Chapter 6

Summary and Conclusions

After two decades, results from various experiments have established that neutrinos have non-zero mass and oscillate from one flavour to another. However, we still have only a limited knowledge of neutrinos viz. their absolute mass, whether they are Dirac or Majorana particles, their mass hierarchy, whether they exhibit CP violation, etc. Further, there are experimental indications of the existence of sterile neutrinos coming from various SBL experiments.

In the present thesis, a study has been carried out on the ICAL magnet at the INO, its response at various strengths of magnetic field to muons and also to the active-sterile neutrino mixing sensitivity. In Chapter 1, the discovery of the neutrino is briefly presented. The various kinds of neutrino sources and their characteristics vis a vis neutrino experiments is also described.

In Chapter 2, the quantum mechanical neutrino oscillation formalism is presented for the 2, 3 and 3 + 1 neutrinos models considering propagation in vacuum as well as in matter. The current status on the active as well as sterile neutrino oscillation parameters is also presented.

In Chapter 3, the ICAL magnet and its importance at the INO is presented. The electromagnetic simulation of the ICAL magnet has been carried out for various configurations to optimize the design of the ICAL detector. The DC current and number of turns in the coil has been optimized for getting a desired B-field at the lowest possible dissipation of power in the coils. From the simulation, considering the B-field distribution over a 16 m × 16 m area, it has been observed that the optimum length of continuous slots is about 10 m. Also, the plate thickness of the ICAL magnet has been optimized with respect to
the B-field distribution and the estimated value is $\geq 4$ cm, justifying the choice of plate thickness of 5.6 cm. It has been observed that configurations C2 and C3 with arrangement of tiles which fill the $16 m \times 16 m$ area seem to provide a better B-field distribution with respect to minimum Ohmic loss in coils. The impact of air gaps on the B-field distribution has been also studied at various gap sizes using the C2 configuration. It has been found that the B-field, as well as its distribution for which $|B| \geq 1$ T, reduces when the size of gaps along tiles increases. However, in a practical situation a gap of 2 mm is sufficient for the arrangement of tiles. The overall B-field distribution was also simulated. The C2 configuration, where about 80% of the volume has a field of $|B| \geq 1$ T, was considered optimum.

The response of the ICAL detector for muons at various strengths of magnetic field is presented in Chapter 4. It has been observed that at a given magnetic field strength and at given incident zenith angle, the detector energy resolution, at lower energies, is affected by the multiple Coulomb scattering whereas at higher energies the poorer resolution is due to the uncertainty in sagitta measurements. We found that the detector energy resolution as well as efficiencies improve with an increase in the magnetic field. It has been concluded that the magnetic field strength of 1.5 T will provide satisfactory results.

In Chapter 5, results are presented on the active-sterile neutrino mixing sensitivity of the ICAL detector at the INO for an exposure of 1 Mton-yr. To find out the sensitivity, we have generated 3 and $3 + 1$ generation neutrino events using the MC method based reweighting algorithm. The detector response, in particular, the detector energy and angular resolution on true events, are implemented using the MC method considering various probability distributions. In the statistical analysis, a $\chi^2$ for each energy and zenith angle bin is estimated considering bins of variable width. It was observed that the ICAL detector has an active-sterile neutrinos mixing sensitivity provided the mixing angle $\theta_{24} \geq 10^\circ$ with squared mass difference of $\Delta m_{41}^2 \geq 0.1$ eV$^2$ at 90% CL, for the case where neutrinos reach at the detector from all directions. We have also put the constraint on mixing angles $\theta_{14}$ and $\theta_{34}$ and upper limit are about 20$^\circ$ to 30$^\circ$. It has been concluded that the ICAL detector at the INO has a sensitivity to an eV$^2$-scale active-sterile neutrino mixing.