Introduction
Chapter I

INTRODUCTION

1.1 Nanoparticles

Nanoparticles are defined as solid particles with a size in the range of 10-1000 nm; depending on the applied synthesis method different structural motifs can be obtained: nanoparticles, nanorods, nanowire, nanoclusters or nanospheres. The nanoparticles have drawn great attention across various areas of science and nanotechnology due to their exclusive physico-chemical properties, which are attributable to the quantum size effect and single-electron transitions. The sciences as chemistry, physics, biology, medicine and electrical engineering are becoming more and more connected with nanotechnology and strongly interrelated. (Kumar, 2010; Suh et al., 2009). When one talks about nanoparticle synthesis, characterization and their properties, it is today obligatory to consider issues related to a tight control over size, shape, crystal structure and morphological purity. Obviously, chemical composition is also critical, but important aspects in the (nano) materials science have been widely demonstrated to correlate with the morphological / structural parameters (Mudring et al., 2009).

1.2 Nanotechnology

Nanotechnology has dynamically developed as an important field of modern research with potential effects in electronics and medicine (Glomm, 2005). Nanotechnology can be defined as a research for the design, synthesis, and manipulation of structure of particles with dimension smaller than 100 nm. A new
branch of nanotechnology is nanobiotechnology. Nanobiotechnology combines biological principles with physical and chemical procedures to generate nano-sized particles with specific functions. Nanobiotechnology represents an economic alternative for chemical and physical methods of nanoparticles formation. These methods of synthesis can be divided into intra cellular and extracellular (Ahmad, 2003). Due to the outbreak of the infectious diseases caused by different pathogenic bacteria and the development of antibiotic resistance, the pharmaceutical companies and the researchers are searching for new antibacterial agents (Rai et al., 2009). In the present scenario, nanoscale materials have emerged up as novel antimicrobial agents owing to their high surface area to volume ratio and its unique chemical and physical properties (Morones et al., 2005; Kim et al., 2007). Nanotechnology is emerging as a rapidly growing field with its application in science and technology for the purpose of manufacturing new materials at the nanoscale level (Albrecht et al., 2006). A nanoparticle is by definition a particle where all the three dimensions are nanometer in scale. Nanoparticles are known to exist in diverse shapes such as spherical, triangular, cubical, pentagonal, rod-shaped, shells, ellipsoidal, etc., Nanoparticles by themselves and when used as building blocks to construct complex nanoclusters and nanoaggregates find use in a wide variety of applications in the fields of electronics, chemistry, biotechnology and medicine, just to mention few: For example, gold nanoparticles are being used to enhance electroluminescence and quantum efficiency in organic light emitting diodes; palladium and platinum nanoparticles are used as efficient catalysts; glucose sensors are developed based on silver nanoparticles; and iron oxide nanoparticles are used as contrast agents in diagnosing cancer in Magnetic Resonance Imaging (MRI).

Nanotechnology has an immense potential to create a wide range of novel, exciting and interesting applications for environment and other sectors like
medicines, electronics and communication. Optical properties of nanosized semiconductor crystallites could be changed so that they are different from their corresponding bulk materials. This is the so-called quantum confinement effect, which is observed as a blue shift in UV spectra with decreasing of particle size (Yu et al., 2010). Today, nanotechnology (NT) is operating in various fields of science via its operation for materials and devices using different techniques at nanometer scale. Nanoparticles are a part of nanomaterials that are defined as single particles with 1–100 nm in diameter. From the last few years, nanoparticles have been a common material for the development of new cutting-edge applications in communications, energy storage, sensing, data storage, optics, transmission, environmental protection, cosmetics, biology, and medicine due to their important optical, electrical, and magnetic properties.

Recently, nanoscience has taken up the cause of a new dimension. Nanotechnology is involving the production, manipulation and use of materials managing in size less than a micron to an individual atom. Although nanomaterials can also be synthesized using chemical approaches. The biological method preferred for various reasons. It is now possible to include the use of fungi, bacteria and other biological materials. Silver is a soft, white, lustrous transition metal having very high electrical and thermal conductivity. The metal occurs naturally in its pure, free form (native silver), as an alloy with gold and other metals and in minerals such as argentite and chlorargyrite. Most silver particles are produced as a by-product of copper, gold, lead and zinc refining methods (Jing et al., 2009).

