverse reactions.

They enhance the solubility of cosmetic ingredients, improve drug accumulation, protect the contents from degradation, and allow for controlled release. Liposomes come in various sizes, from 20 nanometres to several micrometres, and can be unilamellar or multilamellar. Their versatility makes them useful in skincare products, such as moisturizers, sunscreens, antiperspirants, and treatments for hair loss. They are also used to carry active biomolecules, including vitamins A, E, and K, as well as antioxidants like Coenzyme Q10 and carotenoids. By integrating lipids like cholesterol and ceramides, liposomes help rebuild the skin's epidermal layers and maintain moisture. Phosphatidylcholine, the primary lipid in liposomes, is commonly incorporated into skin and hair care formulations due to its conditioning properties. Vegetable phospholipids, which are rich in essential fatty acids, are often used in transdermal treatments as they improve skin barrier function and reduce water loss. In cosmetics, liposomes enhance the penetration of active ingredients into the skin, making them ideal carriers for vitamins, phytonutrients, and even fragrances in products like deodorants and body sprays. Specialized liposomes, like photosomes, protect cells from UV radiation, reducing the risk of skin cancer. However, despite their benefits liposomes face challenges in terms of physical stability and large-scale production.

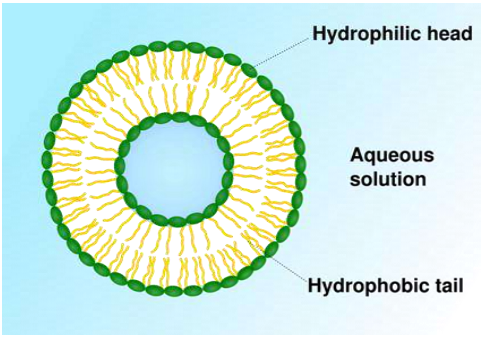

Fig. Liposomes

Nano-emulsions: Nano emulsions are transparent or translucent liquid systems with remarkable kinetic and thermodynamic stability, making them ideal for cosmetic and pharmaceutical applications. These systems can be formulated in different structures, such as oil-in-water (O/W), water-in-oil (W/O), or more complex systems like oil/water/oil (O/W/O) and water/oil/water (W/O/W), depending on the preparation method used. This versatility allows for the creation of formulations with various textures, ranging from watery to creamy or gel-like consistencies. Nano emulsions are produced through methods like high-pressure homogenization, phase inversion, micro fluidization, sonication, and the use of surfactants and co-surfactants, providing excellent stability to the formulation. Their fine texture and appearance make them popular for use in cosmetics like lotions, creams, shampoos, sunscreens, sprays, and deodorants. Notable examples include patented Nano emulsion systems from brands like Kemira and L'Oreal, which use fatty acid esters and phosphoric acid in their formulations. Characteristically, Nano emulsions are known for their small droplet sizes (ranging from a few nanometres to 200 nm), good transparency, low viscosity, and high kinetic stability. These features prevent sedimentation and flocculation, making Nano emulsions more advanced than traditional emulsions. They offer enhanced skin penetration and hydration, making them suitable carriers for bioactive ingredients in skincare and haircare products. Cosmetic companies leverage Nano emulsions for delivering high concentrations of active compounds deep into the skin, with products like La Prairie's Skin Caviar illustrating their value in premium cosmetics. [14]

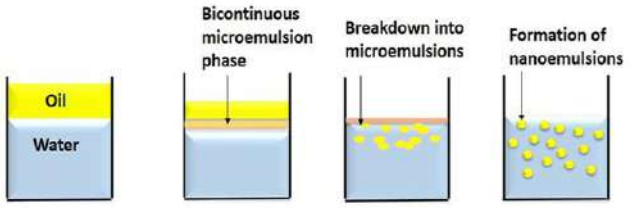

Fig. Formations of Nano-emulsions

Solid Lipid Nanoparticles (SLNs): These were developed in the 1990s, are composed of a solid lipid core stabilized in water by surfactants. These carriers can encapsulate hydrophilic, lipophilic, or poorly soluble substances and are known for their biocompatibility and stability, reducing toxicity risks. SLNs allow for either rapid or sustained drug release, depending on where the active ingredient is located. They enhance skin penetration, offer UV protection, and improve hydration, making them valuable in cosmetics and pharmaceuticals. Nanostructured lipid carriers (NLCs), a more advanced version, offer better drug loading and stability, though their superiority over SLNs is still debated. SLNs are solid at body temperature and act as a protective carrier for active ingredients. Patented formulations combining SLNs or NLCs with polymer coatings or silver nanoparticles further improve penetration and stability, making them suitable for treating skin conditions like psoriasis or for long-lasting cosmetic applications.

