CHAPTER – II

MATERIALS AND METHODS EMPLOYED FOR THE SYNTHESIS AND APPLICATION OF METAL NANOPARTICLES
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This chapter describes the synthesis technique and experimental characterization techniques used for studying synthesized nanoparticles (NPs) applications in this thesis. These techniques include transmission electron microscopy (TEM), scanning electron microscopy (SEM), UV-visible spectroscopy, X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR). Also the methods and materials adopted for the synthesis and applications of monometallic and bimetallic NPs have been described.

**Keywords:** Monometallic; Bimetallic; Nanoparticles; Transmission electron microscopy; Scanning electron microscopy; UV-visible spectroscopy; X-ray diffraction and Fourier transform infrared spectroscopy.
2.1. INTRODUCTION

There has been steady technological progress in all fields of nanostructure synthesis and assembly, in no small part because of the more general availability of characterization tools having higher spatial, energy, and time resolution to clearly distinguish and trace the process of nanostructure formation. The evolution of nanomaterials towards new applications requires knowledge on effects of processing routes and on aspects of long term stability. Metal particles in the nanometer size range can serve as efficient catalyst in many redox reactions due to the fact that they possess a large surface area that acts as a substrate on which the electron transfer reaction occurs. There are several processes for production of nanoparticles (NPs). The processing of nanosized particles can be briefly classified into several regimes: [a] chemical reduction of metal ions generally in the presence of stabilizing agents, (Pyatenko et al., 2005) [b] thermal decomposition in organic solvents, (Kim et al., 2006) [c] reversed micelle processes, (Mafune et al., 2006) [d] photoreaction, (Jin et al., 2001) [e] \( ^{60}\text{Co}-\gamma\)-irradiation (Henglein and Giersig, 1999) and [f] microwave irradiation (Pastoriza-Santos and Liz-Marzan, 2002). Among these methods, metal NPs with spherical, nanowire or nanoprism shapes and with tunable sizes have been manufactured but, in most cases, only with a low concentration of metal colloids (several mill moles per litre or less) in the presence of suitable stabilizers (He et al., 2002; Sun et al., 2002). The stabilizers such as surfactants and polymers cannot be easily removed from the surfaces of the formed metal colloids, which unavoidably affect the physiochemical properties of the resulting NPs. The most widely used substances for the stabilization of metal NPs are ligands and polymers, specially natural or synthetic polymers with a certain affinity toward metals, which are soluble in suitable solvents (Hirai et al., 1985). Such substances can also control the reduction rate of the metal ions and the aggregation process of zerovalent metal atoms. It has been said that the preparation of polymer stabilized NPs (through chemical methods) basically involves two processes: reduction of metal ions into neutral atoms and coordination of the polymer to the metal NPs. The polymers also control the aggregation of metal atoms in solution (Pastoriza-Santos and Liz-Marzan, 2002). Many of the organic species have been reported to be toxic to human beings and harmful to flora and fauna (Orozco et al., 2008; Kannan et al., 2008). Several methods (Ahmad and Haseeb, 2002; Bajpai et al., 2004; Hou et al., 2011) are used for the removal of organic species from effluents. The improvements
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brought about by these advances in technology have been substantial, but perhaps of greater importance for this nascent field of nanostructure science and technology.

In this chapter, materials, methods and techniques used for studying synthesized NPs applications are described. These NPs have been characterized by transmission electron microscopy (TEM), scanning electron microscopy (SEM), UV-visible spectroscopy, X-ray diffraction (XRD) and fourier transform infrared spectroscopy (FTIR).

2.2. MATERIALS

The following reagents and instruments were employed for the purpose of synthesis and applications of metal NPs.

2.2.1. Reagents

The following reagents were employed for the purpose of synthesis of metal NPs and their application to the removal of some selected organic pollutants.

➢ Silver nitrate (AgNO₃)

Silver nanoparticles (AgNPs) were synthesized by using AgNO₃ as precursor. A stock solution of 0.1 M AgNO₃ (Merck, Germany) was prepared by dissolving suitable amount of AgNO₃ in triple distilled water. Appropriate dilutions were made to obtain solutions in the concentration range 0.01M to 0.0001 M.
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- **Chloroauric acid ($\text{HAuCl}_4$)**

Gold nanoparticles (AuNPs) were synthesized by using $\text{HAuCl}_4$ as precursor. 0.1 M solution of $\text{HAuCl}_4$ (Aldrich, Germany) was prepared by dissolving suitable amount of triple distilled water. Then working solution was prepared by appropriate dilution.

