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A COMPREHENSIVE REVIEW ON: GOLD NANOPARTICLES

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ABSTRACT

One kind of nanocarrier with distinctive optical characteristics and exceptional biocompatibility is gold nanoparticles (AuNPs). They are widely used in tissue engineering, diagnostics, and therapy, among other areas of biomedical engineering and medicine. With their distinct physicochemical characteristics, AuNPs are among the most stable metal nanoparticles and are a strong contender for a variety of biological applications. Biological synthesis techniques are preferred over other synthesis methods because they minimize the requirement for hazardous chemicals in the reduction process. Using a variety of materials, surface functionalization gives gold nanoparticles colloidal stability. The biological uses of AuNPs, including bioimaging, biosensing, drug transport, anticancer therapy, hyperthermia, and antibacterial activity, are the primary emphasis of this review. The optical characteristics associated with surface plasmon resonance (SPR) are utilized in biosensing.

KEYWORDS: Gold Nanoparticles, Surface Plasmon resonance (SPR), Photothermal, AuNPs, hyperthermia, drug delivery.

INTRODUCTION

Given that GNPs are among the most stable and readily synthesized nanoparticles, as well as having a number of iteresting features such type assembly and quantum size effect, gold nano particles make an excellent study material.

Gold nanoparticles' optical behavior is dependent upon their surface Plasmon resonance, whic h is determined by the collective motion of conducting electrons and includes a broad range o

f wavelengths from the visible to the infrared. Size and shape of GNPs affects the range of spectrum. (Sundus Jabeen 1). Nanoparticles can enhance cellular and molecular cancer examination. treatment, and diagnosis. These days, gold—more specifically, gold nanoparticles, or GNPs—has developed as a promising field of study for cancer imaging, diagnostics, and treatment in cancer. This is because GNPs have biocompatible qualities. (Babaei M).

The presence of gold nanoparticles in the sub-surface layer of matrix gold nanoparticles.

Gold grains is extensive of the grains of placer metal in alluvial deposits near the source rocks, though during the transporting process, their surface is subjected to strong mechanical deformations and absorption. (Sakineh Alizadeh 3). Gold nanoparticles Due to their excellent biocompatibility, Au particles are widely and specifically used in living things. Although gold nanoparticles are thought to be physiologically inert in their native state, they can be engineered to have chemical, thermal, or photo functional properties. Using photothermal heating, Au Nanorods and Au Nanospheres that can absorb near-infrared radiation (NIR) can eliminate ba[1] cteria and cancer cells. Using the use of NIR photothermal radiation and photodynamic antimicrobial treatment, Au Nanorods connected with photo sensitizers can kill MRSA. Another potential source for nanoparticle manufacturing is microorganisms. However, the difficulty lies in the synthesis's slow speed, which ultimately results in fewer sizes and forms for the NPs created than those made using other methods, such as plant-based material. (Reza Teimuuri-Mofa rd. 4).[2]

Gold nanoparticles can pass through the nucleus and cell membrane due to their small size and diameter of roughly 1 nm. Because of their surface plasmon resonance, gold nanoparticles are widely used in biomedical science, including medication administration, photothermal therapy, tissue or tumor imaging, and immunochromatic detection of pathogens in clinical specimens. (SPR)(AK Khan).[3]

Gold nanoparticles (GNPs) have gained attention as an appealing biosynthesized medication to be researched for bioscience study in recent years because gold is the most biocompatible metal among all available for biomedical purposes. GNPs are employed as superior catalysts because of their distinctive tiny size, biocompatibility, and lack of cytotoxicity. The importance of natural plant biomolecules in the bio reduction of metal salts during the GNPs synthesis with phytoconstituents utilized as antitubercular agents is the primary focus of the

study on GNPs synthesis with herbs for tuberculosis. (Arti Gupta, Sonia Pandey, Jitendra Singh Yadav).[1]