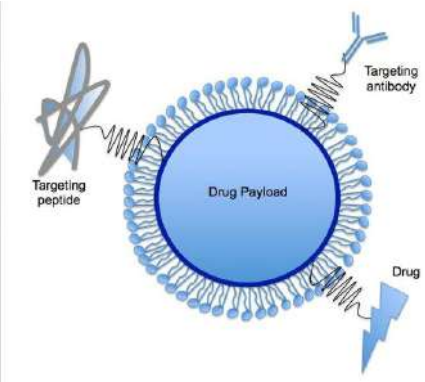

Fig. Solid Lipid Nanoparticles

Nano spheres: These are spherical particles with a core-shell structure that can encapsulate, entrap, or connect medications, providing protection from enzymatic and chemical degradation. The drug is uniformly dispersed within the polymer matrix, which may be either crystalline or amorphous. This technology holds significant promise for improving the delivery of compounds with poor absorption, solubility, or physiological activity. Nano spheres can encapsulate enzymes, DNA, or various drugs within their core. In the cosmetics industry, Nano spheres are employed in skin care products to deliver active ingredients deep into the skin, targeting affected areas with greater precision. They help protect the skin from photo aging and are increasingly utilized in anti-aging, hydrating, and anti-acne formulations. Nano spheres can be categorized into biodegradable and non-biodegradable types, with gelatine, starch, and albumin representing biodegradable forms, while polymathic acid serves as an example of a non-biodegradable nanosphere.

Nano pigments: Nano pigments are recognized for their stability and safety, making them popular in cosmetics and sunscreens, supported by thorough in vitro and in vivo toxicity evaluations. Although generally regarded as safe, there are concerns regarding the potential genotoxicity and oxidative damage associated with ultrafine particles. These pigments effectively block UV radiation, which is why they are vital in sunscreen formulations. Beyond UV protection, Nano pigments are also incorporated into beauty soaps, creams, and gold facial masks, providing various skin benefits. They tend to remain on the skin's surface or within hair follicles, reducing worries about the toxicity of inorganic pigments like titanium dioxide. Similarly, silver nanoparticles are gaining traction for their antimicrobial and preservative properties in cosmetics. They exhibit significant stability, effectively combating bacteria and fungi while not penetrating the skin. Research shows they are safe at low concentrations, making them suitable for sensitive formulations like alcohol-free mouthwashes for immunocompromised individuals. Additionally, gold and silver nanoparticles enhance color options in products such as lipsticks.

Other Examples of Nanocosmeceutical Carriers Include**:** Polymerosomes, Niosomes, Carbon Nanotues, Cubosomes, Gold-Nanoparticles, etc.

Nanomaterials Used in Cosmetics Products: Nanomaterials are substances with at least one

dimension in the nanometre scale, exhibiting unique physicochemical properties. They have been widely used in the cosmetic industry for many years. Cosmetics containing nanomaterials offer several advantages over their micro scale counterparts. The large surface area of these particles enhances their transport, absorption, bioavailability, transparency, and provides a longer-lasting effect. However, it is important to carefully regulate their concentration to avoid potential toxicity. The Table below highlights various nanomaterials used in the cosmetic industry:

