INTRODUCTION

Material science is an area of science which is instrumental in up-gradation of human life and lifestyle. The innovation in materials with enthralling applications has played a dynamic part in technological developments. The arrival of nanotechnology has brought a new revolution in the field of material science.

Nanotechnology and nanomaterials have emerged as a core of scientific inventions and discoveries from last couple of decades. May it be in the field of electronics, catalysis or biomedical applications, nanomaterials have left their footprints at all places. From miniaturisation of equipments, to developing new gadgets, nanomaterials have made a huge contribution in adding ease and smartness to human life.

The concept of nanotechnology was first introduced by physicist Richard P. Feynman in his talk titled “There’s Plenty of Room at the Bottom” at an American Physical Society meeting at Caltech in 1959 [1]. The technological significance of nanoscale phenomena and its devices was promoted by Dr. K. Eric Drexler in 1980 and the term nanotechnology acquired its current sense [2, 3]. However, in heterogeneous catalysis field obtaining high surface was always a challenge for better catalytic activity, but high surface area would achieve if the particles are in nano size. Even Physicist showed the concept of nanotechnology; which was widely used in heterogeneous catalysis.

It first instigated with manipulating size in the scale of nanometre. The unit of nanometre is drawn from its prefix ‘nano’ a Greek word meaning dwarf or extremely small. This followed the research on various possible shapes that could be obtained preserving the nanometre size. From spherical particles to cubes, rods to wires, crystals to
thin films [5-9] nanotechnology has excelled in its entire facet. It has not just paved path
to the interdisciplinary research but at the same time has strengthen it. Ability to control
and manipulate materials at atomic and molecular levels thereby understanding their
fundamental processes has led to the future advancement and innovations.

Nano-materials can be pure metals, ceramics, polymeric materials or composite
materials. The size constraints often produce qualitatively new behaviour which can be
even contradictory to the same material in micro-scale. It is not just reducing size but all
together formation of a new material with unique functionalities. Oxide nano-materials
are imperative part of this ever growing field of nanotechnology. It has emerged as an
important class of materials with a rich collection of properties and great potential for
device applications. These include; transparent electrodes, high-mobility transistors, gas
sensors, photovoltaic’s, photonic devices, energy harvesting, storage devices and non-
volatile memories [10].

Pristine and doped metal oxides such as ZnO, TiO$_2$, Cr$_2$O$_3$, Mn$_2$O$_3$, Co$_3$O$_4$, NiO,
CuO, SnO$_2$, In$_2$O$_3$, Fe$_2$O$_3$, Y$_2$O$_3$, Bi$_2$O$_3$, spinels, perovskites etc. with different size and
shapes have been explored for their properties and applications, this research has been
growing exponentially over the years. It has pioneered the new areas in field of chemical
science.

Dilute Magnetic Semiconductors (DMS) is one of the phenomena recently
associated with metal oxides and nanostructures. In semiconductor devices, charge of
electrons play a major role, on the other hand magnetic materials are more focussed on
the orientation of electron spin. For the development of new electronics both, charge and
spin of electrons are focussed where the spin of electrons that carries the information can
be used as an added degree of freedom in novel electronic devices. Such devices are
known as Spintronics (or spin-based electronics) [11]. Discovery of ferromagnetism in the Mn-doped III–V semiconductors (In, Mn)As and (Ga, Mn)As stimulated the DMS phenomena [12–14]. Diluted Magnetic Oxides (DMO) is a type of DMS materials where a magnetic impurity is added to a diamagnetic host. Transition metal doped ZnO, CeO₂, TiO₂, Ga₂O₃, SnO₂ and In₂O₃ [15, 16] have been the materials of interest in this field. Many reports are available on existence of room temperature ferromagnetism in these metal oxides. Presently the existence and origin of ferromagnetism in DMS has caught the eyeballs of researchers all over the world. In the present study pristine and doped (Co, Cr and Ag) indium oxide and indium doped CeO₂ nanoparticles have been explored for their dilute magnetic properties.

Magnetic nano-ferrites is yet another class of magnetic materials which finds its application in computer memory chips, high density recording media, high frequency transformers, heterogeneous catalysis etc. [17-20]. Super-paramagnetism is one such exceptional property of magnetic nanoparticles that is significant in modern technology including magnetic resonance imaging, ferro-fluids, magneto-caloric refrigeration, drug delivery and so on [21-25]. Investigation of the basics of magnetism in nano-size which would stimulate some unique properties that can be tailored for the future application is a challenging field. In the present work we have focussed on the magnesium ferrite preparation and characterisation, where variations in its magnetic properties are studied on doping with indium.

Catalysis is one of the fundamental fields of research in chemistry. A catalyst has the ability to increase the rate of a reaction by lowering the activation energy. Heterogeneous catalysis is a type of catalysis in which a catalyst is insoluble in solvent or reaction mixture. Advent of nano-materials has served as a boon to catalytic field. Nano-
materials render a high surface area owing to reduction in size. This property can be very well exploited in the field of catalysis. Metal oxide nanomaterials have been extensively utilized as heterogeneous catalyst in various reactions including detoxification of exhaust gases [27], degradation of dyes by photo-catalysis [28] and several organic transformations [26]. The important property of the heterogeneous catalyst is that it can be recycled and used over and over again. The high surface area makes it feasible to use lower concentrations of catalyst, thus making the process faster as well as economical.