Advantages of gold nanoparticles

1. GNPs as catalyst: Au nanoparticles (Au-NPs) have been used in a variety of catalytic processes, such as selective hydrogenation of nitro compounds, acetylene hydrochlorination, low-temperature CO oxidation, and selective oxidation of alcohols. Over the past three decades, numerous findings have demonstrated that Au-NPs can catalyze a wide range of compounds, activating and reacting in the process. These findings have completely altered researchers' perceptions about Au, a metal long thought to exhibit chemical inertia. (Matumuene Joe Ndolomingo).[4]

2. Covalent immobilization of antibodies on GNPs: We adopted our previous findings and covalently placed the IC4 antibodies on GNPs. First, in 0.1 M sodium bicarbonate (pH 8.5), the antibodies and succinimidyl carboxymethyl ester (OPSS–PEG–NHS) cross-linker interacted at a 10:1 molar ratio for an entire overnight. The modified antibodies were purified by gel filtration and combined at the ratios indicated in Table 3 with 20 mL of GNPs that had been dispersed in water for two hours to form conjugates. The next step involved adding 20 µL of 1 mM PEG-SH to stabilize the nanoparticles. After a centrifugation for 15 minutes, the conjugates were finally resuspended. (Nadezhda A. Byzova).[5]

3. Size: Because they are so small, nanoparticles are easily absorbed by the body and can pass through smaller capillaries, facilitating effective medication accumulation at the desired spot. The drug's encapsulation is well protected by it. (Khadeeja Parveen).[6]

4. GNPs as carrier: Because these nanoparticles have variable sizes, they can be employed as carriers for proteins, peptides, and nucleic acids like DNA. Additionally, they transport insulin. Because chitosan is coated on the surface of gold nanoparticles, insulin can be easily absorbed by them, improving insulin's transmucosal delivery. (Avnika Tomar).[7]

5. Gold nanoparticles against lung cancer treatment: Since gold nanoparticles are highly stable against oxidation in vivo, they can be used to treat a variety of disorders, particularly cancer. They are also easily functionalized with chemotherapeutic drugs. GNPs function as unique carriers for biomedical applications in lung cancer because they have the site

specificity of the entrapped drug and also increase bioavailability because of their ability to interact with visible light (Guinart A).[8]

Disadvantages of GNPs

1. Toxicity due to GNPs: Many companies form dietary supplements which contain gold nanoparticles and produced them in form of drinks which acts as anti-inflammatory agents which also helps in up lifting of the mood. AuNP s can cause toxicity in many situations due to their size and shape. These distinctive features causes different chemical attributes in which some were resulted to be non- toxic while others as toxic due to transforming of chemical attributes into different cellular studies. (Tian F 2015).[9]

2. Biodistribution and Size: In GNPs, size and biodistribution is taken as one of the important factors which must be considered apart from the toxicity. Rosli et. Al, recorded that the gold nanoparticles with size of 50 nm have high rate of cytotoxicity in a breast cancer line as comparing with gold nanoparticles with size of 13 and 70 nm counterparts. (Anik MI Mahmud).[10]

3. Optical limitation: The Optical limitation of AuNP s is that the optical signals may be weak as compared to the quantum dot. (Dawson J).[11]

4. Risk to healthy cells: When GNPs are used for cancer therapy, they can also affect normal healthy cells and along with cancerous ones they may harm healthy tissues of our body. (Lim ZZJ).[12]

5. Immune system impact: The Gold Nanoparticles can weaken our immune system. When designing treatments, the immune system impact must be carefully considered. (Stephenson M).[13]

Application of AuNPs

Gold nanoparticle applications are growing quickly and now include

1. Diagnostics: The advancement of nanotechnology has led to improvements in diagnostic test sensitivity, specificity, and combination. Important and superior optical characteristics are exhibited by AuNPs, principally surface-enhanced Raman scattering (SERS) and localized surface Plasmon resonance (LSPR), both of which are crucial for diagnostics. (Xiaopei Hu^{+} 16).[14]

2. Gold nanoparticles as Drug Carriers: Due to its optical, tunable, and surface plasmon resonance (SPR) qualities, gold nanoparticles have attracted the interest of scientists for potential application as drug carriers. It is simpler to manage their dispersion because they may be manufactured in a wide range of core diameters, from 1 to 150 nm. Gold nanoparticles are easily changeable due to their negative charge on their surface. This implies that the addition of different biomolecules, including medications, targeted ligands, and genes, can readily functionalize them. Furthermore, gold nanoparticles' biocompatibility and lack of toxicity make them a great option for usage as drug carriers. (Priyanka Singh).[15] Because they may be essential to the delivery of drugs, nanoparticles have been studied in great detail and employed in the treatment of cancer. Gold nanoparticles' surfaces may be modified to increase their stability, reduce aggregation, and promote adhesion to target cells and anti-cancer drugs.(Li W).[16] Among the special qualities of Au NPs that make them useful in medicine are their radioactivity, localized surface Plasmon resonance, and high X-ray absorption coefficient. Moreover, Au NPs have amazing optical and electrical characteristics that allow for controlled interactions with organic molecules that have electro-donating groups. The applications of functionalized Au nanoparticles have grown as a result of their advancements(Siddique S).[17]

3. Au NPS As Catalyst: When employed as catalysts in organic reactions, gold nanoparticles provide stable, economical, and environmentally friendly substitutes for the synthetic conversions of heterocyclic scaffolds. Gold catalysts exhibit superior activity in CO and other oxidations at low temperatures. Nitrogen and oxygen containing heterocyclic atoms are the fundamental prime units existing in diverse carbon-based vibrant lives and are significant for industrial, pharmaceutical, and agrochemicals (Ma Z)[18] The performance of the catalyst is improved by the presence of a partially reducible oxide (ceria or a transition metal oxide) as well as small (~5nm) particle sizes. (Grisel R).[19]

4. Au NPs in separation science: Usage of Au NPs in separation sciences, particularly in electromigration and chromatographic procedures. Applying Au NPs to specific separation techniques, such as microchip CE, CE(Capillary Electrophoresis), MEKC (Micellar Electrokinetic Chromatography), CEC (Capillary Electrochromatography), HPLC (High Performance Liquid Chromatography), and GC, is classified based on the molecular size of the analytes, varying from low molecular mass compounds to biopolymers (proteins and nucleic acids). (M Das).[20]

A common citrate technique that depends on the reduction of AuCl4- by citrate ions produces aqueous gold colloidal dispersions. In order to produce a pseudo stationary phase, two distinct GNP species were added as additives to the BGE. Initially, capillaries coated with poly (diallyl ammonium chloride) (PDADMAC) were created along with unaltered citrate stabilized GNPs (~18 nm). The BGE was acetate buffer that had been adjusted up to pH 5.0. Second, untreated fused silica (FS) capillaries were combined with sodium 3-mercaptopproprionate GNPs (~5nm) that were produced. The BGE in the most recent instance was phosphate buffer (pH 6.4). The model analytes used to investigate the impact of GNPs on the separation process were the structural isomers of aromatic acids and bases. (Yokoyama K).[21]

METHODS FOR SYNTHESIS OF GOLD NANOPARTICLES

Different methods have been used for development of gold nanoparticles. Various methods include are

1. Biological: An energy-efficient, dynamic, and safe way to create nanoparticles is by biological synthesis. This method uses a variety of biological resources, including eukaryotes and prokaryotes, to generate NPs in vivo. The stability of metallic ions and their bio reduction to NPs are significantly influenced by metabolites (proteins, fatty acids, carbohydrates, enzymes, and phenolic compounds) present in these sources. (Ines Hammami 7).[22] Because of their extremely rapid growth rates and simple handling methods, bacteria are thought to be among the best prospects for the development of AuNP. Compared to other microbes, the genetic modification and manipulation of grown bacteria and actinomycetes for the synthesis of AuNP is simpler and more effective. (Homa Hassan 8).[23]

2. Microbial: As microbes can be easily handled, maintained, and grown on low-cost media like cellulosic wastes or wastelands, they are employed in the synthesis of nanoparticles. (Soumya Menon 9).[24]

Many types of microbes create AuNPs. despite the similar basic procedures that lead to the reduction of gold ions to create AuNPs. There is a theory that suggests the enzymes released by microbes are crucial for the reduction of metal ions, leading to the nucleation and development of NP. (Utkarsha Shedbalkar 10).[25]

3. Chemical: Citrate thermal reduction method was employed for synthesis of gold nanoparticles exhibiting excellent SERS (surface enhanced Raman spectroscopy) in short

reaction times by using a low- cost reagent inositol hexaphosphate (IP6) as reducing agent for HAuCI4. (Khan AK).[3]

4. Green synthesis of plant extract-AuNPs: The abundance of plants found in nature offers a number of benefits, including low cost, high repeatability, environmental friendliness, and exact purification as compared to other biological approaches that also benefit the environment. The use of plant extracts as stabilizers and reducing agents in green methods for the manufacture of gold nanoparticles has recently attracted more attention. (Ines Hammami 11).[26] Target binding, site-specific delivery, low toxicity, and excellent therapeutic efficacy characterize the sustainable manufacturing of nanoparticles. There are two common methods for synthesizing NPs: top-down and bottom-up. The bottom-up strategy, in which NPs are created from simpler molecules, is where the majority of NP synthesis methods are located 1(Ganesh Kumar V).[27] AuNPs are created by bio reducing plant extracts or microbial cultures added to the precursor gold salt solution. The manufacture of AuNPs involves a variety of metabolites and biomolecules, including sugars, fatty acids, proteins, enzymes, and phenols. (Santhosh PB).[28]

5. Turkevich method: Compared to other methods, the Turkevich approach shows promise in the chemical production of GNPs. A mild reducing agent, such as citrate, ascorbic acid, or tannic acid, is used in the Turkevich method to reduce Au3+ ions in an aqueous media. GNPs that are biocompatible and of a reasonable size are created during this technique.(Roya Herizchi 14).[29]

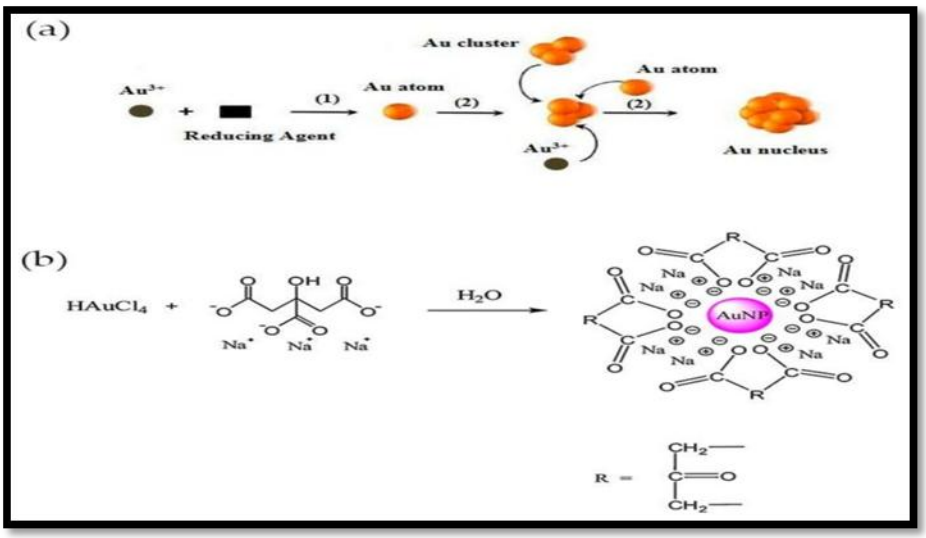

Figure 1: AuNP synthesis using the Turkevich method.

(b) In this method, Trisodium citrate is used both as reducing and stabilizing agent.

⬇

These agents are added to Chloroauric acid ($HAuCl_4$) boiling solution

⬇

Vigorous stirring of the solution.

⬇

A red –wine solution is obtained at the end of the reaction.

⬇

By owing to the formulation of AuNPs with an average diameter of around 20nm, with a negatively charged surface and electrostatically stabilized by citrate ions.(Antonio M).[30]

6. Vacuum Sputtering: The application of a potential difference between the two electrodes in the vacuum chamber with an electric field is the base of this method.

Firstly, Inside the chamber an inert gas is added and becomes ionized.

⬇

An argon plasma with bombardment of a metal target (Cathode) takes place.

⬇

As a result, atomic clusters are released from the target region and fall to the ground or into the ground or into a liquid medium.

⬇

In below figure a graphic representation of the solution preparation principle.

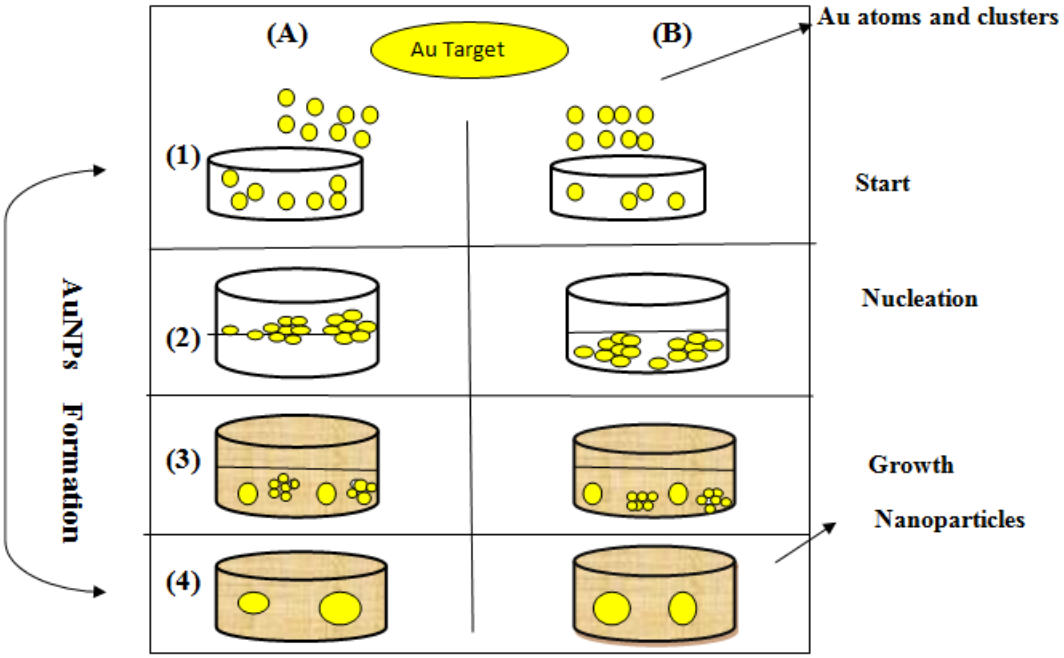

Figure 1.2: Preparation of Nanoparticles by Vacuum Sputtering into a Liquid (A) nucleation starts at the oil/vacuum interface (B)at the bulk liquid phase. (Petr slepicka).

7. Two-Phase Brust-Schiffrin method: The Two Phase Brust –Schiffrin method can be used to create extremely stable noble gold nanoparticles. (Tong YJ).[31]

Firstly, took a beaker and add N (C8H17) 4Br, a phase-transfer catalyst is mixed with a gold ion solution (HAuCl4.4H2O).

↓

The toluene phase takes the gold ions.

↓

Add a salt which is phase transfer catalyst with a long chain alkyl ammonium cation that is soluble in organic solvents and water.

↓

Anion exchange occurs between the anion (Br-) in the phase-transfer catalyst and anion ([AuCl4]-) in the aqueous solution.

↓

Then add toluene solution of ($C_{12}H_{25}SH$) as a protective agent.

↓

Next, add a reducing agent which is aqueous solution of ($NaBH_4$).

↓

As a result, Blackish-brown toluene-dispersed AuNPs are produced when the gold ions are reduced. (Mao Hamamoto).

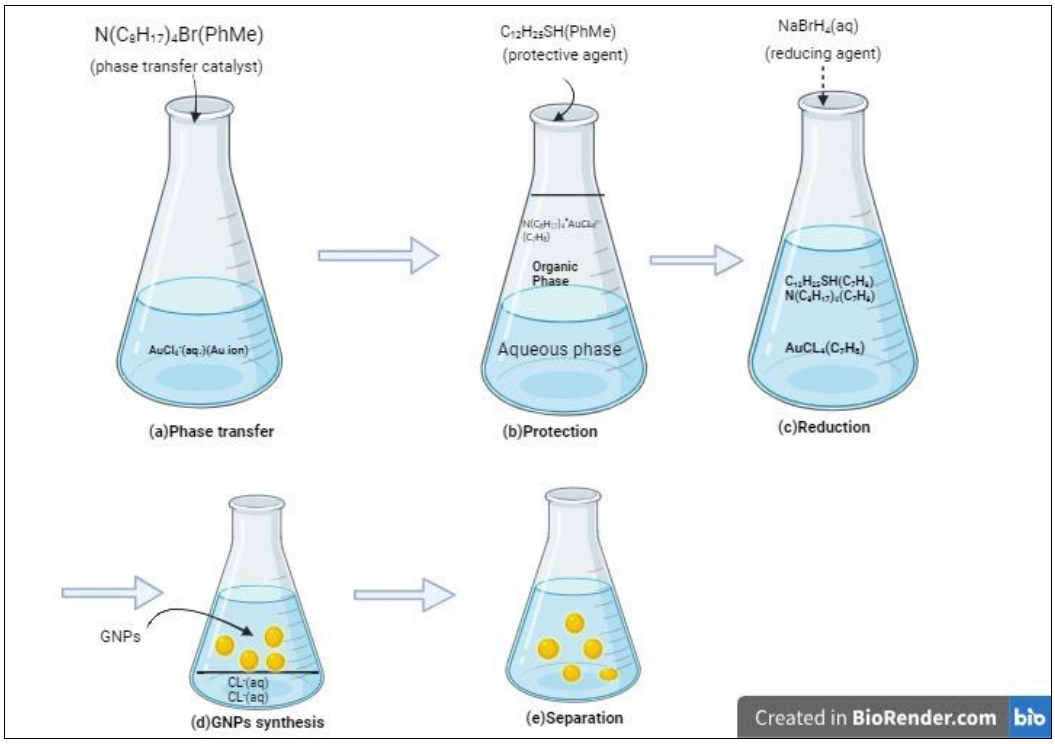

Figure 1.3: Two- Phase Brust Schiffrin Method.

Future Prospects of gold nanoparticles

- Research should concentrate on ways to stop AuNPs from aggregating as well as the stability of AuNPs. In addition to their function in synthesis, these synthesis-related proteins are frequently reported to stabilize the NPs. Newer stabilizing agents for NPs must be discovered in order for them to be used in a variety of industries.

- The study should also concentrate on optimizing the growing conditions of microorganisms and physicochemical factors that affect synthesis, such as pH, temperature, culture age, biomass content, and salt concentration. More thorough research is required to understand the large-scale microbial synthesis of monodispersed AuNPs. (Utkarsha Shedbalkar).[25]

By modifying the size and form of materials at the nanoscale, nanotechnology is a new science that can help fight pollution. Because of its high surface energy and large surface area, the nanoparticles can absorb a lot of pollutants or catalyze reactions more quickly, they can either assist stop the release of contaminants or use less energy during degradation. The

particles nano size also makes it possible to access locations that would otherwise be unreachable, which encourages in-situ remediation as opposed to ex-situ remediation (Wang C Yu C).[32]

- GNPs will likely significantly lower potential negative effects while significantly boosting the efficacy of medicinal drugs. GNPs are excellent prospects for nano-oncology because to their water-based manufacture, variable size, shape, and optical features, which alter the surface chemistry. Several anti-cancer medications might be delivered by GNPs to the tumor site at the same time, attacking vital biological pathways that contribute to the growth of the tumor. (Ahmed Muhammad Zakir).[33]

CONCLUSION

GNPs are the most stable and readily synthesized nanoparticles, as well as having a number o f interesting features, GNPs—has developed as a promising field of study for cancer imaging, diagnostics, and treatment in cancer. Au Nanorods and Au Nanospheres that can absorb near-infrared radiation (NIR) can eliminate bacteria and cancer cells. GNPs act as catalyst and are used in catalytic processes such as Acetylene Hydrochlorination .These nanoparticles have variable sizes, they can be employed as carriers for proteins, peptides, and nucleic acids like DNA. AuNPs can cause toxicity in many situations due to their size and shape. the gold nanoparticles with size of 50 nm have high rate of cytotoxicity in a breast cancer line.

GNPs can be prepared by using different-different methods such as biological, chemical, microbial, Turkevich method etc.

REFERENCES

1. Gupta A, Pandey S, Yadav JS. A review on recent trends in green synthesis of gold nanoparticles for tuberculosis. Adv Pharm Bull, 2021; 11(1): 10-27. doi:10.34172/apb.2021.002
2. Mofrad R, Hadi R, Tahmasebi B, Farhoudian S, Mehravar M, Nasiri R. Green synthesis of gold nanoparticles using plant extract: Mini-review. Nanochem Res., 2017; 2(1): 8-19. doi:10.22036/ncr.2017.01.002
3. Khan AK, Rashid R, Murtaza G, Zahra A. Gold nanoparticles: Synthesis and applications in drug delivery. Trop J Pharm Res., 2014; 13(7): 1169-1177. doi:10.4314/tjpr.v13i7.23

4. Ndolomingo MJ, Bingwa N, Meijboom R. Review of supported metal nanoparticles: synthesis methodologies, advantages and application as catalysts. J Mater Sci., 2020; 55(15): 6195-6241. doi:10.1007/s10853-020-04415-x
5. Byzova NA, Zherdev A V., Khlebtsov BN, Burov AM, Khlebtsov NG, Dzantiev BB. Advantages of highly spherical gold nanoparticles as labels for lateral flow immunoassay. Sensors (Switzerland), 2020; 20(12): 1-15. doi:10.3390/s20123608
6. Parveen K, Banse V, Ledwani L. Green synthesis of nanoparticles: Their advantages and disadvantages. AIP Conf Proc, 2016; 1724. doi:10.1063/1.4945168
7. Tomar A, Garg G. Short review on application of gold nanoparticles. Glob J Pharmacol, 2013; 7(1): 34-38. doi:10.5829/idosi.gjp.2013.7.1.66173
8. Guinart A, Perry HL, Wilton-Ely JDET, Tetley TD. Gold nanomaterials in the management of lung cancer. Emerg Top Life Sci., 2021; 4(6): 627-643. doi:10.1042/ETLS20200332
9. Tian F, Clift MJD, Casey A, et al. Investigating the role of shape on the biological impact of gold nanoparticles in vitro. Nanomedicine, 2015; 10(17): 2643-2657. doi:10.2217/nnm.15.103
10. Anik MI, Mahmud N, Al Masud A, Hasan M. Gold nanoparticles (GNPs) in biomedical and clinical applications: A review. Nano Sel., 2022; 3(4): 792-828. doi:10.1002/nano.202100255
11. Dawson J. Optical limiting materials based on gold nanoparticles. Published online, 2014; 1-12.
12. Lim ZZJ, Li JEJ, Ng CT, Yung LYL, Bay BH. Gold nanoparticles in cancer therapy. Acta Pharmacol Sin., 2011; 32(8): 983-990. doi:10.1038/aps.2011.82
13. Stephenson M. Northumbria Research Link (www.northumbria.ac.uk/nrl). Acad Manag, 2021; 51(September): 1-51.
14. Hu X, Zhang Y, Ding T, Liu J, Zhao H. Multifunctional Gold Nanoparticles: A Novel Nanomaterial for Various Medical Applications and Biological Activities. Front Bioeng Biotechnol, 2020; 8(August): 1-17. doi:10.3389/fbioe.2020.00990
15. Singh P, Pandit S, Mokkapati VRSS, Garg A, Ravikumar V, Mijakovic I. Gold nanoparticles in diagnostics and therapeutics for human cancer. Int J Mol Sci., 2018; 19(7). doi:10.3390/ijms19071979
16. Li W, Cao Z, Liu R, et al. AuNPs as an important inorganic nanoparticle applied in drug carrier systems. Artif Cells, Nanomedicine Biotechnol, 2019; 47(1): 4222-4233. doi:10.1080/21691401.2019.1687501