Sr. No.	Nanomaterial	Advantage	Disadvantage	Uniqueness	Type of Cosmeceutical	Commercially Available Product (Indian)
1	Inorganic particles (TiO_2, ZnO)	Hydrophilic, biocompatible, safe, and stable	Pulmonary toxicity	Absorb/reflect UV light	Sunscreen	Lotus Safe UV Screen Matte Gel SPF 50, Biotique Bio Sandalwood Sunscreen
2	Carbon black	Light weight; ↑ chemical and thermal stability; and ↓ cost	Cytotoxicity; alters the phagocytic property of macrophages	Color pigment	Facemask, Mascara	Lakme Absolute Kohl Ultimate Kajal, Sugar Cosmetics- Honour Intense Kajal
3	Nano-organic (tris-biphenyl triazine)	Powerful and photostable filter	Hazardous to the aquatic environment	Most efficient UVB and UVA 2 filter	Sunscreen	Aqualogic Glow+ Dewy SPF 50++, Derma Co Ultra Mattes Sunscreen
4	Nano-hydroxyapatite	Dental desensitizer and polish remineralization of teeth	Very brittle nature	Safe in pediatric toothpaste	Toothpaste	Colgate, Hindustan Unilever Pepsodent, Lotus herbals, Ozone Ayurvedics,
5	Gold and silver nanoparticles	Uniform shape, size, and branch length; tuned pharmacokinetics and bio distribution; antibacterial and antifungal activity; and chemical stability	Damages human cells and DNA at high doses; pulmonary toxicity	Surface-enhanced Raman scattering	Facemask, Anti-aging cream	VLCC Gold Facial Kit, Patanjali Ayurved- Swarn Kanti Fairness Cream, Soundarya Radiance Cream with 24k

❖ **Table No. 2:** Nano materials used in cosmetics with their advantages, disadvantages, uniqueness and commercially available products [3]

Inorganic Particles: These particles are more hydrophilic, biocompatible, safer, and considerably more stable compared to natural nanoparticles. A key difference lies in their composition, as these nanoparticles are synthesized from inorganic materials like silver (Ag), gold (Au), and titanium (Ti), whereas natural nanoparticles are typically made from polymers.[20]

Gold and silver nanoparticles: Gold and silver nanoparticles possess notable antibacterial and antifungal properties and are extensively used in cosmetic products like antiperspirants, anti-aging creams, and face masks. Historically, gold has been employed for skincare and beauty in Egypt, where it was believed to enhance skin complexion and flexibility. Today, gold is found in various skincare products, such as creams and treatments, often referred to as colloidal gold or Nano gold when sized between 5 nm to 400 nm. Its color can range from red to purple, depending on the particle size and surface area. Gold nanoparticles come in various shapes, including Nano spheres, Nano rods, nanoclusters, nanostars, Nano shells, nanotubes, and Nano triangles, with their shape influencing cellular uptake and optical properties. Due to their stability and biocompatibility, gold nanoparticles are ideal for use in skincare and cosmetic applications. Their well-documented antibacterial, antifungal, and anti-aging benefits are valuable in cosmeceutical products and wound healing treatments. These nanoparticles help repair skin damage, improve skin texture and elasticity, and have soothing properties that make them effective for treating conditions like skin inflammation, sunburn, and allergies, making them suitable for face masks and other cosmetic products. Silver nanoparticles, on the other hand, are effective in inhibiting the growth of various microorganisms. Silver-based compounds are frequently used to control bacterial growth in different formulations. However, the use of silver in cosmetics presents challenges due to its tendency to precipitate in mixtures, which can be mitigated by using silver nanoparticles. In Europe, the safety of colloidal silver in nanoparticle form for oral and dermal cosmetics. [9] [10] [15]

Carbon black (CI 77266): It is a key ingredient in many cosmetic formulations, commonly used as a colorant in products for the eyes and skin. In the EU, its use in nanostructure form is approved, with a maximum concentration of 10%. Studies on carbon black nanoparticles have shown a greater potential for causing cytotoxicity, inflammation, and altered phagocytosis in human monocytes compared to micron-sized particles. According to EU regulations, carbon black can be used in cosmetic products as long as there is no risk of inhalation. [21]

Nano-organic (Tris-biphenyl triazine): It is a cutting-edge, highly effective, and photos table filter used specifically in sunscreen formulations. In its Nano form, it acts as a broad-spectrum UV protectant and is widely incorporated into sunscreens, known for its excellent photo stability. It is approved as a UV filter in Europe. Another approved UV filter in the EU, methylene bis-benzo triazolyl tetra methyl butyl phenol (Nano), or MBBT, can be used at concentrations of up to 10% w/w in topical cosmetic products. According to an assessment by the Scientific Committee on Consumer Safety (SCCS), MBBT poses no risk to human health when applied to intact skin. However, concerns have been raised about its potential harmful effects and bioaccumulation in certain tissues.

Nano-hydroxyapatite: It is commonly used in cosmetic products designed for oral care, specifically for treating severe dental sensitivity and promoting enamel demineralization. It is considered a safe and effective option by the US Food and Drug Administration (USFDA). Due to its remineralizing and desensitizing properties, Nano-hydroxyapatite has been incorporated into various oral formulations, including toothpaste and mouthwash, offering a potential alternative to fluoride-based products. [13]

Applications of Nanotechnology in Cosmetics:

Nanotechnology has dramatically transformed the cosmetics industry by boosting the effectiveness, stability, and delivery of active ingredients in beauty products. Using nanoparticles like liposomes, Nano emulsions, and Nano capsules,

cosmetic products achieve superior penetration, targeted delivery, and enhanced texture. Key applications of nanotechnology in cosmetics include.

Anti-Aging Products: Nanotechnology enhances anti-aging creams and serums by using liposomes and Nano capsules to deliver key ingredients like peptides, vitamins, and antioxidants deep into the skin. This targeted delivery helps reduce wrinkles, fine lines, and age spots more effectively than traditional products.

Sunscreens: Nanoparticles of zinc oxide and titanium dioxide improve sunscreens by offering broad-spectrum UV protection without leaving a white residue. These nanoparticles absorb and scatter UV rays, making sunscreens more comfortable to use and increasing user compliance.

Makeup Products: Nano emulsions improve the texture, application, and durability of makeup, ensuring even pigment distribution and enhanced color intensity. This technology provides a smoother, longer-lasting finish, resistant to smudging and fading.

Moisturizers and Serums: Nano emulsions in moisturizers and serums boost absorption and hydration by penetrating deeper into the skin. These formulations improve skin elasticity and smoothness, providing lightweight, non-greasy hydration for healthier skin.

Hair Care Products: Nanotechnology in hair products like shampoos and serums delivers nutrients directly to the hair follicles and shafts. Nanosome strengthen hair, reduce breakage, and support healthier growth, making hair care more effective.

Skin Whitening and Brightening Products: Nanoparticles enhance the delivery of ingredients like vitamin C and niacinamide, used in skin-whitening products. This allows for deeper penetration, improved stability, and better results in reducing hyperpigmentation and uneven skin tone.

Acne Treatment: Nanoparticles in acne treatments deliver active ingredients, such as salicylic acid and benzoyl peroxide, directly to affected areas. This targeted approach reduces irritation and improves the effectiveness of acne treatment, promoting faster, more efficient results.

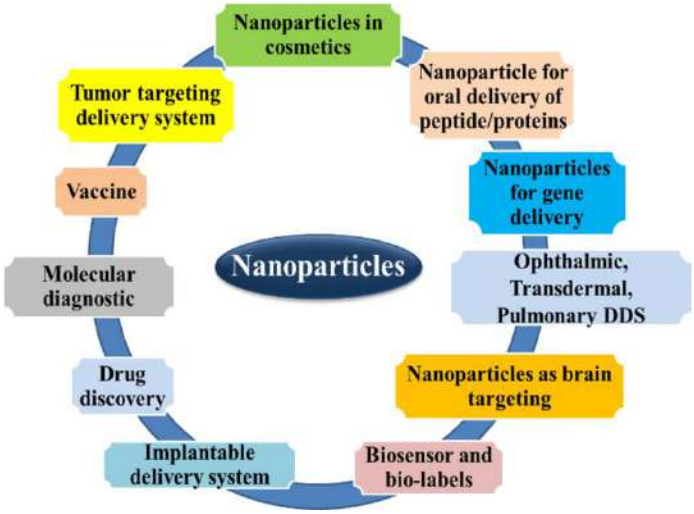

Fig. Applications of Nanoparticles

In conclusion it can be said that, Nanotechnology has revolutionized the cosmetics industry by improving the performance and efficacy of beauty products. Whether it's delivering anti-aging ingredients deeper into the skin or enhancing sunscreen protection, nanotechnology offers safer, more effective solutions. Its ongoing research and

development promise to shape the future of personalized skincare and beauty products. [8]