- **Palladium chloride ($\text{PdCl}_2$)**

Palladium nanoparticles (PdNPs) were synthesized by using $\text{PdCl}_2$ as precursor. A stock solution of 0.01 M $\text{PdCl}_2$ (Merck, Germany) was prepared by dissolving suitable amount of $\text{PdCl}_2$ in triple distilled water. Appropriate dilutions were made to obtain solutions in the concentration range 0.001M to 0.0001 M.

- **Platinum chloride ($\text{H}_2\text{PtCl}_6.6\text{H}_2\text{O}$)**

Platinum nanoparticles (PtNPs) were synthesized by using $\text{H}_2\text{PtCl}_6.6\text{H}_2\text{O}$ as precursor. A stock solution of 0.1 M $\text{H}_2\text{PtCl}_6.6\text{H}_2\text{O}$ (Merck, Germany) was prepared by dissolving suitable amount of $\text{H}_2\text{PtCl}_6.6\text{H}_2\text{O}$ in triple distilled water. Appropriate dilutions were made to obtain solutions in the concentration range 0.01M to 0.0001 M.

- **Glucose**

Glucose has been used as reducing agent for NPs preparation. A 0.5 M solution of glucose (Molychem, India) was prepared by dissolving suitable amount of glucose in triple distilled water.
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- **Polyvinylpyrrolidone (PVP)**

  PVP has been used as stabilizing agent for NPs preparation. A 1% (w/v) solution of PVP (Himedia, India) was prepared in triple distilled water.

- **Sodium alginate**

  Sodium alginate is reducing and stabilizing agent used for NPs preparation. 0.2 M solution of sodium alginate (LOBA, India) was prepared by triple distilled water.

- **Calcium chloride (CaCl$_2$)**

  CaCl$_2$ is used for alginate stabilized NPs beads formation. 0.1 M CaCl$_2$ (Qualigens, India) solution was prepared in triple distilled water.

- **Methyl orange (MO)**

  MO is a model dye for removal by using AgNPs and AuNPs coated AC. A 1000 mg/L stock solutions of MO (Himedia, India) was prepared in triple distilled water. A series of working solution was prepared by appropriate dilution.

- **Congo red (CR)**

  CR is a model dye for removal by using AgNPs and AuNPs coated AC. A 1000 mg/L stock solution of CR (LOBA, India) was prepared in triple distilled water. Then working solution was prepared by appropriate dilution.
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- **Rodamine B (RB)**

RB is a model dye for removal by using alginate stabilized AgNPs beads. A 1000 mg/L solution of RB (LOBA, India) was prepared in triple distilled water. Then working solution was prepared by proper dilution.

- **Malachite green (MG)**

MG is a model dye for removal by using alginate stabilized AgNPs beads. A 1000 mg/L stock solution of MG (Himedia, India) was prepared in triple distilled water. A series of working solution was prepared by appropriate dilution.

- **Methylene blue (MB)**

MB is a model dye for removal by using alginate stabilized AgNPs beads. A 1000 mg/L stock solution of MB (LOBA, India) was prepared in triple distilled water. Then working solution was prepared by appropriate dilution.

- **Brilliant green (BG)**

BG is a model dye for removal by using monometallic and bimetallic NPs. A 1000 mg/L stock solution of BG (LOBA, India) was prepared in triple distilled water. Then working solution was prepared by appropriate dilution.
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- **Methyl violet (MV)**

MV is a model dye for removal by using monometallic and bimetallic NPs. A 1000 mg/L stock solution of MV (Himedia, India) was prepared in triple distilled water. Then working solution was prepared by appropriate dilution.

- **Alizarin red S**

Alizarin red S is a model dye for removal by using monometallic and bimetallic NPs. A 1000 mg/L stock solution of alizarin red S (LOBA, India) was prepared in triple distilled water. Then working solution was prepared by appropriate dilution.

- **Bismark brown R**

Bismark brown R is a model dye for removal by using monometallic and bimetallic NPs. A 1000 mg/L stock solution of bismark brown R (LOBA, India) was prepared in triple distilled water. A series of working solution was prepared by appropriate dilution.

- **Eosin**

Eosin is a model dye for removal by using monometallic and bimetallic NPs. A 1000 mg/L stock solution of Eosin (LOBA, India) was prepared in triple distilled water. A series of working solution was prepared by appropriate dilution.
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- **Phenol**

Phenol is a model compound for removal by using alginate stabilized AgNPs and AuNPs beads. A 1000 mg/L stock solution of phenol (Merck, Germany) was prepared in triple distilled water. A series of working solution was prepared by appropriate dilution.

- **m-Cresol**

m-Cresol is a model compound for removal by using monometallic and bimetallic NPs. A 1000 mg/L stock solution of m-cresol (Merck, Germany) was prepared in triple distilled water. Then working solution was prepared by appropriate dilution.

- **Nitrobenzene (NB)**

Nitrobenzene is a model compound for removal by using monometallic and bimetallic NPs. A 1000 mg/L solution of NB (Merck, Germany) was prepared in triple distilled water. A series of working solution was prepared by appropriate dilution.

- **Atrazine**

Atrazine is a model compound for removal by using alginate stabilized AgNPs beads. A 1000 mg/L stock solution of atrazine (Gramoxone, India) was prepared in triple distilled water. Then working solution was prepared by appropriate dilution.
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- **Sodium Hydroxide (NaOH)**

NaOH has been used for adjusting the pH of the solution at basic range. A 0.1 M NaOH (Fluka, India) solution was prepared in triple distilled water.

- **Hydrochloric acid (HCl)**

HCl has been used for adjusting the pH of the solution at acidic range. A 0.1 M HCl (Fluka, India) solution was prepared in triple distilled water.

### 2.2.2. Instruments

The following instruments/ equipments/ devices were employed for the purpose of synthesis and characterization of metal NPs; and their application to the removal of some selected organic pollutants.

- **Electronic balance**

Electronic balance is used for accurate measurement of solid compounds. An electronic balance is a device for the accurate measurement of weight. This is achieved by using a device called the load cell which acts as the transducer. The load cell is a wheatstone bridge wired to give a small but accurate voltage (usually in millivolts) to a stable electronic amplifier. The amplifier converts the millivolts to display the same as a digital display of grams or kilograms. There are additional features such as tare, total and preset which can be included in the standard scale ([http://balances.com/sartorius/gc803.html](http://balances.com/sartorius/gc803.html)). An electronic balance is a device for the accurate measurement of weight.
Figure 2.1. Sartorius electronic balance employed in the present work

A Sartorius electronic balance (Figure 2.1) with 10 µg precision (model-CP225D, AG Gottingen, Germany) was used for measurement of weight (http://balances.com/sartorius/gc803.html).

- **Micropipette**

Micropipette is used for accurate measurement of liquid compounds. Micropipette can deliver accurate and precise volumes of solution.

Variable volume (10-100) µL micropipette (Figure 2.2), Glaxo Smithkline pharmaceuticals Ltd., Finland was used for handling liquid volumes (www.siemens.com/pharma).
Domestic microwave oven

Microwave oven is used for NPs synthesis. Microwave radiation is known to have a faster heating rate than the conventional heating through conduction and convection (Yamamoto et al., 2004; Komarneni et al., 2002). The microwave radiation heats up a material through its dielectric loss, which converts the radiation energy into thermal energy.

Samsung CE2877L domestic microwave oven (850 W) (Figure 2.3) Samsung India Electronics Ltd., New Delhi, India (samsungovens.shopzilla.com).

Figure 2.2. Variable volume micropipette used in the present work

Figure 2.3. Samsung domestic microwave oven employed in the work
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Magnetic stirrer

Magnetic stirrer is used for mixing of organic species into NPs. A magnetic stirrer or magnetic mixer is a laboratory device that employs a rotating magnetic field to cause a stir bar (also called "flea") immersed in a liquid to spin very quickly, thus stirring it.

For homogenous magnetic stirring of reaction mixture 5 MLH stirrer, Remi Equipments (Figure 2.4) Pvt. Ltd., India (http://www.asilabindia.com) was employed in the present work.

Ultrasonic bath

Ultrasonic bath is used for cleaning of glasswares. An ultrasonic cleaner is a cleaning device that uses ultrasound (usually from 20–400 kHz) and an appropriate cleaning solvent (sometimes ordinary tap water) to clean delicate items. The ultrasound can be used with just water, but use of a solvent appropriate for the item to be cleaned and the soiling enhances the effect. Cleaning normally lasts between three and six minutes.
Glassware were cleaned with ultrasonic cleaning bath (Figure 2.5), Spectra lab India, model UCB-40 (www.hilsonic.co.uk) using mild detergent and after proper washing rinsed with triple distilled water.

