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THE EFFECT OF METAL NANOPARTICLES AND THEIR OXIDES ON BACTERIAL CELLS

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ABSTRACT

Metal nanoparticles and their oxides is one probable possibility for producing a new class of anti- bacterial agents. Active interest in nanomaterials is driven by the fact that the transition to the nanodimensional level leads to a change in the basic characteristics of a substance that is related with the exhibition of so-called "quantum dimensional effects." The biological activity of metal nanoparticles and their oxides is induced by their tiny size; nanoparticles may approach a bioobject, interact with it, and touch it. In this study, the basic mechanisms of antibacterial activity of nanoparticles of silver, copper, nickel, and titanium oxide are explored; the metal nanoparticle biological activity dependency on their physicochemical qualities is proven. The requirement of investigating the physicochemical properties of metal nanoparticles and their oxides for the standardization of their further utilization as antibacterial agents is determined.

Keywords: Nanoparticles, nano materials, oxides, quantum

1. INTRODUCTION

Because of the rapid rate at which microorganisms develop resistance to antibiotics, it is imperative that new antimicrobial medicines with a different mechanism of action be discovered. In this scenario, nanoparticles of metals and the oxides of those metals are a promising contender for the production of a new category of antibacterial drugs.

Because transitioning to the nanodimensional level causes changes in the fundamental properties of a substance (such as its magnetic and optical characteristics, melt temperature, thermal capacity, and surface and catalytic activities), there has been a recent uptick in interest in nanomaterials. This is because the manifestation of so-called quantum dimensional effects is responsible for the transformation. The reason for the shift in state density in the valence and conducting bands is an increase in size; this shift has an effect on the magnetic and electrical properties that are induced by the behaviour of electrons. The "continuous" state density of characteristics that are available at the macroscale is converted into discrete levels, and the distances that exist between them are determined by the size of the nanoparticles. Within this context, the material in question either ceases to display the physical properties of macrostate substances or is able to demonstrate those properties in a modified form.

An expanded surface is the other primary feature that contributes to the physical properties of nanoparticles. It is the fundamental one that accounts for the majority of surface phenomena. The symmetry of the intensity distribution is disturbed on the surface of nanoparticles because of uncompensated atom bonds, and this is the source of a rise in free energy on the surface as well as the stimulation of adsorption processes as well as ionic and atomy exchanges. When compared to the surface area of a substance with a high-range order, the surface area of a material with ultradispersity is significantly larger. Because of it, totally new physical occurrences and characteristics emerge in a solid substance. Because of the structure and characteristics of the enormous substrate, it is hard to make accurate predictions about these events and properties. Because of the highly developed active surface that nanoparticles possess, their sorption capacity is significantly increased.

The small size of nanoparticles (less than 100 nm), which is the same as the size of cells, viruses, proteins, and DNA, determines the biological activity of nanoparticles. Nanoparticles can approach a biological object, become compatible with it, and bind to it. This is because nanoparticles are the same size as biological objects.

2. INFLUENCE OF METAL NANOPARTICLES AND THEIR OXIDES ON BACTERIAL CELLS

The mechanisms of the antibacterial activity of metal nanoparticles and their oxides have been the subject of a significant amount of study conducted by Russian and international writers. In their study on the growth dynamics of E. coli in the presence of silicon oxide, iron oxide, and gold nanoparticles, D.N. Williams and colleagues (2006) came to the conclusion that the presence of these substances led to changes in the subcellular formations of the bacteria, such as genes and proteins. This was one of the findings of their study. Nanoparticles have a high degree of consistency. As a result, they are not subjected to a biological change and are not taken from a cell, which would cause stress in the cell and ultimately lead to its destruction.

There is a complete lack of clarity on the precise mechanism behind the antibacterial activity of ultrafine particles of metal or their oxides. At the present time, there are three putative processes that get widespread circulation:

1. Because of bacteria, a cell absorbs ions that have been removed by metal nanoparticles; this disrupts both ATP production and DNA replication.