Potential Nano cosmetics Toxicity and Hazards: Cosmeceuticals containing nanoparticles (NPs) have raised significant toxicological concerns due to their potential effects on the skin barrier, altering its permeability and posing various health risks. NPs are widely used in skincare and cosmetic formulations because of their small size and unique properties, but their safety remains a critical issue. Insoluble nanoparticles are generally considered less harmful than soluble ones because they have lower diffusion rates, meaning they do not penetrate as easily into tissues. However, this does not eliminate the risks, especially when nanoparticles are made of common cosmetic ingredients like lipids, surfactants, and other soluble materials, which can be readily absorbed and cause adverse effects. The toxicity of nanoparticles is highly dependent on various factors, including particle size, surface characteristics, and chemical composition. Smaller particles, in particular, pose a greater risk due to their larger surface area, which can lead to increased reactivity and toxicity. Nanoparticles can enter the human body through several routes, including ingestion, inhalation, and dermal absorption, each posing unique risks. For instance, ingestion can occur when nanoparticles are transferred from hands to the mouth, potentially from products like lipsticks, lip balms, and other lip care items. Although most ingested nanoparticles are rapidly excreted, some may be absorbed and accumulate in organs, such as the liver, spleen, heart, and brain. Inhalation of airborne nanoparticles, such as those found in spray sunscreens containing titanium dioxide (TiO2), is another common exposure route. Inhaled particles can lodge in the lungs, and studies in animals suggest they may even migrate to the brain through the nasal passage or enter the bloodstream, posing further health risks, including inflammation and potential neurological damage.

Dermal absorption is a primary concern for nanoparticle exposure, particularly in cosmetics applied directly to the skin. Nanoparticles can penetrate the skin through trans cellular, Trans follicular, and intracellular routes, with particles smaller than 10 nm being especially problematic due to their ability to pass through intact skin layers. However, even larger particles can penetrate if the skin barrier is compromised by cuts, wounds, or conditions like dermatitis. For example, studies have shown that zinc oxide and copper nanoparticles, which are commonly used in cosmeceuticals, can cause significant damage to internal organs, while silver nanoparticles found in products such as soaps and face creams can generate reactive oxygen species (ROS). These ROS can lead to oxidative stress, damaging cell membranes, proteins, DNA, and other cellular components. Nanoparticles like titanium dioxide (TiO2) and zinc oxide (ZnO), frequently used in sunscreens, are particularly concerning due to their ability to produce ROS when exposed to ultraviolet (UV) light. This reaction can disrupt cellular structures and increase the risk of oxidative damage. Research has demonstrated that nanoparticles such as fullerenes, used in some face creams, can harm aquatic life and human cells, though their overall toxicity in humans is still not fully understood. While some studies indicate that Nano sized TiO2 can cause significant oxidative damage and Geno toxicity, others have found that these effects are not consistent across all conditions. Highlighting the need for careful evaluation. Regulatory bodies like the Scientific Committee on Consumer Safety suggest that the use of nanoparticles in sunscreens may be safe within certain concentrations, but there remains a need for further research to fully understand the broader implications of nanoparticle exposure in

cosmeceuticals, especially as their use continues to grow in the cosmetic industry. [17] [18]

Safety Concerns Related to Nano cosmetics: Nanoparticles in cosmetics present a dual concern: while offering enhanced beautification benefits, they also raise significant health and safety risks due to potential changes in properties when reduced to nanoscale. These particles may enter the bloodstream through skin application, inhalation, or ingestion, raising concerns about their toxicity, which remains not fully understood. In the U.S., the FDA highlighted the need for detailed characterization and toxicological data of nanomaterials used in cosmetics. This includes information on nanoparticles' physicochemical properties, impurities, and their biological interactions to manage possible health risks like poisoning, allergies, or contamination.