1.3 Properties of Nanoparticles

A bulk material should have constant physical properties regardless of its size, but at the nanoscale size-dependent properties are often observed. Thus, the
properties of materials change as their size approaches the nanoscale and as the percentage of atoms at the surface of a material becomes significant. For bulk materials larger than one micrometer (or micron), the percentage of atoms at the surface is insignificant in relation to the number of atoms in the bulk of the material. The interesting and sometimes unexpected properties of nanoparticles are therefore largely due to the large surface area of the material, which dominates the contributions made by the small bulk of the material. Nanoparticles of usually yellow gold and gray silicon are red in color; gold nanoparticles melt at much lower temperatures (nearly 300°C for 2.5 nm size) than the gold slabs (1064 °C); and absorption of solar radiation in photovoltaic cells is much higher in materials composed of nanoparticles than it is in thin films of continuous sheets of material, the smaller the particles, the greater the solar absorption. Suspensions of nanoparticles are possible since the interaction of the particle surface with the solvent is strong enough to overcome density differences, which otherwise usually resulting a material either sinking or floating in a liquid (Yadav et al., 2007). Nanoparticles also often possess unexpected optical properties as they are small enough to confine their electrons and produce quantum effects. For example, gold nanoparticles appear deep red to black in solution. The high surface area to volume ratio of nanoparticles provides a tremendous driving force for diffusion, especially at elevated temperatures. Moreover, nanoparticles have been found to impart some extra properties to various day to day products. For example, the presence of titanium dioxide nanoparticles imparts what we call the self-cleaning effect, and the size being nanorange, the particles cannot be observed. Zinc oxide particles have been found to have superior UV blocking properties compared to its bulk substitute. This is one of the reasons why it is often used in the preparation of sunscreen lotions.
1.4 Advantages of Nanoparticles

The advantages of using nanoparticles include the following: Particle size and surface characteristics of nanoparticles can be easily changed to achieve both passive and active drug targeting after parenteral administration. They control and sustain release of the drug during the transportation and at the site of localization, altering organ distribution of the drug and subsequent clearance of the drug so as to achieve increase in drug therapeutic efficiency and reduction in side effects. Drug loading is relatively high and drugs can be incorporated into the systems without any chemical reaction; this is an important factor for preserving the drug activity. Site-specific targeting can be achieved by attaching targeting ligands to surface of particles or use of magnetic guidance. The system can be used for various routes of administration including oral, nasal, intraocular etc (Taghvaei et al., 2010).

1.5 Application of Nanoparticles

Nanoparticles have been extensively investigated due to the attraction of their unique physical properties, chemical reactivity, and potential applications with high academic and industrial impacts (Jing et al., 2009; Craighead, 2000). Usually when metal nanoparticles are prepared by chemical methods, the metal ions reduced by the reducing agents and a protective agent or phase transfer agents are also added to stabilize the nanoparticles (Bonneman et al., 1998). Several types of toxic reducing agents containing boron commonly have been employed to produce metal nanoparticles from inorganic salts; the resulting metal nanoparticles are contaminated with borides. This allows for the preparation of boride free metal nanopowders especially for use in biological and medical purposes.
One of the most important environmental applications of nanomaterials is their use as sensors with enhanced monitoring capabilities for pollutants. They are used for treating contaminated water, soil or air and in green technologies to eliminate or decrease harmful emissions and wastes from industry using photo catalytic processes. Heterogeneous photocatalysis is a good method for the decontamination and mineralization of organic pollutants because of its high efficiency, low energy consumption and satisfactory environmental compatibility. As an important II-VI semiconductor \((E_g = 2.42 \text{ eV})\), CdS has promising applications in many technical fields including mechanical and optoelectronic fields, and use in solar cells, and the photo degradation of water pollutants \((Yu \ et \ al., \ 2010)\). The preparation of CdS nanoparticles has become a very popular research area in recent years \((Taghvaei \ et \ al., \ 2010)\).