2. The production of active oxygen forms by nanoparticles and metal ions is the root cause of the oxidative damage that is caused to cellular structures.

3. The buildup of nanoparticles in a bacterial membrane results in a shift in the membrane's permeability, which is caused by the prolonged release of lipopolysaccharide, membrane proteins, and intracellular components. According to the findings of a number of studies, the process by which nanoparticles interact with a bacterial cell takes place in phases. The ensuing electrostatic pressure causes metal nanoparticles to adsorb to the surface of a microbe during the first step (which is the physical stage). Following that, nanoparticles will enter the system. Research conducted on a submicroscopic scale has shown this out. The cellular membrane

undergoes changes at the subsequent phases (the molecular and cellular stages), including emboly, perforation, and an expansion of the cellular wall. The release of the intracellular matrix occurs as a result of the perforation of the cellular wall of a microbe by nanoparticles.

The nanoscale size and extensive surface area of metal nanoparticles and their oxides are the determining factors in their ability to inhibit bacterial growth. This places them in close proximity to the cellular membrane of the microbe they are interacting with. According to the findings of N.S. Wigginton, the size of nanoparticles is the most important factor in determining how they interact with cellular enzymes, membrane proteins, and other components of the bacterial cell (for example, with the tryptophanase found in E. coli). This interaction results in the disruption of the enzyme's normal conformation. According to the findings of A.A. Rahmetova's (2011) research, the antibacterial activity of cuprum nanoparticles might vary depending on the dispersity of the particles as well as the phase compositions. In addition, a significant amount of data suggests that there is a clear connection between metal nanoparticles and the antibacterial activity that they exhibit. Nanoparticles with a smaller size have grown surface areas to a greater degree. Because of this, the contact that takes place between it and the bacterial cell is enhanced, and as a consequence, the antibacterial impact that it has is magnified.

3. INFLUENCE OF SILVER NANOPARTICELS ON PROKARYOTIC CELLS

Nanoparticles made of metal have significant biological activity, including bacteriostatic and bactericidal properties. The antibacterial activity of silver nanoparticles, especially their effectiveness against polyantibiotic-resistant pathogens, has been the subject of research presented in a number of publications. It has been shown that the antibacterial impact of ultrafine silver is significantly stronger than that of its ionic form.

The ability of ultrafine silver to liberate ions has been demonstrated by a number of writers. This is the primary factor that defines the mechanism behind its antibacterial action. Silver ions that had been extracted were able to suppress the activity of respiratory enzymes. Because of this, free oxygen is activated, which in turn causes damage to the bacterial cell.

Nanoparticles of silver have the ability to absorb into the cellular walls of microorganisms. This results in the perforation of it.

On the surface of a bacterial membrane and also within a cell, silver nanoparticles bind to substances that contain phosphorus and sulphur, such as proteins and nucleic acids. This process occurs both outside and inside of the cell. Nanoparticles create silver ions, which then bind with phosphorous-containing DNA segments. Because of this, replication is stopped before it can take place. It is possible that the function of sulfur-containing proteins might be inhibited by the interaction of silver ions with such proteins.

The size and structure of the silver nanoparticles determines the rate at which the antibacterial activity of the nanoparticles manifests itself. According to several studies, the effectiveness of silver triangle nanoparticles as bactericide agents against E. coli is significantly higher than that of nanoparticles with spherical or rod geometries. The factors that led to this outcome are not well understood at all.

4. INFLUENCE OF CUPRUM NANOPARTICLES ON PROCARYOIC CELLS

Copper nanoparticles can kill bacteria, and this is now a well-known fact. Studies by N. Cioffi et al. (2005) showed that ultrafine metal particles stop bacteria from growing and kill fungi.