Two main groups are at risk: manufacturers and consumers. Workers in production plants may inhale airborne nanoparticles, especially without proper safeguards. Consumers face exposure via inhalation, ingestion, or skin contact, particularly through products like perfumes, lipsticks, and skin care items. Nanoparticles inhaled through sprays can reach the alveoli, be absorbed by nasal nerves, or enter the circulatory system. Ingested nanoparticles are largely excreted, but a small fraction enters the bloodstream. While the skin serves as a barrier against nanoparticle penetration, certain conditions can increase the likelihood of deeper skin absorption:

- When nanomaterial is of low Molecular size and weight. (E.g. dendrimers of 2.9 nm size)
- When intact skin is damaged (Burns, scrapes, skin diseases etc.)
- When penetration enhancers are used or the skin flexes.
- The prevalence of appendageal pathways.

Nanomaterials used in cosmetics pose potential health risks due to their minuscule size and unique characteristics. Exposure to these materials has been linked to various health issues and diseases, including the following:

Respiratory Issues: Inhalation of nanoparticles like titanium dioxide or zinc oxide, often found in sunscreens and makeup, can lead to lung irritation and inflammation. Long-term exposure may contribute to chronic respiratory conditions such as asthma or pulmonary fibrosis.

Skin Irritation and Allergic Reactions: Due to their ability to penetrate the skin, nanoparticles may cause irritation, redness, or allergic reactions. Individuals with sensitive skin may experience conditions like dermatitis or other skin disorders with prolonged use of nanomaterial-based products.

Oxidative Stress: Metal-based nanomaterials, when exposed to UV light, can generate reactive oxygen species (ROS), leading to oxidative stress. This process accelerates skin aging, damages DNA, and increases the risk of skin cancer.

DNA Damage: Studies have shown that nanoparticles found in anti-aging formulations can damage the DNA of skin cells. This damage can potentially lead to mutations and an increased likelihood of developing cancer over time.

Cytotoxicity: Certain nanoparticles, such as carbon nanotubes, exhibit toxic properties, harming human cells and inducing cell death or harmful alterations. This cytotoxicity raises the risk of cancer and other serious health conditions.

Immune System Impacts: Once nanoparticles enter the bloodstream, they may provoke immune responses, leading to chronic inflammation or other immune-related diseases.

Neurotoxicity: In some instances, nanoparticles can cross protective barriers like the blood-brain barrier, resulting in neurotoxic effects and potentially contributing to neurological disorders.

Reproductive and Developmental Toxicity: Emerging studies suggest that prolonged exposure to certain nanoparticles may impact reproductive

health, potentially affecting fertility and foetal development.[11] [16]

Regulatory and Legal Framework of Nano cosmetics in India: The use of nanotechnology in cosmetics, or "Nano cosmetics," represents a significant advancement in the beauty industry, bringing enhanced product performance and efficacy. However, this innovation also raises concerns regarding safety, environmental impact, and consumer health, making regulatory oversight crucial. In India, the regulatory framework for Nano cosmetics is still in its formative stages, with efforts ongoing to establish comprehensive guidelines for their safe and responsible use. This article delves into the regulatory and legal landscape governing Nano cosmetics in India, highlighting the current status, challenges, and future directions. Nano cosmetics typically involve the use of nanoparticles, such as liposomes, Nano emulsions, and Nano capsules, in beauty products to deliver active ingredients more efficiently. These particles' small size allows for deeper skin penetration and improved product stability, leading to enhanced cosmetic performance. However, these advantages come with potential risks, such as toxicity, skin irritation, and environmental concerns. Therefore, regulatory measures are vital to ensuring consumer safety. In India, the regulation of cosmetics, including those utilizing nanotechnology, falls under the purview of the *Central Drugs Standard Control Organization (CDSCO)*, operating under the Ministry of Health and Family Welfare. The primary legislation governing cosmetics is the *Drugs and Cosmetics Act of 1940* and the *Drugs and Cosmetics Rules of 1945*. However, these existing regulations do not specifically address nanomaterials, leading to a regulatory gap that must be addressed. While India has made strides in regulating the broader cosmetics industry, its regulation of nanotechnology remains underdeveloped. Key elements of the current regulatory framework include the absence of specific regulations for nanomaterials, with no clear definition of Nano cosmetics or distinct safety assessment requirements for nanoparticles. Presently, cosmetics must be approved by the CDSCO before they can be marketed, but Nano cosmetics undergo the same evaluation process as traditional cosmetics, potentially overlooking the unique risks associated with nanoparticles. Furthermore, current labeling regulations do not require companies to disclose the presence of nanomaterials in their products, leaving consumers unaware of potential health risks. Testing standards for Nano cosmetics are also lacking, as there are no standardized methods to assess the safety of nanoparticles, complicating efforts to evaluate their toxicity and long-term effects on both human health and the environment. Internationally, various regulatory bodies, such as the European Union (EU), the U.S. Food and Drug Administration (FDA), and the International Organization for Standardization (ISO), have begun addressing the regulation of nanomaterials in cosmetics. The EU, for instance, mandates specific safety assessments and labeling requirements for products containing nanoparticles, ensuring consumer awareness and safety. While the FDA monitors the use of nanotechnology in cosmetics in the U.S., it has not yet implemented specific regulations, though it encourages manufacturers to consider the unique properties of nanoparticles when conducting safety evaluations. Additionally, the ISO has developed international standards for nanotechnology, which provide a valuable framework for countries like India to establish their own regulations. The Indian regulatory authorities could benefit from adopting best practices from these established frameworks to create more robust regulations for Nano cosmetics, helping to protect consumers from potential health risks associated with nanotechnology. Despite the