Figure 2.5. Ultrasonic bath used in the current work

- **pH-meter**

A pH-meter is an electronic device used for measuring the pH (acidity or alkalinity) of a liquid. A typical pH meter consists of a special measuring probe (a glass electrode) connected to an electronic meter that measures and displays the pH reading.

All pH measurements of aqueous solution were carried out by Systronic types-324, digital pH-meter (Figure 2.6) (www.mt.com/pH-measurement).
Figures 2.6. pH meter used in the current work

➢ **Transmission electron microscopy (TEM)**

TEM is used for characterization of NPs. The TEM operates on the same basic principles as the light microscope but uses electrons instead of light. What we can see with a light microscope is limited by the wavelength of light. A TEM uses electron as “light source” and their much lower wavelength makes it possible to get a resolution thousand times better than that with a light microscope. We can see objects to the order of a few angstrom ($10^{-10}$ m). For example, we can study small details in the cell or different materials down to near atomic levels. The possibility for high magnifications has made the TEM a valuable tool in both medical, biological and materials research (Telkar et al., 2004).

The particle size and morphology of the NPs were characterized by Morgagni 268D TEM (Figure 2.7) operating at 80KB (Mega view III Camera CCD) at the All India Institute of Medical Sciences (AIIMS), New Delhi (www.horiba.com/scientific).
Scanning electron microscopy (SEM)

SEM is used for characterization of NPs. SEM is extremely useful for the direct observations of surfaces because they offer better resolution and depth of field than optical microscope. The SEM creates the magnified images by using electrons instead of light waves. The SEM shows very detailed 3-dimensional images at much higher magnifications than is possible with a light microscope (Liua et al., 2004). The images created without light waves are rendered black and white.

The morphology of the NPs was characterized by JEOL–JSI, model no–5600, SEM (Figure 2.8) at the National Centre for Experimental Mineralogy and Petrology, Allahabad (www.ncemp.org).
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Figure 2.8. Scanning electron microscopy employed in the work

➢ **UV-visible spectrophotometer**

UV-visible spectrophotometer is used to get absorbance spectra of NPs and organic species. The UV-visible range is a tiny part of the total electromagnetic spectrum, and is generally taken to be from wavelengths of 190 nm at the high energy UV end to about 750 nm at the red end of the spectrum (Henglein, 1993). The range is not an arbitrary assignation; rather the energies of this particular radiation are sufficiently high to promote various electron transitions within a molecule. Other regions of the spectrum correspond to different types of transitions and hence different spectroscopies. For example, IR radiation is not energetic enough to cause electron transitions. All radiation is quantised; that is to say it can only exist as discrete amounts of energy (quanta, photons in the case of light). This gives rise to the concept that the energy possessed by, say, an electron is also quantised, and thus we talk about the energy levels of the electron. The electron is able to change its energy level by gaining or losing energy, but only in amounts exactly corresponding to the difference between the two levels. So the promotion of the electron from the ground state (lowest possible energy) at energy E₁ to energy E₂ can only occur if the molecule absorbs a photon which has an energy = (E₂ - E₁). This electron at a higher energy is said to be excited and to be in an excited state. Excited states only last for very short periods of time (1 to 10
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nanoseconds), because the higher energy state is energetically unstable, and the extra energy is lost through relaxation processes such as emission of light or heat. The absorption of UV or visible radiation corresponds to the excitation of outer electrons.

Absorption spectra were recorded in a Varian Carry 50 UV-visible spectrophotometer (Figure 2.9) equipped with a peltier temperature controller unit (www.microspectra.com).

![UV-visible spectrophotometer](image)

**Figure 2.9.** UV-visible spectrophotometer employed in the work

- **X-ray diffraction (XRD)**

XRD is used for characterization of NPs. X-rays are electromagnetic radiation with wavelength of the order of $10^{-10}$ m. They are typically generated by bombarding a metal with high-energy electrons. The high-energy electron must penetrate through the outer electron shells and interact with the inner-shell (or core) electrons. If more than a critical amount of energy is transferred to an inner-shell electron, that electron is ejected; i.e. it escapes the attractive field of the nucleus, leaving a hole in the inner shell and generates ionized atom. The ionized atom can return almost to its lowest energy (ground state) by filling in the missing electron with one from the outer shells. It is this transition which is accompanied either by the emission of an X-ray (Telkar et al., 2004).
The XRD measurements were carried out using Bruker D8 Advance X-ray diffractometer (Figure 2.10) at UGC-DAE Consortium for Scientific Research INDORE-CENTRE (www.csr.res.in/xray_diffraction.html). The X-rays were produced using a sealed tube and the wavelength of X-ray was 0.154 nm (Cu K-alpha). The X-rays were detected using a fast counting detector based on silicon strip technology (Bruker-LynxEye detector).

- **Fourier transform infrared spectroscope (FTIR)**

FTIR is used for characterization of NPs. FTIR have recently replaced dispersive instruments for most applications due to their superior speed and sensitivity. They have greatly extended
the capabilities of infrared spectroscopy and have been applied to many areas that are very
difficult or nearly impossible to analyze by dispersive instruments. Instead of viewing each
component frequency sequentially, as in a dispersive IR spectrometer, all frequencies are
examined simultaneously in FTIR spectroscopy (Torres et al., 2005). The FTIR measures an
infrared spectrum by Fourier-transform of an interferogram.

*FTIR is preferred over dispersive or filter methods of infrared spectral analysis for several reasons:*

- It is a non-destructive technique.
- It can increase speed, collecting a scan every second.
- It can increase sensitivity – one second scans can be co-added together to ratio out
  random noise.
- It has greater optical throughput.
- It is mechanically simple with only one moving part.

All spectral scans in the region 4000-400 cm$^{-1}$ were made employing a FTIR (Figure 2.11)
(IR Affinity-1, Shimadzu).

*Figure 2.11. Fourier transform infrared spectroscope used in the current work*
2.3. METHODS

2.3.1. Synthesis of monometallic nanoparticles

❖ *Synthesis of silver nanoparticles (AgNPs)*

(a) In a typical procedure, the reaction solution was prepared by dissolving in a 50-ml conical flask, glucose, and AgNO₃ and PVP in triple distilled water to obtain a homogeneous reaction mixture. The mixture was irradiated in the microwave oven at a power of watt for the duration of the reaction discontinuously to prevent an increase of pressure. After irradiation, the pale yellow coloured dilute colloidal solution was cooled to room temperature for characterization.

\[
\text{AgNO}_3 (0.0001\text{M}) + \text{glucose (0.5M)} + \text{PVP (1%)} \xrightarrow{4\text{min} \atop 300\text{W}}} \text{AgNPs (pale yellow colour)}
\]

(b) The alginate stabilized AgNPs were prepared using a microwave irradiation method. To alginate stabilized AgNPs, the following procedure was adopted: Firstly the reaction solution was prepared by dissolving in triple distilled water, sodium alginate and AgNO₃ in a 50-ml conical flask to obtain a homogeneous reaction mixture. Then the flask was placed on the turntable of the microwave oven. The mixture was irradiated at a power of watt for the duration of time; the reaction was carried discontinuously to prevent an increase of pressure. After irradiation, the dilute colloidal solutions with pale yellow colours were cooled to room temperature for characterization.

\[
\text{AgNO}_3 (0.0001\text{M}) + \text{sodium alginate (0.2M)} \xrightarrow{4\text{min} \atop 300\text{W}}} \text{AgNPs (pale yellow colour)}
\]
Synthesis of gold nanoparticles (AuNPs)

(a) AuNPs were synthesized by using PVP as a protective agent and using HAuCl$_4$ as precursor and glucose as reducing agent. The reaction solution was prepared by dissolving glucose, HAuCl$_4$ and PVP in triple distilled water in a 50-mL conical flask to obtain a homogeneous reaction mixture. Then the conical was placed on the turntable of the microwave oven. The mixture was irradiated at a power of watt for duration of time. The reaction was carried out discontinuously to prevent an increase of pressure. After irradiation, the dilute colloidal solution with purple colour was cooled to room temperature for characterization.

HAuCl$_4$ (0.0001M) + glucose (0.5M) + PVP (1%) $\xrightarrow[300W \text{min}]{4 \text{min}}$ AuNPs (purple colour)

(b) In a typical procedure, the reaction solution was prepared by dissolving sodium alginate and HAuCl$_4$ in a 50-mL conical flask to obtain a homogeneous reaction mixture. Then the conical was placed on the turntable of the microwave oven. The mixture was irradiated at a power of watt for the duration of the reaction discontinuously to prevent an increase of pressure. After irradiation, the dilute colloidal solution with purple colour was cooled to room temperature.

HAuCl$_4$ (0.0001M) + sodium alginate (0.2M) $\xrightarrow[300W \text{min}]{4 \text{min}}$ AuNPs (purple colour)

Synthesis of platinum nanoparticles (PtNPs)

In a typical procedure, the reaction solution was prepared by dissolving in 50-ml conical flask glucose, H$_2$PtCl$_6$$\cdot$6H$_2$O and PVP in triply distilled water to obtain a homogeneous reaction mixture. The mixture was irradiated in the microwave oven at a power of watt for the duration of the reaction discontinuously to prevent an increase of pressure. After
irradiation, the black coloured dilute colloidal solution was cooled to room temperature for characterization.

\[
\text{H}_2\text{PtCl}_6.6\text{H}_2\text{O} (0.0005) + \text{glucose (0.5M)} + \text{PVP (1%)} \xrightarrow{3\text{min}} \xrightarrow{450\text{W}} \text{PtNPs (black colour)}
\]

**Synthesis of palladium nanoparticles (PdNPs)**

In a typical synthesis, an aqueous solution of PdCl\(_2\) was mixed with an aqueous solution of glucose and PVP in a 50-ml conical flask to obtain a homogeneous reaction mixture. Then the flask was placed on the turntable of the microwave oven. The mixture was irradiated at a power of watt for the time duration of the reaction discontinuously to prevent an increase of pressure. After irradiation, appearance of a faint black colour indicates the formation of PdNPs.

\[
\text{PdCl}_2 (0.0001) + \text{glucose (0.5M)} + \text{PVP (1%)} \xrightarrow{3\text{min}} \xrightarrow{450\text{W}} \text{PdNPs (faint black colour)}
\]

**2.3.2. Synthesis of bimetallic nanoparticles**

**Synthesis of Au/AgNPs**

The synthesis of bimetallic Au/AgNPs was carried out by mixing specific volume of HAuCl\(_4\) solution and AgNO\(_3\) solution were mixed with an aqueous solution of glucose and PVP in a 50-ml conical flask to obtain a homogeneous reaction mixture. Then the flask was placed on the turntable of the microwave oven. The mixture was irradiated at a power of watt. After complete irradiation, appearance colour indicates the formation of NPs. The prepared NPs were cooled to room temperature for characterization.
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HAuCl₄ (0.0001) + AgNO₃ (0.0001M) + Glucose (0.5M) + PVP (1%) → Au/AgNPs

\[
\text{AgNO}_3 (0.0001) + \text{H}_2\text{PtCl}_6 \cdot 6\text{H}_2\text{O} (0.0001\text{M}) \ + \ \text{Glucose} (0.5\text{M}) + \text{PVP}(1\%) \rightarrow \text{Ag/PtNPs}
\]

\[
\text{PdCl}_2 (0.0001\text{M}) + \text{AgNO}_3 (0.0001) + 450 \text{ W} \rightarrow \text{Ag/PdNPs}
\]

\[\text{AgNO}_3 (0.0001) + \text{H}_2\text{PtCl}_6 \cdot 6\text{H}_2\text{O} (0.0001\text{M}) + \text{Glucose} (0.5\text{M}) + \text{PVP}(1\%) \rightarrow \text{Ag/PtNPs}\]

\[\text{AgNO}_3 (0.0001) + \text{PdCl}_2 (0.0001\text{M}) + \text{Glucose} (0.5\text{M}) + \text{PVP}(1\%) \rightarrow \text{Ag/PdNPs}\]
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Synthesis of Au/PtNPs

The synthesis of bimetallic Au/PtNPs was carried out by mixing specific volume of HAuCl₄ solution and H₂PtCl₆·6H₂O solution were mixed with an aqueous solution of glucose and PVP in a 50-ml conical flask to obtain a homogeneous reaction mixture. Then the flask was placed on the turntable of the microwave oven. The mixture was irradiated at power of watt. After complete irradiation, appearance colour indicates the formation of NPs. The prepared NPs were cooled to room temperature for characterization.

HAuCl₄ (0.0001) + H₂PtCl₆·6H₂O (0.0001M) + Glucose (0.5M) + PVP (1%) → Ag/PtNPs

Synthesis of Au/PdNPs

The synthesis of bimetallic Au/PdNPs was carried out by mixing specific volume of HAuCl₄ solution and PdCl₂ solution were mixed with an aqueous solution of glucose and PVP in a 50-ml conical flask to obtain a homogeneous reaction mixture. Then the flask was placed on the turntable of the microwave oven. The mixture was irradiated at power of watt. After complete irradiation, appearance colour indicates the formation of NPs. The resultant Au/PdNPs solution was left to sit at room temperature.

HAuCl₄ (0.0001) + PdCl₂ (0.0001M) + Glucose (0.5M) + PVP (1%) → Au/PdNPs