### 1.6 Limitations of Nanoparticles

In spite of these advantages, nanoparticles do have limitations. For example, their small size and large surface area can lead to particle aggregation, making physical handling of nanoparticles difficult in liquid and dry forms. In addition, small particles size and large surface area readily result in limited drug loading and burst release. These practical problems have to be overcome before nanoparticles are made commercially available.

The application of nanoscale materials and structures, usually ranging from 1 to 100 nanometers (nm), is an emerging area of nanoscience and nanotechnology. Nanomaterials may provide solutions to technological and environmental challenges in the areas of solar energy conversion, catalysis, medicine, and water treatment \((Anastas \ and \ Warner, \ 1988)\). This increasing demand must be accompanied by “green” synthesis methods. In the global efforts to reduce generated hazardous
waste, “green” chemistry and chemical processes are progressively integrating with modern developments in science and industry. Implementation of these sustainable processes should adopt the twelve fundamental principles of green chemistry. These principles are geared to guide in minimizing the use of unsafe products and maximizing the efficiency of chemical processes. Hence, any synthetic route or chemical process should address these principles by using environmentally benign solvents and nontoxic chemicals.

1.7 Green Chemistry

Green chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products (Anastas and Warner, 1998). Upon hearing the word "green chemistry" for the first time, one might get the impression that it deals with chemistry involving plants. In fact, green chemistry encompasses several science fields. But more than anything else, it is a philosophy of constantly searching for ways to do things better and cleaner (Rajendran, 2013).

Sustainability is increasingly an important issue in the wider context dealing with population, health, environment, energy, technology, renewable resources, and, in the sciences, as an integral part of the rapidly emerging field called ‘green chemistry’ (Kumar, 2009). This is a multidisciplinary field, requiring integrated study in the chemical, biological and physical sciences as well as many aspects of engineering. Even nanotechnology is important in green chemistry, providing a way of dematerializing society while providing the benefits of technology (Okafer et al., 2013). The twelve principles of Green Chemistry, as defined by Anastas and Warner, and generally accepted internationally, cover complex issues including waste minimization, reduction in energy usage, and the
use of renewable resources rather than depleting natural resources such as oil, coal and gas. Biocatalysis is an important area of green chemistry providing a means of converting biomass, a renewable resource, into commodity chemicals. In the chemical sciences, there is a need to develop benign synthetic pathways which, in addition to being high yielding (historically the most important measure of the success of a reaction), are simple and exhibit high atom efficiency, hence a reduced number of steps and no waste, are safe, and are environmentally acceptable (Anastas and Warner, 1998). The emergence of green chemistry has resulted in a paradigm shift in the way chemists develop processes and products, and requires the development of a green chemistry toolbox. Removing organic solvents in chemical synthesis is important in the drive towards benign chemical technologies. Organic solvents are high on the list of toxic or otherwise damaging compounds because of the large volumes used in industry, and difficulties in containing volatile compounds (Rajendran and Priyadarshini, 2010). Replacement reaction media include ionic liquids (which have extremely low vapor pressure and can be recycled), liquid and supercritical CO$_2$, water (often at high temperature under microwave irradiation), and polyethylene and polypropylene glycol (Keskin et al., 2007). The choice of solventless or specific non-organic solvent reaction medium will depend on several issues, including selectivity, stereochemistry, yield, and waste, and viscosity, eases of recycling, energy usage, and ease of isolation of product, competing reactions, and heat of reaction (Rajendran et al., 2011). In using a reaction medium, there are many choices within each system, for example using ionic liquids with the appropriate hydrophobic–hydrophilic balance, and varying the density of liquid and supercritical CO$_2$, which can affect the stereo chemical outcome of addition reactions. Advantages in using solventless reactions, particularly those described herein, relative to using organic or other reaction media include: (i) there is no reaction medium to collect, purify and recycle, (ii) the compounds formed are often
sufficiently pure to circumvent extensive purification using chromatography, and indeed in some cases the need for recrystallization, (iii) sequential solventless reactions are possible in high yielding systems, (iv) the reactions can be rapid, often reaching substantial completion in several minutes compared to hours in organic solvents, (v) there is often no need for specialized equipment, (vi) energy usage can be much lower, (vii) the need for pre-formed salts and metal–metalloid complexes may often be dispensed with, (viii) functional group protection–deprotection can be avoided, (ix) lower capital outlay for equipment in setting up industrial processes, and (x) considerable batch size reduction and processing cost savings are achievable such that such solvent-free protocols are not only more environmentally benign but are also more economically feasible. This is one of the original considerations in bringing green chemistry to the forefront (Rajendran, 2013).

1.7.1 Origin of Green Chemistry

Green Chemistry traces its origin in the Pollution Prevention Act (PPA) of 1990. Its main objective is the prevention of pollution at the source level itself rather than the treatment of pollutants after they are formed. This goal became the prime objective of the Environmental Protection Agency (EPA) in 1991. Kenneth Hancock of the National Science Foundation (NSF) and Joe Breen are the most prominent and early advocates of green chemistry, the latter after twenty years of service at the Environment Protection Agency (EPA) became the first director of the Green Chemistry Institute (GCI), USA during the late 1990s.

1.7.2 Principles of Green Chemistry

The famous twelve principles of green chemistry were charted by the scientists Anastas and Warner in 1998. These serve as guidelines for chemists
seeking to lower the ecological footprint of the chemicals they produce and the processes by which such chemicals are made (Anastas and Warner, 1998). The 12 principles are:

1. **Prevention:**

   It is better to prevent waste than to treat or clean up waste after it has been created.

2. **Atom Economy:**

   Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. **Less hazardous chemical syntheses:**

   Wherever practicable synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. **Designing safer chemicals:**

   Chemical products should be designed to preserve efficacy of function while minimizing their toxicity.

5. **Safer solvents and auxiliaries:**

   The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

6. **Design for energy efficiency:**

   Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Use of renewable feedstock:
   A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. Reduce derivatives:
   Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. Catalysis:
   Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. Design for degradation:
   Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. Real-time analysis for pollution prevention:
   Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. Inherently safer chemistry for accident prevention:
   Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions and fires.
Therefore, green chemistry is a tool not only for minimizing the negative impact of those procedures aimed at optimizing efficiency, although clearly both impact minimization and process optimization are legitimate and complementary objectives of the subject. Green chemistry, however, also recognizes that there are significant consequences to the use of hazardous substances, ranging from regulatory, handling and transport, and liability issues, to name a few. To limit the definition to deal with waste only would be to address only part of the problem. Green chemistry is applicable to all aspects of the product life cycle as well. Finally, the definition of green chemistry includes the term “hazardous”. It is important to note that green chemistry is a way of dealing with risk reduction and pollution prevention by addressing the intrinsic hazards of the substances rather than those circumstances and conditions of their use that might increase their risk (Anastas and Warner, 1998).

1.7.3 Application of Green Chemistry in Various Industries

Pharmaceuticals

Ibuprofen is the active ingredient in many analgesic and inflammatory drugs such as Advil, Motrin, and Medipren. Beginning in the 1960s, ibuprofen was produced by a six-step synthesis with an atom economy of only 40 percent. This means that less than half (40 percent) of the weight of all the atoms of the reactants are incorporated in the ibuprofen, and 60 percent are wasted in the formation of unwanted by-products. The annual production of approximately 30 million pounds of ibuprofen by this method resulted in over 40 million pounds of waste. But during the 1990s, the BHC company developed a new synthesis of ibuprofen with an atom economy of 77 to 99 percent. This synthesis not only produces much less waste, it is
also only a three-step process. A pharmaceutical company can thus produce more ibuprofen in less time and with less energy, which results in increased profits.

**Pesticides**

Dichlorodiphenyltrichloroethane (DDT) is one of the most well-known insecticides. During World War II, it saved thousands of allied lives by killing disease-carrying insects, but during the 1960s, the significant environmental damage caused by DDT was brought to the public's attention by Rachel Carson in Silent Spring (1962). As a result of the controversy generated by this book and other media coverage, the substance's use was banned in the United States in 1973. During the 1960s and 1970s organophosphates largely replaced organo-chlorine pesticides such as DDT. These pesticides rapidly degrade in the environment, but they are much more toxic to mammals. They are deadly to a wide array of insects and kill not only the target organism but also beneficial insects, such as bees and predatory beetles, and are harmful to humans also.

One approach to producing less environmentally harmful pesticides is to use compounds that destroy only the target organisms. One manufacturer, Rohm and Haas, has developed insecticides that mimic a hormone used only by molting insects. Insects that do not molt are not affected, leaving many beneficial insects unharmed. A more recent strategy for protecting plants from pests and disease involves the use of genetically altered plants. This method is controversial.

Another approach to protecting plants from pests and diseases is to activate their natural defense mechanism against pests or diseases. EDEN Bioscience Corporation has developed what is known as harpin technology. Harpin is a naturally occurring protein that is isolated from genetically altered bacteria. When
applied to the leaves and stems of plants, this protein elicits their natural defense systems. The EPA has classified harpin as Category IV, which is reserved for materials with the lowest hazard potential. As an added benefit, harpin also stimulates plant growth.

**Polymers**

Synthetic polymers or plastics are everywhere. They are used in cars, computers, planes, houses, eyeglasses, paints, bags, appliances, medical devices, carpets, tools, clothing, boats, batteries, and pipes. More than 60 million pounds of polymers are produced in the United States each year. The feed stocks that are used to produce these polymers are virtually all made from petroleum, a non-renewable resource. Approximately 2.7 percent of all crude oil is used to generate chemical feedstock.

In order to decrease human consumption of petroleum, chemists have investigated methods for producing polymers from renewable resources such as biomass. Nature Works polylactic acid (PLA) is a polymer of naturally occurring lactic acid (LA), and LA can be produced from the fermentation of corn. The goal is to eventually manufacture this polymer from waste biomass. Another advantage of PLA is that, unlike most synthetic polymers which litter the landscape and pack landfills, it is biodegradable. PLA can also be easily recycled by conversion back into LA. It can replace many petroleum-based polymers in products such as carpets, bags, cups, and textile fibers.

**Computer Chips**

The manufacture of computer chips requires excessive amounts of chemicals, water, and energy. Estimates indicate that the weight of chemicals and
fossil fuels required to make a computer chip is 630 times the weight of the chip, as compared to the 2:1 ratio for the manufacture of an automobile. Scientists at the Los Alamos National Laboratory have developed a process that uses supercritical carbon dioxide in one of the steps in chip preparation, and it significantly reduces the quantities of chemicals, energy, and water needed to produce chips.

**Dry Cleaning**

Condensed phase carbon dioxide is also used as a solvent for the dry cleaning of clothes. Although carbon dioxide alone is not a good solvent for oils, waxes, and greases, the use of carbon dioxide in combination with a surfactant allows for the replacement of perchloroethylene (which is the solvent used most often to dry clean clothes, although it poses hazards to the environment and is a suspected human carcinogen).

**Nanochemistry**

Metallic nanoparticles exhibit novel dimension-dependent properties leading to attractive applications in catalysis, optoelectronics, and environmental remediation. Metallic nanoparticles of specific sizes and morphologies can be readily synthesized using various chemical and physical methods. However, most of these methods use aggressive reducing agents, toxic solvents, and non-biodegradable stabilizing agents, or have high energy consumption, and as such pose potential environmental and biological risks (Manas and Pleixats, 2003). Biological methods using plant extracts and microorganisms have been proposed as alternative environmentally friendly methods in the synthesis of metallic nanoparticles. Biomolecules can function as both reducing and capping agents, eliminating the use and generation of substances hazardous to human health and the
environment. Moreover, biological methods can afford completely green synthetic protocols if environmentally benign solvents are employed in the extraction process. Thus, metallic nanoparticles synthesized using biological methods may find widespread technological and medicinal applications. Noble metals such as gold, silver, and platinum are extensively used for jewelry and in various biomedical applications, including drug delivery, imaging, photo thermal therapy, and immune chromatography. Consequently, there is a growing need to synthesize noble metal nanoparticles using methods that do not involve toxic chemicals. Gold and silver nanoparticles have been synthesized using various plant extracts, including hibiscus (*Hibiscus rosasinensis*) leaf extract black tea leaf extract (Kamat, 2002). The size of the nanoparticles was controlled by varying the concentration of the lemon grass extract in the reaction medium. The average size of triangular and hexagonal particles decreased with increasing concentration of the lemon grass extract. Additionally, the ratio of the number of spherical nanoparticles to triangular / hexagonal particles in the reaction medium increased with increasing concentration of the lemon grass extract. Gold nano triangles were also synthesized using tamarind (*Tamarindus indica*).

1.8 Green Chemicals

1.8.1 Ionic Liquids (ILs)

Green chemicals are a class of compounds that are biodegradable. Ionic liquids have emerged as a class of material, having properties that make them green solvents which had found applications in a large number of organic transformations (Rajendran and Priyadarshini, 2010; Yung *et al.*, 2011; Shelton *et al.*, 2009). Ionic liquids (ILs) consist of cations and anions and are commonly understood as one of the green solvents. Ionic liquids are the salts with the melting point below 100°C.
Due to their higher complexity and larger dimensions of the ions (generally large organic cations and inorganic anions), the crystalline structure is energetically not favored and the salt becomes liquid. However, the ionic liquid can be solidified at low temperature (Figure 1).

The following are some of the examples of organic cations and inorganic anions that form ionic liquids

![Ionic liquid structures](image)

Ionic liquids (ILs), commonly termed room temperature ionic liquids (RTILs), are a class of organic slats. These molecules typically contain an organic cation with delocalized charge and a bulky inorganic anion.
Interest in RTILs continues to grow because of their potential as greener solvent alternatives to conventional environmental damaging organic solvents. Ionic liquids (ILs), also known as molten salts with melting point under 100 or 150° C, have attracted an increasing attention in the context of green synthesis in recent years. Even though, ionic liquids were initially introduced as an alternative green media because they are room temperature molten salts that are nonvolatile, thermally stable, recyclable, and easy to handle, they have marched far beyond showing their significant catalytic activities for many reactions (Sahoo et al., 2006).

Ionic liquids represent new-generation chemistry with potential use in various market segments, e.g. in the chemical, bio-chemical, or pharmaceutical industries. Academic and industrial researchers have now realized the importance and advantages of ionic liquids over other conventional solvents. With our comprehensive and continuously growing knowledge of ionic liquids achieved by cutting-edge research and co-operations with various academic and industrial partners, we can successfully support the chemical world in the development of
competitive processes. The availability of a great variety of different cations and anions give ionic liquids their numerous unique properties, making them suitable for very different applications in chemical, bio-chemical, pharmaceutical and technical industries. A virtually endless number of chemical compositions open up a wide spectrum of possibilities, offering considerable safety and efficiency benefits (Wang et al., 2006).

The following are the important properties of ionic liquids; they

- Are non-volatile (negligible vapor pressure).
- Are non-flammable and non-explosive.
- Have a high solvation capacity for various materials.
- Can have a broad electro-chemical window of up to 6 V.
- Have a high thermal stability.
- Are liquid over a wide temperature range.

1.8.2 Classification of Ionic Liquids

Classification on the basis of pH

They are broadly classified into the following three types on the basis of their physical and chemical properties (like pH)

1. **Acidic ionic liquids**

   Example: Silica sulphuric acid

2. **Basic ionic liquids**

   Example: 1-n-Butyl-3-methylimidazoliumhydroxide [BMIM] OH
3. **Neutral ionic liquids**

Example: 1-Ethyl-3-methylimidazolium chloride [EMIM] Cl

**Classification on the basis of temperature**

Based on the physical nature (liquid nature) with respect to temperature, they are classified into the following 1. Room Temperature Ionic Liquids [RTILs] and 2. Low Temperature Ionic Liquids [LTILs]

**Room Temperature Ionic Liquids (RTILs)**

Room temperature ionic liquids (RTILs) are salts with melting points lower than 25°C. They look like a classical liquid but they do not contain any molecules; they are made of ions. The structure of these liquids is completely different from the structure of any other solvents made of molecules (Jing et al., 2009). The properties of a given solvent depend on the interaction between the solvent molecules. If there are strong interactions between the solvent molecules, the solvent is called a “polar” solvent, e.g. water, methanol, ethanol. If the interactions between the solvent molecules are weak, it is an “apolar” solvent, e.g. hexane, heptane, petroleum ether. The great originality of RTILs is that they are not made of molecules. Ions are present in the liquid with an exactly equal number of positive and negative ions so that the whole liquid is electrically neutral. Ionic liquids are known for decades, but they were molten salts at very high temperature, e.g. the melting points of sodium, potassium, aluminum and calcium chloride are respectively 801, 770, 190 and 782°C. Most organic molecules are decomposed at these elevated temperatures. The potential of the new solvent class of ionic liquids at room temperature is actively investigated. The first RTIL was discovered during World War I, in 1914, looking for new explosives. It was ethyl ammonium nitrate with a melting point of 12°C. In the eighties, Seddon and coworkers started to use RTILs as non-aqueous polar-like solvents for electrochemical and spectroscopic studies of transition metal complexes. Typically, RTIL consists of nitrogen- or phosphorous containing organic
cations and large organic or inorganic anions. Bulky organic cations such as $N$-alkylpyridinium and 1-alkyl-3-methylimidazolium are combined with inorganic anions such as $\text{Cl}^-$, $\text{Br}^-/\text{AlCl}_3$, $\text{NO}_3^-$, $\text{PF}_6^-$ and $\text{BF}_4^-$. Less common anions include bis(trifluoromethanesulfonyl) imide ($\text{CF}_3\text{SO}_2\text{N}^-$) and trifluoromethanesulphonate ($\text{CF}_3\text{SO}_3^-$). The combination of such cations and anions can lead to a large number of ionic liquids that provide considerable flexibility in the selection of the most suitable pair for a specific chemical application. The main physicochemical properties of RTILs are: (i) under an inert atmosphere, they remain liquid over a temperature range of 200 to 300°C; (ii) they have practically no vapor pressure; (iii) they are reported to have a wide window of electrochemical stability, good electrical conductivity, high ionic mobility and excellent chemical stabilities. With all these properties, it is hoped that they can act as “green solvents” and they will replace volatile organic solvents in several chemical reactions (Keskin et al., 2007).

**Low Temperature Ionic Liquids (LTILs)**

Low temperature ionic liquids are those which exist as liquids even below room temperature (below 130 Kelvin). These have been proposed as the fluid base for an extremely large diameter spinning liquid mirror telescope to be based on the earth's moon. Low temperature is advantageous in imaging long wave infrared light which is the form of light (extremely red-shifted) that arrives from the most distant parts of the visible universe. Such a liquid base would be covered metallic film that forms the reflective surface. A low volatility is important for use in the vacuum conditions present on the moon (Rajendran, 2013).

**OTHER TYPES**

**Task specific ionic liquids**

The synthesis of ionic liquids (ILs), their characterization, and possible applications have been developing progressively, as the properties of this class of organic salts with melting points below the boiling point of water have gained
intensive attention in nearly all fields of chemistry, furthermore, through the incorporation of functional groups, the synthesis of task specific ionic liquids (TSILs) has been a focus of research leading to tailor made substances for desired applications. A wide spread research field is the use of ILs as well as TSILs incorporating disulphide-, thioether-, urea-, or hydroxybenzylamine groups as extracting agents for metals. Most of ILs or TSILs for extracting applications described in the literature are based on imidazolium-, piperdinium-, pyrrolidinium- and pyridinium cations and fluorine containing anions, whereas diverse functional groups are generally appended to the cation. In contrast, the newly synthesized ILs described here is based on a hydrophobic, long chain tetraalkylammonium cation with aliphatic and aromatic carboxylate anions. An example of this type is tricaprylmethylammoniumchloride (Visser et al., 2002).

Benefits of Ionic Liquids

- Increase of process safety by excluding volatile organic chemical (VOC) emission in chemical processes.
- Increase of reaction rates, reaction selectivity and yield.
- Tunable miscibility with water and inorganic solvents.
- Tailoring ionic liquids to optimize our chemical processes
- Recoverable and reusable
- They form hydrogen bond system in the liquid state so that they are very helpful for the self assembly of nanoscale structures.
REFERENCES


