

Table of Contents

Abstract	iii
Declaration	vi
Certificate	vii
Acknowledgements	viii
Table of Contents	x
List of Tables	xiii
List of Figures	xvi
List of Abbreviations	xxii
1 Introduction	1
1.1 Present Status of Neutrino Physics	1
1.2 Neutrino in the Standard Model	2
1.3 Extension of Standard Model and Neutrino Mass	5
1.4 Three-Neutrino Mixing	7
1.5 Neutrino Oscillation	8
1.5.1 Neutrino Oscillation in Vacuum	9
1.5.2 Neutrino Oscillation in Matter (MSW effect)	10
1.6 Neutrino Mass Hierarchy	12
1.7 Different Neutrino Oscillation Experiments	14

1.7.1	Neutrino Detection Method	14
1.7.2	Solar Neutrino Oscillation Experiments	16
1.7.3	Atmospheric Neutrino Experiments	20
1.7.4	Reactor Experiments	21
Bibliography		23
2 Perturbations to $\mu - \tau$ Symmetry and Leptogenesis with Type II		
Seesaw		30
2.1	Introduction	30
2.2	Seesaw Mechanism: Type I and Type II	34
2.3	$\mu - \tau$ Symmetric Neutrino Mass Matrix	37
2.4	Deviations from $\mu - \tau$ Symmetry	39
2.5	CP violation and Leptogenesis	41
2.6	Numerical Analysis	46
2.7	Results and Discussion	67
Bibliography		69
3 Discriminating Majorana Neutrino Textures in the light of Baryon		
Asymmetry		80
3.1	Introduction	80
3.2	Majorana Texture Zeros	85
3.2.1	One-zero texture	85
3.2.2	Two-zero texture	86
3.3	Leptogenesis	87
3.4	Numerical Analysis	91
3.4.1	Parametrization of One-zero Texture	93
3.4.2	Parametrization of Two-zero Texture	94
3.4.3	Calculation of Baryon Asymmetry	95
3.5	Results and Conclusion	109
Bibliography		113
4 Stability of Neutrino Masses and Mixing with non-zero θ_{13} using		
RGE		120
4.1	Introduction	120

4.2	A_4 model for neutrino mass	123
4.3	RGE for neutrino masses and mixing	125
	4.3.1 Evolution equations for mixing angles	128
4.4	Numerical analysis and results	129
4.5	Conclusion	145
Bibliography		146
5 Conclusion and Future Scope		154
5.1	Conclusion	154
	5.1.1 Chapter 2	154
	5.1.2 Chapter 3	156
	5.1.3 Chapter 4	157
5.2	Future Prospects	158
List of publications		160

List of tables

Table	Caption	Page No.
Table 3.1	Physical properties of different parent materials used for the synthesis of poly(3,4-ethylenedioxythiophene) nanoparticles, nanofibers and nanotubes	45-46
Table 4.1	Crystallite size (L) and degree of crystallinity (K) of PEDOT nanostructures at different dopant concentrations	72
Table 4.2	Characteristic IR bands of PEDOT and their assignments	74
Table 4.3	Characteristic Raman bands of PEDOT and their assignments	75
Table 4.4	T_{onset} , T_{rpd} and residue at 550°C of PEDOT nanoparticles, nanofibers and nanotubes for different dopant concentrations	78
Table 4.5	Activation energy (E_d) of thermal degradation of PEDOT, nanoparticles, nanofibers and nanotubes for 1M Dopant concentration	80
Table 5.1	Transport parameters calculated from resistivity data for PEDOT nanoparticles, nanofibers and nanotubes	92
Table 5.2	Transport parameters calculated from resistivity data for PEDOT nanotubes at different CSA concentrations	93
Table 5.3	Frequency exponent (s) at different temperature for 1M DBSA, 1M SDS and 1M CSA doped PEDOT nanoparticles, nanofibers and nanotubes, respectively	103
Table 5.4	Transport parameters calculated from AC conductivity vs. frequency plots for PEDOT nanoparticles, nanofibers and nanotubes at different dopant concentrations	104
Table 6.1	Calculated values of α_{hm} and β_{hm} from real part of dielectric permittivity plots of PEDOT nanostructures at different dopant concentrations	115

Table 6.2	Calculated values of α and β_{KWW} from the imaginary parts of impedance and modulus plots of PEDOT nanostructures at different temperatures	118
Table 6.3	Calculated values of activation energy (E_a) of 1M DBSA, SDS and CSA doped PEDOT nanoparticles, nanofibers and nanotubes	125

List of figures

Figure	Caption	Page No.
Figure 1.1	Chemical structure of some conjugated conducting polymers	2
Figure 1.2	Formation of polaron and bipolaron in PEDOT upon doping	7
Figure 1.3	Formation of polaron and solitons in trans-polyacetylene	8
Figure 1.4	Schematic diagram of band formation in solids	10
Figure 1.5	Schematic diagram of band formation in conducting polymers	10
Figure 1.6	Formation of bands in conducting polymers with increasing doping concentration: (a) neutral conducting polymers, (a) formation of polaron at low doping concentration, (c) formation of bipolaron at moderate doping concentration and (d) formation of bipolaron bands at high doping concentration	13
Figure 1.7	Schematic diagram of different polarization mechanisms under alternating electric field	14
Figure 1.8	Schematic diagram of synthesis of conducting polymer nanofibers by interfacial polymerization method	17
Figure 1.9	Schematic diagram of synthesis of conducting polymer nanotubes using hard template	18
Figure 1.10	Schematic representation of synthesis of conducting polymer nanoparticles through self-assembly method	19
Figure 1.11	Chemical structure of 3,4-ethylenedioxythiophene (EDOT)	22
Figure 1.12	Chemically oxidative polymerization of EDOT into PEDOT	23

Figure 3.1	Block diagram of synthesis of PEDOT nanoparticles	47
Figure 3.2	Block diagram of synthesis of PEDOT nanofibers	48
Figure 3.3	Block diagram of synthesis of PEDOT nanotubes	49
Figure 3.4	High resolution transmission electron microscope (JEOL, model JEM-2100)	51
Figure 3.5	X-ray diffraction measurement unit (Rigaku, MiniFlex)	52
Figure 3.6	(a) Typical X-ray diffractogram of a semi-crystalline polymer and (b) XRD patterns showing the superposition of crystalline peaks and an amorphous hump	54
Figure 3.7	Photograph of FTIR spectrometer (Perkin Elmer, model spectrum 100)	55
Figure 3.8	Photograph of micro-Raman spectrometer (Renishaw in-via)	56
Figure 3.9	Photograph of set-up used for thermogravimetric analysis (Perkin Elmer, model STA 6000)	57
Figure 3.10	Set-up used for dielectric and AC conductivity measurements	60
Figure 3.11	(a) The set-up used for measuring DC resistivity and magnetoresistance, and (b) schematic of four probe measurement	61
Figure 4.1	Representative HRTEM images of PEDOT nanoparticles for (a) 0.003M and (b) 1M DBSA concentration	64
Figure 4.2	Diameter distribution histogram of PEDOT nanoparticles for (a) 0.003M and (b) 1M DBSA concentration	65
Figure 4.3	SAED patterns of PEDOT nanoparticles for (a) 0.003M and (b) 1M DBSA concentration	65
Figure 4.4	HRTEM images of PEDOT nanofibers for (a) 0.03M and (b) 1M SDS concentration	66

Figure 4.5	Diameter distribution histogram of PEDOT nanofibers for (a) 0.03M and (b) 1M SDS concentration	66
Figure 4.6	SAED patterns of PEDOT nanofibers for (a) 0.03M and (b) 1M SDS concentration	67
Figure 4.7	HRTEM images of PEDOT nanotubes for (a) 0.001M and (b) 1M CSA concentration	68
Figure 4.8	Diameter distribution histogram of PEDOT nanotubes for (a) 0.001M and (b) 1M CSA concentration	68
Figure 4.9	SAED patterns of PEDOT nanotubes for (a) 0.001M and (b) 1M CSA concentration	69
Figure 4.10	X-ray diffraction pattern of PEDOT nanoparticles for (a) 0.003M, (b) 0.01M, (c) 0.1M and (d) 1M DBSA concentration	70
Figure 4.11	X-ray diffraction pattern of PEDOT nanofibers for (a) 0.03M, (b) 0.1M, (c) 0.5M and (d) 1M SDS concentration	70
Figure 4.12	X-ray diffraction pattern of PEDOT nanotubes for (a) 0.001M, (b) 0.01M, (c) 0.1M and (d) 1M CSA concentration	71
Figure 4.13	FTIR spectra of PEDOT (A) nanoparticles for (a) 0.003M, (b) 0.01M, (c) 0.1 and 1M DBSA concentration (B) nanofibers for (a) 0.03M, (b) 0.1M, (c) 0.5 and 1M SDS concentration and (C) nanotubes for (a) 0.001M, (b) 0.01M, (c) 0.1 and 1M CSA concentration	73
Figure 4.14	Micro-Raman spectra of PEDOT (A) nanoparticles for (a) 0.003M, (b) 0.01M, (c) 0.1 and 1M DBSA concentration (B) nanofibers for (a) 0.03M, (b) 0.1M, (c) 0.5 and 1M SDS concentration and (C) nanotubes for (a) 0.001M, (b) 0.01M, (c) 0.1 and 1M CSA concentration	76

Figure 4.15	Thermogravimetric plots of PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes for different dopant concentration	77
Figure 4.16	Derivative TG plots of PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes at different dopant concentrations	78
Figure 4.17	$\log\beta$ vs. $1000/T$ plots at five different heating rates (10, 15, 20, 25 and $30^{\circ}\text{C}/\text{min}$) for different degree of conversions (X) of (a) 1M DBSA doped PEDOT nanoparticles, (b) 1M SDS doped PEDOT nanofibers and (c) 1M CSA doped PEDOT nanotubes	80
Figure 5.1	Temperature dependent resistivity plots of PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes for different dopant concentrations. Error bars represent the standard deviation.	86
Figure 5.2	Log-log plots of W vs. T for PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes for different dopant concentrations. Error bars represent the standard deviation.	88
Figure 5.3	$\ln\rho$ vs. $T^{-1/4}$ plot of (a) DBSA doped PEDOT nanoparticles, (b) SDS doped PEDOT nanofibers and (c) CSA doped PEDOT nanotubes at different dopant concentrations. In figure symbols are the experimental data and red solid lines are best linear fitted lines. Error bars represent the standard deviation.	89
Figure 5.4	$\ln\rho$ vs. $T^{-1/2}$ plot of PEDOT nanotubes with varying CSA concentration. In figure symbols are the experimental data and red solid lines are best linear fitted lines. Error bars represent the standard deviation.	90

Figure 5.5	$\ln[\rho(B, T)/\rho(0, T)]$ vs. $T^{-3/4}$ plots of resistivity data at magnetic field 8 T for (a) DBSA doped PEDOT nanoparticles, (b) SDS doped PEDOT nanofibers and (c) CSA doped PEDOT nanotubes. In figure symbols are the experimental data and red solid lines are best linear fitted lines. Error bars represent the standard deviation.	91
Figure 5.6	MR (%) vs. B of (a) 0.003M DBSA doped PEDOT nanoparticles, (b) 0.01M DBSA doped PEDOT nanoparticles and (c) 1M DBSA doped nanoparticles at eight different temperatures. Error bars represent the standard deviation.	94
Figure 5.7	MR (%) (at $B = 8T$) vs. temperature plot for 0.003M, 0.01M and 1M DBSA doped PEDOT nanoparticles. Error bars represent the standard deviation.	94
Figure 5.8	MR (%) vs. B of (a) PEDOT nanofibers and (b) PEDOT nanotubes at eight different temperatures. Error bars represent the standard deviation.	95
Figure 5.9	MR (%) (at $B = 8T$) vs. temperature plots of (a) SDS doped PEDOT nanofibers and (b) CSA doped PEDOT nanotubes at different dopant concentrations. Error bars represent the standard deviation.	96
Figure 5.10	MR (%) vs. B^2 plots of the positive magnetoresistance data of (a) 1M DBSA doped PEDOT nanoparticles, (b) 1M SDS doped PEDOT nanofibers and (c) 1M CSA doped PEDOT nanotubes. Error bars represent the standard deviation.	98

Figure 5.11	Room temperature frequency dependent AC conductivity plots of (a) DBSA doped PEDOT nanoparticles, (b) SDS doped PEDOT nanofibers and (c) CSA doped PEDOT nanotubes for different dopant concentrations. In Figs. Symbols are the experimental data and red solid lines are the fitted lines according to eq. (5.11). Error bars represent the standard deviation.	100
Figure 5.12	Frequency dependent AC conductivity plots of (a) 1M DBSA doped PEDOT nanoparticles, (b) 1M SDS doped PEDOT nanofibers and (c) 1M CSA doped PEDOT nanotubes at different temperature. In Figs. symbols are the experimental data and red solid lines are the fitted lines according to eq. (5.11). Error bars represent the standard deviation.	101
Figure 5.13	Frequency exponent vs. temperature plot of 1M DBSA, 1M SDS and 1M CSA doped PEDOT nanoparticles, nanofibers and nanotubes, respectively. Error bars represent the standard deviation.	103
Figure 5.14	Scaling of AC conductivity spectra at different temperature for 1M (a) DBSA doped nanoparticles, (b) SDS doped nanofibers and (c) CSA doped nanotubes. Error bars represent the standard deviation.	106
Figure 6.1	Variation of real part of dielectric permittivity ($\epsilon'(\omega)$) of PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes at room temperature for different dopant concentration. In figure symbols indicate the experimental data and the red solid lines represent the theoretical best fit obtained from Eq. (6.3). Error bars show the standard deviation.	112

Figure 6.2	Variation of real part of dielectric permittivity ($\epsilon'(\omega)$) of PEDOT (a) 1M DBSA doped nanoparticles, (b) 1M SDS doped nanofibers and (c) 1M CSA doped nanotubes at different temperature. Error bars show the standard deviation.	113
Figure 6.3	log-log plots of ϵ'' vs. ω at room temperature for PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes for different dopant concentrations. Error bars show the standard deviation.	116
Figure 6.4	Variation of imaginary part of complex impedance (Z'') as a function of frequency for (a) DBSA doped PEDOT nanoparticles, (b) SDS doped PEDOT nanofibers and (c) CSA doped PEDOT nanotubes with varying dopant concentrations. Error bars show the standard deviation.	117
Figure 6.5	Variation of imaginary part of complex impedance (Z'') as a function of frequency for (a) 1M DBSA doped PEDOT nanoparticles, (b) 1M SDS doped PEDOT nanofibers and (c) 1M CSA doped PEDOT nanotubes at different temperatures. Error bars show the standard deviation.	119
Figure 6.6	Variation of real modulus M' with frequency for PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes at room temperature for different dopant concentrations. Error bars show the standard deviation.	120
Figure 6.7	Variation of imaginary modulus M'' with frequency for PEDOT (a) nanoparticles, (b) nanofibers and (c) nanotubes at room temperature for different dopant concentrations. Error bars show the standard deviation.	122

Figure 6.8	Variation of imaginary modulus M'' with frequency for PEDOT (a) 1M BDSA doped nanoparticles, (b) 1M SDS doped nanofibers and (c) 1M CSA doped nanotubes at different temperatures. Error bars show the standard deviation.	123
Figure 6.9	$\ln\tau_{\max}$ vs. $1000/T$ plot of 1M DBSA, 1M SDS and 1M CSA doped PEDOT nanoparticles, nanofibers and nanotubes, respectively. Error bars show the standard deviation.	125
Figure 6.10	Scaling plots of Z'' at different temperatures for (a) 1M DBSA doped PEDOT nanoparticles, (b) 1M SDS doped PEDOT nanofibers and (c) 1M CSA doped PEDOT nanotubes. Error bars show the standard deviation.	126
Figure 6.11	Scaling plots of M'' at different temperatures for (a) 1M DBSA doped PEDOT nanoparticles, (b) 1M SDS doped PEDOT nanofibers and (c) 1M CSA doped PEDOT nanotubes. Error bars show the standard deviation.	127

List of abbreviations

Abbreviation	Meaning
AAO	Anodic aluminum oxide
AC	Alternating current
CB	Conduction band
CBH	Correlated barrier hopping
CCD	Charge-coupled device
CSA	Camphorsulfonic acid
DBSA	Dodecylbenzene sulfonic acid
DC	Direct current
DDW	Double distilled water
DOS	Density of states
EDOT	3,4-ethylenedioxythiophene
eV	electron Volt
FTIR	Fourier transforms infrared spectroscopy
FWHM	Full-width at half-maximum
HOMO	Highest occupied molecular orbital
LUMO	Lowest unoccupied molecular orbital
Mott-VRH	Mott-Variable range hopping
MR	Magnetoresistance
OLPT	Overlapping large polaron-tunneling
PA	Polyacetylene
PEDOT	Poly(3,4-ethylenedioxythiophene)
PPy	Polypyrrole
PTMs	Particle track-etched polymeric membranes
QMT	Quantum mechanical tunneling
SAED	Selected area electron diffraction
SDS	Sodium dodecyl sulfate
SP	Small polaron
TGA	Thermogravimetric analysis
V	Volt
VB	Valence band

VRH

Variable range hopping

XRD

X-ray diffraction

List of symbols

Symbol	Meaning
\AA	Angstrom
B	Magnetic field
C	Capacitance
$^{\circ}\text{C}$	Degree Celsius
d	Thickness of the sample
e	Electronic charge
E_a	Activation energy
E_d	Activation energy of thermal degradation
E_F	Fermi energy
G	Conductance
\hbar	Reduced Planck's constant
K	Kelvin
K	Degree of crystallinity
k_B	Boltzmann constant
L	Crystallite size
L_B	Magnetic relaxation length
L_{loc}	Localization length
M^*	Complex electric modulus
M'	Real part of electric modulus
M''	Imaginary part of electric modulus
$N(E_F)$	Density of states
R_{hop}	Hopping length
R_{ω}	Hopping distance at a particular angular frequency ω
T	Temperature
T_{Mott}	Characteristic Mott temperature
T_{onset}	Onset decomposition temperature
T_{rpd}	Rapidest decomposition temperature
W	Reduce activation energy
W_b	Barrier height
W_M	Binding energy

X	Degree of conversion
Z^*	Complex impedance
Z'	Real part of impedance
Z''	Imaginary part of impedance
ω	Angular frequency
ρ	Resistivity
σ_{dc}	DC conductivity
ε^*	Complex dielectric permittivity
ε'	Real part of dielectric permittivity
ε''	Imaginary part of dielectric permittivity
ε_0	Dielectric permittivity at free space
τ	Relaxation time
λ	Wavelength
θ	Bragg diffraction angle
ϕ	Phase angle