J. Ramyadevi et al. (2012) looked into how cuprum nanoparticles kill bacteria like Micrococcus luteus, S. aureus, E. coli, Klebsiella pneumonia, P. aeruginosa, Aspergillus flavus, A. niger, and Candida albicans. The data from these authors showed that cuprum nanoparticles were more effective at killing bacteria than they were at killing fungi.

By their activity, silver nanoparticles are linked to the fact that copper nanoparticles can kill bacteria. K. Yoon et al. did research in 2007 on how copper and silver nanoparticles affect Bacillus subtilis and E. coli strains that are used in labs. They found that 100-nm-diameter copper nanoparticles were very effective against B. subtilis. At the same time, E. coli strains were not affected much by silver nanoparticles with a size of 40 nm.

The question of how copper nanoparticles kill bacteria is still up in the air. It is clear that the electrostatic interaction between the negatively charged surface of the microorganism and the positively charged metal nanoparticles is where the interaction between the metal nanoparticles and the bacterial cell begins. D.G. Deryabin et al. (2013) looked at the zeta-potential of cells from the sensor K12 TG1 E. coli strain. They found that the -potential of bacterial cells was positive and that of copper nanoparticles was negative. When cuprum nanoparticles interact with a suspension of microorganisms, the values change in a way that leads to a positive result. This proved the theory of electrostatic attraction as a result. Electron microscopic studies show that this theory is good. They show that the nanoparticles of copper touch the surface of the bacterial cell. Because of this interaction, peptidoglycane is broken down. An increase in osmotic pressure causes the murein sacculus to burst, releasing parts of the cytoplasm and pieces of the cell wall.

In the study by V.S. Lebedev et al., they found that the antibacterial effect of copper nanoparticles is caused by damaging the barrier function of the cellular membrane of a microorganism (2002). It has been found that when copper nanoparticles are used to process a bacterial cell, K+ is released. This shows how many redox processes are going on in the premembrane area.

Nanostructural metal can be the reason why natrium, calcium, phosphorus, and kalium are taken out of the ground. It causes the membrane to become less stable and cell parts to be lost. Calcium is an important part of how cells work and keeps the lipopolysaccharide on the surface of gram-negative bacteria from falling apart.

Researchers D.G. Deryabin et al. (2013) looked at how cuprum nanoparticles kill bacteria in luminescent E. coli strains (E. coli K12MG1655 pSoxS::lux, ketG::lux, recA::lux) found out how nanoparticles kill bacteria when they are exposed to oxidative stress. This happens when electrons move from copper nanoparticles in the membrane of a bacterial cell to molecules of oxygen. Reactive oxygen intermediates damage the DNA molecule as a result.

Scientists have found that the antibacterial activity of cuprum nanoparticles depends on many things, such as temperature, aeration, pH, and the number of bacterial cells and nanoparticles in a solution. It was shown that high temperature, air flow, and clumping, as well as low pH and clumping, make the antibacterial effect of cuprum nanoparticles stronger. When metal nanoparticles don't stick together too much, they have a lot of surface area to interact with bacterial membranes.

Based on data about how well copper nanoparticles kill bacteria, the United States Committee for Environmental Conservation was able to confirm that they should be registered as an antimicrobial agent that kills cancer-causing bacteria.

INFLUENCE OF TITANIUM OXIDE NANOPARTICLES ON PROCARYOTIC CELLS

Photocatalytic activity is present in TiO_2 nanoparticles. TiO_2 nanoparticles are photocatalytic because when they are exposed to light, they can grab electrons from molecules that are close to them. This process makes reactive oxygen intermediates, especially hydroxyl–radical, when nanoparticles are dissolved in water. When HO and O_2- radicals are made, they oxidise the lipids, peptidoglycanes, and lipopolysaccharides in the cell membranes of microorganisms. This is why TiO_2 nanoparticles are good at killing germs. Also, it has been shown that TiO_2 is genotoxic because it stops DNA chains from working in cells when they are exposed to light.

Research done by G.B. Zavilgelsky et al. in 2011 showed that when UV-A light hits titanium dioxide nanoparticles, hydric dioxide is made in the cells of E. coli. The microorganism dies from oxidative stress caused by hydric dioxide.

In a number of studies, it has been shown that when nanoparticles of titanium dioxide are exposed to UV light, they kill bacteria. It has also been shown that the activity against bacteria goes up as the amount of TiO_2 nanoparticles and the strength of UV light go up. Because TiO_2 nanoparticles absorbed on the surface of the bacterial cell, the most antibacterial effect was seen when the cell walls of the microorganisms touched them.

Researchers looked at how antibacterial titanium dioxide nanoparticles were against P. fluorescens and found that it depended on how well they killed bacteria when they were spread out.

5. INFLUENCE OF NICKEL NANOPARTICLES ON MICROORGANISMS

Nickel nanoparticles can conduct electricity and act like magnets. They can also hold his-tagged proteins in a way that no other material can. It was shown that groups of nickel nanoparticles can link up with pieces of single-stranded DNA (ssDNA) to form stable complexes.

It is not clear at all how nickel nanoparticles work to kill bacteria. There are a few articles that talk about how this metal affects certain types of microflora. So, K. Yoon et al. (2007) looked into the antimicrobial effects of nickel and silver nanoparticles on E. coli and B. subtilis standard strains and found that nickel nanoparticles had a high antimicrobial effect.

H. Kumar et al. found in 2010 that nickel nanoparticles kill standard strains of E. coli, Lactobacillus spp., S. aureus, P. aeruginosa, and B. subtiles even in very small amounts. It was found that the antimicrobial activity was oligodynamic. Animal tests have shown that metal nanoparticles made of ultrafine powders of nickel are less dangerous than silver nanoparticles.

6. CONCLUSION

Nickel nanoparNowadays, one actual issue of medicine is the spread of polyresistant strains of microorganisms. Surely, the search for new antibacterial drugs against resistant strains of microorganisms is of theoretical and practical interest now.

The specific features of metals in ultrafine conditions open up wide possibilities for the creation of new effective materials and use in biology and medicine.

Metal nanopowders have strong biological activity, including bacteriostatic and bactericidal. Many authors have shown the bacteriostatic and bactericidal action of metal nanoparticles. Most studies are about the antibacterial activity of metal nanoparticles and their oxides, including those which are against resis- tant strains of microorganisms [28, 29, 31]. However, data on the mechanism of the antimicrobial action of metal nanoparticles need to be researched in future.

For the purpose of this review, there were no observed risk factors in medical use: issues of toxicity of metal nanoparticles, exposure levels for use of metal nanoparticles and their oxides, or risks of their accu- mulation in target organs.

A complex analysis of antibacterial action and risk factors of metal nanoparticles and their oxides offers the opportunity to detect more perspective drugs for clinical use against puoinglammatory suquela and other pathologies.

Besides being able to conduct electricity and operate as magnets, nickel nanoparticles also retain his-tagged proteins in a way that no other material can. Aggregates of nickel nanoparticles have been demonstrated to form stable complexes with fragments of single-stranded DNA (ssDNA).

Although nickel nanoparticles have been shown to inhibit bacterial growth, the exact mechanism by which they do this remains unclear. Certain microflora have been shown to be affected by this metal, although these studies have only been published in isolation. As a result, K. Yoon et al. (2007) studied the antibacterial effects of nickel and silver nanoparticles on laboratory strains of Escherichia coli and Bacillus subtilis, finding that nickel nanoparticles exhibited much higher antimicrobial activity.

Standard strains of Escherichia coli, Lactobacillus spp., Staphylococcus aureus, Pseudomonas aeruginosa, and

Bacillus subtilis were all shown to be killed by exposure to nickel nanoparticles at extremely low concentrations (H. Kumar et al., 2010). This study found that antibacterial action is oligodynamic in nature. Studies on animals show that ultra-fine powdered nickel has a lower toxicity than silver nanoparticles.

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