ANNEXURE - III

DEPARTMENT OF PHYSICS

PONDICHERRY UNIVERSITY

New Ph.D. Guide Papers

(2022-23 Onwards)

PHYS-607 – MAGNETIC NANOPARTICLE (4 credits)

(total 60 h = Lecture 45 h + tutorial 15 h)

Unit I. Basic concept of magnetic materials **12 L**

Diamagnet, paramagnet, ferromagnet, antiferromagnet and ferrimagnet, spontaneous magnetization, Curie Temperature, Saturation magnetization and Neel Temperature, Origin of various kinds of magnetic anisotropy, Domain theory and its application in magnetic hysteresis, Single domain particle, multi-domain particle, and nanoparticle.

Unit II. Material synthesis techniques **12 L**

Chemical route, mechanical milling/alloying, thermal evaporation technique, Pulsed Laser deposition technique, solid state sintering route, effect of synthesis techniques on material structural stability and physical properties, Physical and chemical reactions and mechanisms during material synthesis.

Unit III. Models for magnetic nanoparticles and applications **12 L**

Core-shell model for ferromagnetic and antiferromagnetic nanoparticle. The importance of core-shell model to explain the properties of magnetic nanoparticle, e.g., Particle Magnetization, particle anisotropy, magnetic ordering temperature, Inter-particle interactions and surface magnetism. Role of vacancy on magnetic properties of nanomaterial, defect induced ferromagnetism.

Unit IV. Special topics (preliminary idea) **12 L**

Super paramagnetism, Collective magnetic Oscillation, Exchange bias effect, Magnetic Quantum Tunneling, Magneto- resistance and Colossal magneto-resistance, multiferroics, Spin induced ferroelectricity.

Part V. Techniques for Material characterization **12 L**

Synthesis of any magnetic material, characterization of the materials by using XRD, SEM-EDAX, XPS Magnetometry and I-V characteristics study.

Text books:

1. K H Buschow, Hand book of magnetic materials, Vol-8 North Holand, Amsterdam, 1995.

2. J L Dorman and D Fiorani, Magnetic properties of fine particles, North Holland, Amsterdam, 1991.

3. J A Mydosh, Taylor and Francis, Spin Glass an Introduction, London, 1993.

4. R C Handley, Modern Magnetic Materials: Principle and applications, Wiley Newyork, 2000.

5. C Kittel, An introduction to Solid State Physics, 8th Edition, Wiley, Newyork, 2004

Supplementary Readings

1. Eoin P. O'Reilly, Quantum Theory of Solids, Taylor & Francis, First Edition (2002).
2. Ashcroft, Neil W. and Mermin, N. David, Solid State Physics. New York (1976).
3. Dekker A. J. Solid State Physics. MacMillan India Ltd, New Delhi, reprint (1967).
4. J. S. Blakemore, Solid State Physics, Cambridge University Press, 2nd edition (2012).
5. David W. Snoke, University of Pittsburgh, Solid State Physics: Essential Concepts, 2^{nd} Edition (2020).

PHYS 622 Nonlinear Optics and Materials

Unit I 12hours

Origin Of Optical Nonlinearities

Classical theory of anharmonic oscillators. Wave equations description of nonlinear optical susceptibilities Quantum mechanical treatment of nonlinear optical susceptibilities, Frequency and intensity dependence of polarization and dielectric susceptibility First order and higher order susceptibilities

Unit II 12 hours

Second order optical nonlinearities:

Second harmonic generation –sum and difference frequency generation, parametric processes- Simple theory andcalculation of nonlinear polarization –Various phase matching technique in SHG

Unit III 12 hours

Third order optical nonlinearities:

Third harmonic generation, Four wave mixing, Kerr Nonlinearity, Intensity dependent effect, Self Phase modulation, Cross phase modulation Stimulated Raman Scattering (SRS) Stimulated Brillioun Scattering, Parametric gain –Parametric amplification and oscillation

Unit IV 12 hours

Applications: Optical bistability, Optical Phase Conjugation Theory and Applications, Electro-Optic Effect (Pockel and Kerr Effect) Photorefractive effect and applications, Solitons Theory and applications.

Unit V 12 hours

Nonlinear optical materials (Structure property relations and its applications):

Nonlinear Optics of Organics and Polymers, Liquid Crystal, Photorefractive materials, Organic doped glasses, Rare earth doped glasses and crystals, Semiconductors, Optical Fibers and Photonic Crystals Fibers, Ferroelectric Materials and other Novel optical materials

Text Books

1. Nonlinear Optics– Robert W Boyd
2. Nonlinear Photonics-Y Guo, C K Kao, E.H.Li, K. S.Chiang
3. Principles of Nonlinear Optics- Y R Shen
4. Nonlinear Optics – N. Bloembergen
5. Nonlinear Optics of Organic Molecules and Polymers- H S Nalwa and S Miyata
6. Optical Phase Conjugation-R A Fischer
7. Quantum Electronics–A Yariv
8. Growth and Characterization of Nonlinear Optical Materials – N B Singh

Supplementary Reading

1. Handbook of Nonlinear Optics-R Sutherland

PHYS-624: Computational Neuroscience (4 Credit)

Unit I: Modeling Neural Data **15 Hrs**

Various Neuroimaging Techniques: design and conduct of EEG (ElectroEncephaloGram), MEG MagnetoEncephaloGraphy, MRI (Magnetic Resonance Imaging), fMRI (functional Magnetic Resonance Imaging), PET (Positron Emission Tomography), TMS (Transcranial Magnetic Stimulation), NIRS (Near-InfraRed Spectroscopy) - MATLAB basics and applications in neurosciences - PYTHON basics and applications in Neurosciences - Analysis of neuroimaging data.