17. Siddique S, Chow JCL. Gold nanoparticles for drug delivery and cancer therapy. Appl Sci., 2020; 10(11). doi:10.3390/app10113824
18. Ma Z, Overbury SH, Dai S. Gold Nanoparticles as Chemical Catalysts. Encycl Inorg Chem.(February), 2005. doi:10.1002/0470862106.ia407
19. Grisel R, Weststrate KJ, Gluhoi A, Nieuwenhuys BE. Catalysis by gold nanoparticles. Gold Bull., 2002; 35(2): 39-45. doi:10.1007/BF03214836
20. Das M, Shim KH, An SSA, Yi DK. Review on gold nanoparticles and their applications. Toxicol Environ Health Sci., 2011; 3(4): 193-205. doi:10.1007/s13530-011-0109-y
21. Yokoyama K, Ichiki A. Spectroscopic investigation on the affinity of SARS-CoV-2 spike protein to gold nano-particles. Colloids Interface Sci Commun, 2021; 40(November 2020): 100356. doi:10.1016/j.colcom.2020.100356
22. Hammami I, Alabdallah NM, jomaa A Al, kamoun M. Gold nanoparticles: Synthesis properties and applications. J King Saud Univ - Sci., 2021; 33(7). doi:10.1016/j.jksus.2021.101560
23. Hassan H, Sharma P, Hasan MR, Singh S, Thakur D, Narang J. Gold nanomaterials – The golden approach from synthesis to applications. Mater Sci Energy Technol, 2022; 5: 375-390. doi:10.1016/j.mset.2022.09.004
24. Menon S, S. R, S. VK. A review on biogenic synthesis of gold nanoparticles, characterization, and its applications. Resour Technol, 2017; 3(4): 516-527. doi:10.1016/j.reffit.2017.08.002
25. Shedbalkar U, Singh R, Wadhwani S, Gaidhani S, Chopade BA. Microbial synthesis of gold nanoparticles: Current status and future prospects. Adv Colloid Interface Sci., 2014; 209: 40-48. doi:10.1016/j.cis.2013.12.011
26. Baptista P, Pereira E, Eaton P, et al. Gold nanoparticles for the development of clinical diagnosis methods. Anal Bioanal Chem., 2008; 391(3): 943-950. doi:10.1007/s00216-007-1768-z
27. Ganesh Kumar V, Dinesh Gokavarapu S, Rajeswari A, et al. Facile green synthesis of gold nanoparticles using leaf extract of antidiabetic potent Cassia auriculata. Colloids Surfaces B Biointerfaces, 2011; 87(1): 159-163. doi:10.1016/j.colsurfb.2011.05.016
28. Santhosh PB, Genova J, Chamati H. Review Green Synthesis of Gold Nanoparticles: An Eco-Friendly Approach. Chem., 2022; 4(2): 345-369. doi:10.3390/chemistry4020026
29. Herizchi R, Abbasi E, Milani M, Akbarzadeh A. Current methods for synthesis of gold nanoparticles. Artif Cells, Nanomedicine Biotechnol., 2016; 44(2): 596-602. doi:10.3109/21691401.2014.971807

30. António M, Nogueira J, Vitorino R, Daniel-da-silva AL. Functionalized gold nanoparticles for the detection of c-reactive protein. Nanomaterials, 2018; 8(4): 1-21. doi:10.3390/nano8040200
31. Tong YJ. Mechanistic Insights into the Brust – Schiffrin Synthesis of Stabilized Metal Nanoparticles, 2011; (7): 1-24.
32. Wang C, Yu C. Detection of chemical pollutants in water using gold nanoparticles as sensors: A review. Rev Anal Chem., 2013; 32(1): 1-14. doi:10.1515/revac-2012-0023
33. Ahmad MZ, Akhter S, Rahman Z, et al. Nanometric gold in cancer nanotechnology: Cu rrent status and future prospect. J Pharm Pharmacol, 2013; 65(5): 634-651. doi:10.1111/jphp.12017