Use of magnetically separable catalyst adds yet another simplicity and ease to the process and has been a topic of interest among the researchers in recent past. Magnetically separable catalyst can be easily separated from the reaction mixture thus can be easily recycled. We have shown the application of the prepared nanoparticles in the field of heterogeneous catalysis for CO oxidation and few organic transformations.

Use of nanotechnology in biomedical field has fascinated the scientific community over several years and their potential applications have increased in the last decade owing to their exceptional optical properties, oxidation resistance and high penetration. Nano-materials have displayed their key role in antimicrobial activity, diagnostics and recently in enzyme inhibition. Owing to the small size of nanoparticles they are highly used as drug delivery agents, thereby targeting the specific cells. Further improvements are brought about in the activity of nanoparticles by functionalising. The nanoparticles are functionalised by organic components and then used for desired application such as target specific reactions [29]. In the present work we have explored the enzyme inhibition activity of Ag doped In$_2$O$_3$ nanoparticles against alpha-amylase and alpha- glucosidase enzyme.
Nanoparticles, despite showing the captivating applications in biomedical fields are accompanied with a toxicity risk. The small size which serves as a boon for several applications may also prove to be a limitation in certain situations if found toxic by retaining in the body. This motivated us to carry out the toxicity studies of few of our samples employed for biomedical and catalytic applications.

Synthesis plays a key role in governing the applications of nano-materials. Designing a profound preparative method that would yield the nanoparticles with desired shape and size is all together an amazing science. Optimising a preparative method for such a shape or size directional synthesis can be simple as well as complex. The two well known approaches for the synthesis of nano-materials include top down where a bulk material is cut down to get nano-sized particle while another is bottom up where starting from atomic level the material is grown into nanoparticle. Both the approaches are widely used and both encompass their own pros and cons. Chemical synthesis is a widely used bottom up approach for synthesizing nanoparticles. Various methods have been reported in literature of chemical synthesis viz co-precipitation [30], precursor [31], sol-gel [32], hydrothermal [33], chemical vapour deposition [34], micro-emulsion [35] combustion [36, 37] etc.

Considering the case of metal oxide nanoparticles, incorporating the metal ions as dopants and thereby manipulating its properties directing towards a particular application has led to several new inventions. In the present work, combustion and sol-gel are the two techniques employed for the nanoparticle preparation. The prepared nanoparticles are thoroughly characterised by employing several spectroscopic and microscopic techniques and their application in the magnetic, catalytic and biomedical field has been explored.
The emergence of nanotechnology and adaptation of its fundamental processes for the betterment of society has developed as the prime function of scientists and researchers worldwide. The growth in this field has been exponential and the output has been enormous. This period might be recognised as nanotechnology era in the coming years. In view of curiosity generated for learning the facts and processes that nano-materials and its applications brings, the work presented in the thesis has been carried out. It is the aura of this field that has motivated us for this work.

**Highlights of the Thesis**

- Pristine, and Co, Cr and Ag doped indium oxide nanoparticles have been prepared by glycine combustion method while pristine, and In doped CeO$_2$ and MgFe$_2$O$_4$ nanoparticles have been prepared by sol-gel method using citric acid.
- The prepared compounds have been characterised by X-ray diffraction (XRD), Thermal analysis (TG-DTA/DSC), Infrared spectroscopy (IR), UV-Visible Diffuse reflectance spectroscopy and X-ray photoelectron spectroscopy. Scanning and Transmission electron microscopy has been used to study morphology and size of the metal oxides.
- DC- electrical resistivity studies has been carried out on two probe electrical resistivity set up and magnetic properties of the compounds are studied using Vibrating Sample Magnetometer (VSM). AC susceptibility and Mössbauer analysis has been carried out for In doped MgFe$_2$O$_4$ compounds.
- The prepared compounds have been investigated for their catalytic activity in CO oxidation and few organic transformations.
- Pristine and Ag doped In$_2$O$_3$ nanoparticles have been explored for *In vitro* enzyme inhibition activity. The toxicity studies are also reported for Co and Ag doped indium oxide compound.
Organisation of thesis

The present thesis is divided into following chapters:

**Chapter 1. Introduction:** Brief introduction about the metal oxide nano-materials, and their importance is highlighted.

**Chapter 2. Literature Review:** Literature studies highlighting the work carried out on the systems presented in the thesis

**Chapter 3. Experimental and characterisation techniques:** Details of synthetic procedures and characterisation techniques employed.

**Chapter 4. Spectroscopic and solid state studies:** Different spectroscopic analysis and magnetic studies carried out on the compounds are highlighted.

**Chapter 5. Catalytic and biomedical applications:** This chapter discusses the application of prepared nanomaterials in catalytic CO oxidation, organic transformations and enzyme inhibition; also toxicity studies of few compounds are reported.

**Chapter 6. Summary and Conclusion:** In this chapter the results are summarised and based on them the conclusions are derived.