Unit II: Neurobiology **15 Hrs**

Introduction: membranes, neurons, networks and the brain - Structural and functional properties of the brain - Basic electrical properties of biological membranes -Structure and function of single neurons - Interaction of neurons within and between the neural networks - Neural information processing, neural coding and neural computation.

Unit-III: Neurophysics **15 Hrs**

Information processing in neuronal systems - Physical basis of bio-potentials - Action potential - Nernst-Planck equation - Hodgkin-Huxley model - A statisticalMechanics Perspective: Little's Model - Hopfield's Model -Ising spin versus Interactive Neurons - Boltzmann machine representation of Neural Network – Free Energy - Energy minimization - Entropy measurement models.

Unit-IV: Computation in Networks **15 Hrs**

Single neuron models; integrate-and-fire models, network and multiscale models; models of neural plasticity; Neural Oscillations – Single neuron oscillators; Oscillators as nonlinear dynamical systems; Information representation; Neural encoding and decoding; Memory – Plasticity.

Text Books:

1. MATLAB for neuroscientists: An introduction to scientific computing in MATLAB by P. Wallish, M.Lusignan, M. Benayoun, Taniya I. Baker, A.S. Dickey, N.G. Hatsopolos.

2. Peter Dayan and L. F. Abbott, Theoretical Neuroscience: Computational and Mathematical Modeling of Neural Systems, The MIT press, 2005.

Reference Books:

3. Christof Koch and Idan Segev (Eds), Methods in Neuronal Modeling: From Ions to Networks, The MIT press, second edition, 1998.
4. Eric De Schutter (Ed.), Computational modeling methods for neuroscientists, The MIT press, 2009.
5. Eugene Izhikevich, Dynamical systems in neuroscience: the geometry of excitability and bursting, The MIT press, 2006.
6. Alwyn Scott, Neuroscience - A Mathematical Primer, (Springer, New York, 2002).
7. P.S.Neelakanta, Dolores DeGroff, Neural Network Modeling: Statistical Mechanics and Cybernetics Perspectives (CRC Press, 1994).
8. G. Bard Ermentrout David H. Terman, Mathematical Foundations of Neuroscience (Springer, 2010).
9. Nicholls JG, Martin AR, Wallace BG, Fuchs, PA (2001) From Neuron to Brain. Sinauer Assoc., Sunderland MA. (4th ed).
10. Kandel ER, Schwartz JH, Jessell TM (2000) Principles of Neural Science. McGrawHill(4^{th} ed).
11. PYTHON in neuroscience by E. Muller, J.A. Bednan, Markus Diesmann, Mark-Oliver Gewaltig, Michael Hines, Andrew P. Davison.

PHYS-625: Relativity and Cosmology (4 Credit)

Unit I: A Brief Review of Special Theory of Relativity 12 Hrs

Galilean Transformation, Postulate of Special Relativity, Lorentz Transformation, Length Contraction, Time Dilation, Relativistic Mass, Mass-Energy Equivalence, Light Cone, Four-Vectors, Electromagnetic Field Tensor, Covariant Form of Maxwell's Equation, Photons and Neutrinos.

Unit II: Tensor Analysis 12 Hrs

Line Element: Riemannian Space, Transformation of Coordinates, Contravariant and Covariant Vector, The Metric tensor, Contravariant and Covariant Tensor, Fundamental Tensor, Raising and Lowering of Indices.
Geodesic Curves: Manifolds, Covariant Derivative, Christoffel's 3-Index Symbols, Geodesics, Covariant Derivatives of Tensors.
Curvature Tensor: Riemannian Coordinates, Riemann-Christoffel Curvature Tensor, Bianchi Identities, Ricci Tensor, Einstein Tensor, Flat Space-Time Curvature, Energy-Momentum Tensor for Perfect Fluid.

Unit III: General Theory of Relativity (GTR) 12 Hrs

Einstein's Field Equations (EFE): Principle of Equivalence, EFE by Heuristic Derivation, EFE by Variational Technique, Postulates of GTR.
Schwarzschild Solution: Schwarzschild Line-Element, Killing Vector, Particles Trajectories in Schwarzschild Space-Time, Static Line-Element with Spherical Symmetry for Non-Empty Space, Schwarzschild Exterior and Interior Solution, Conservation Laws in Curved Space.

Unit IV: Gravitational Waves and Black Holes 12 Hrs

Linearized Field Equations and wave solutions, Detection of gravitational waves, Quadrupolar Nature of Gravitational Waves, Emission of Gravitational Waves.
Black Holes: Schwarzschild Black Holes, Kerr Metric in Boyer, Frame Dragging, Rotating Black Holes, Reissner-Nordstrom Solutions.

Unit V: Cosmology and Astrophysics 12 Hrs

Cosmology: Weyl's Postulate, Static Cosmological Models, Friedmann Equations, Time Evolution of Universe, Red-Shift, Early Universe, Cosmological Constant in EFE, Cosmic Microwave Background.
Astrophysics: Tolman-Oppenheimer -Volkoff Equations, Degeneracy of Matter, Model of Stars, Lane-Emden Equation, Chandrashekhar Mass Limit.

Text Books:

1. Cheng, Ta-Pei. Relativity, gravitation and cosmology: a basic introduction. Vol. 11. Oxford University Press, 2009.
2. Weinberg, Steven. