Chapter VI

Conclusions

This chapter contains conclusions of the salient features of the work described in this thesis and the scope for future potential developments in this field.
6.1 Summary of the work

The work presented in this thesis mainly focuses on biological methods for the synthesis of nanomaterials and their toxicity evaluation. All this has been described in different chapters and the summary for each chapter has been described here.

The bacterium *Actinobacter* spp. was isolated as a contaminant from a mixture of K$_4$Fe(CN)$_6$ and K$_3$Fe(CN)$_6$ left open for one week. It has been used for the synthesis of different technologically important nanomaterials such as Si/SiO$_2$ nanocomposites, TiO$_2$ and ZnO nanoparticles under environmentally benign conditions. The known chemical and physical methods for synthesis of these nanomaterials involve high temperature and pressure. In contrast to that the method we report is an attractive alternative to such methods. Elemental silicon embedded within SiO$_2$ matrix (Si/SiO$_2$ nanocomposites) has several applications in photonic devices. We have shown that two proteins reductases and hydrolases secreted by the bacteria probably lead to the reduction of Si$^{4+}$ to Si$^0$ and subsequently to SiO$_2$. Other oxides (TiO$_2$ and ZnO) have also been extensively used for different applications and probably are the first ones to be used at market level as photocatalytic and UV-absorbent agents. Since visible light mediated photocatalytic technology has attracted much attention in the recent research trend, a successful attempt has been performed by simultaneous doping of C, N and F elements into the biosynthesized TiO$_2$ (B-TiO$_2$) lattice. Doping made this material a potential agent for photocatalytic degradation of methylene blue dye under sunlight illumination. A comparative study between doped B-TiO$_2$ and B-ZnO (biosynthesized ZnO) is also presented, which suggested B-ZnO, as better visible light phaotocatalyst than titania.

Glycolipid (sophorolipid) mediated synthesis of gold and silver nanoparticles have also been reported. Yeast (*Candida bombicola*) mediated synthesis/capping of this bio-surfactant, which has been employed successfully to obtain these nanoparticles in powder form, which could be completely redispersed in aqueous medium. The silver nanoparticles thus synthesized exhibited enhanced bactericidal activity against both Gram-positive and Gram-negative bacterial species. As most of the pathogenic microbes are gaining resistance to most of the available antibiotics,
silver nanoparticles have been used extensively especially as antimicrobial agent. The simple method for the synthesis of silver nanoparticles makes a cheap and best alternative to the antibiotics.

Toxicity studies of nanomaterials are very hot topics of research now days, as people are more concerned towards the possible short term and long term risk of nanoparticles. The fast developing field of nanoscience has also provoked researchers to look towards the potential environmental and biological effects of nanoparticles. We have also made an attempt to evaluate cytotoxicity as well as genotoxicity of the above-mentioned bio-mediated/biosynthesized metal and metal-oxide nanoparticles. These materials were found to be biocompatible up to the millimolar concentrations (except B-ZnO). B-ZnO nanoparticles showed DNA damage even at $10^{-5}$ M concentrations.

6.2 Scope for future work

One of the most challenging aspects of microbial synthesis of nanomaterials is to identify the proteins/enzymes and their subsequent DNA fragment, which actually governs the biochemical pathway. This would lead to synthesis of respective nanomaterials in bulk quantity and thus biotechnologists would be able to fulfil the industrial needs.

Sophorolipid molecules, by virtue of the presence of glucose moieties are expected to be able to cross the blood brain barrier. Therefore, quantum dots conjugated with these molecules could be used as potential agents for imaging as well as drug delivery in brain. Silver nanoparticles synthesized by biological means or conjugated with biomolecules can serve as good wound healing agents. To further improve on this idea, these nanoparticles could be incorporated into suitable matrices such as polymers to acts as wound dressing agents or can be formulated into creams for topical applications.

The toxicity evaluation of nanomaterials can be further studied in depth at the genetic level where the genes involved in the process can be identified in order to put forth well-accepted mechanism.