progress being made globally, India faces several challenges in regulating Nano cosmetics. First, the regulatory bodies in India may lack the necessary expertise and resources to effectively evaluate the safety of nanomaterials, including the need for specialized testing facilities and trained personnel to conduct thorough risk assessments. Secondly, consumer awareness about nanomaterials in cosmetics remains limited, and without clear labeling, consumers are often unable to make informed choices about the products they use. Thirdly, there is an increasing concern about the environmental impact of Nano cosmetics, particularly regarding the release of nanoparticles into wastewater systems, a factor that India's current regulations do not adequately address. Moving forward, India needs to develop a dedicated regulatory framework that specifically addresses the challenges posed by nanotechnology in cosmetics. Key actions include developing specific guidelines for the safe use of nanomaterials, implementing enhanced safety assessments that take into account the unique properties of nanoparticles, and mandating clear labeling of nanomaterials in cosmetic products. Additionally, public education efforts are essential to raise awareness about nanotechnology in cosmetics and its potential risks, enabling consumers to make informed decisions. Furthermore, collaboration with international regulatory bodies would allow India to align its regulations with global best practices, ensuring consistency in safety standards and consumer protection. In conclusion, while the regulatory framework for Nano cosmetics in India is still evolving, the lack of specific regulations for nanomaterials presents significant challenges to ensuring product safety and protecting consumers. Establishing a comprehensive legal framework that addresses the unique aspects of nanotechnology in cosmetics is essential for India to meet global standards, safeguard public health, and promote innovation in the beauty industry. [12] The regulation of Nano cosmetics in India is primarily governed by the **Drugs and Cosmetics Act, 1940**, and the **Drugs and Cosmetics Rules, 1945**, which outline the general standards for cosmetics and pharmaceutical products. However, these regulations do not yet include specific provisions for nanomaterials or products incorporating nanotechnology, such as Nano cosmetics. The Indian Pharmacopoeia primarily focuses on setting medicinal standards and currently lacks detailed regulations specifically for nano cosmetics. As nanotechnology progresses, it is expected that the regulatory framework will adapt, introducing targeted guidelines for testing, safety evaluations, and labeling of nanomaterials in cosmetics.

The present legal framework governing nano cosmetics in India includes the following:

- **Drugs and Cosmetics Act, 1940:** Regulates the overall scope of cosmetics and pharmaceuticals.
- **Drugs and Cosmetics Rules, 1945:** Offers comprehensive guidelines on the manufacturing, sale, and labeling of cosmetic products.
- **Bureau of Indian Standards (BIS):** Establishes safety and quality benchmarks for cosmetics, although specific standards for nanomaterials are still absent.
- **Environment Protection Act, 1986:** Covers environmental safety concerns, including nanomaterials, but regulations dedicated to nanotechnology are still under development.

Although these laws offer a broad regulatory framework, they do not yet include specific provisions for nanotechnology in cosmetics. However, such regulations are likely to emerge as the field advances.

Current & Future Developments: Nanotechnology is becoming increasingly popular as a part of modern era cosmetics. Constantly more and more innovative application of materials

resulting from the use of nanotechnology is being recognized. A few of the sophisticated applications that possibly will revolutionize the cosmetics market in the future are discussed in this section. Sustained and controlled release of sunscreens, with improved moisturizing capacity along with anti-aging properties could possibly be established. Some very promising delivery systems are being looked into for an array of practical applications. While some may not find their way out of the laboratory, others will bring great transformation in the cosmetic world. An exceptionally unique nanomaterial, carbon Nano buds have been identified with combined properties of carbon nanotubes and fullerenes. They are prepared by combining two most common allotropes of carbon, fullerenes and carbon nanotubes. Carbon nanotubes are specifically covalently bonded to fullerene like "sprouts/ buds ". They possess remarkably good field emitting properties. This may be in particular used in lipsticks and mascaras. Furthermore, new Nano sized metal pigments, in addition to the most known titanium dioxide and zinc oxide should be continuously investigated and proposed for color cosmetics. In addition, if appropriately explored, Nano cosmetics may open new vistas in therapy of complex skin problems and disorders. Specifically shaped nanoparticles to fill the uneven surfaces especially after plastic surgery for aesthetic appearance of body parts may open new horizons. Another promising area could be triggered release of nanomaterials on skin facilitated by skin pH gradient. Enzymes conjugated with protein Nano carriers are also receiving attention due to their exceptional water binding capacity into the horny layers of skin. The number of patent applications received in the last five years suggests that there could be an increased activity in the protein conjugation area in the immediate years ahead. In spite of the plethora of benefits Nano cosmetics may bring one cannot deny the potential dangers that are linked to some nanomaterials. Furthermore, risk estimation of nanomaterials ought to be executed on an item- by-item basis, using relevant information. [7] [19]

CONCLUSION: In conclusion, nanotechnology has fundamentally transformed the cosmetics industry, offering enhanced product efficacy, stability, and safety. The incorporation of nanoparticles into beauty products has revolutionized skincare, sunscreens, and anti-aging formulations by enabling deeper penetration and targeted delivery of active ingredients. These innovations lead to better results and longer-lasting effects, thus significantly improving consumer satisfaction. However, the use of nanomaterials also brings challenges, particularly concerning safety and regulatory oversight. The potential health risks posed by nanoparticles, such as toxicity and skin penetration, require stringent evaluation and regulation. Despite these concerns, ongoing research and advancements in nanotechnology continue to open new avenues for personalized skincare and environmentally friendly products. As the industry moves forward, the collaboration between scientists, regulators, and manufacturers will be key in ensuring that nanotechnology fulfills its potential while maintaining safety and environmental sustainability

REFERENCES

1. Information was gathered through online sources (e.g. http://www.googlescholar.com, www.pharmajournal.com, www.researchgate.com) and from physical resources available at the library of Pravara Rural College of Pharmacy, Loni.
2. Raj, S., Jose, S., Sumod, U.S. and Sabitha, M. (2012) Nanotechnology in Cosmetics: Opportunities and Challenges. Journal of Pharmacy and Bio allied Science, 4, 186-193. https://doi.org/10.4103/0975-7406.99016
3. http://www.nanoandme.org

4. Table 2 of Nano materials used in cosmetics with their advantages, disadvantages, uniqueness and commercially available products https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7279536/#B81-nanomaterials-10-00979
5. History of Cosmetics from Ancient Times: http://www.cosmeticsinfo.org/Ancient-history-cosmetics

HOW TO CITE: Ketan Sonawane*, Uday Satpute Shahid Jakir Shaikh, Nanotechnology In Cosmetics: A Comprehensive Review Of Innovations, Applications, And Challenges, Int. J. of Pharm. Sci., 2024, Vol 2, Issue 11, 796-811. https://doi.org/10.5281/zenodo.14178566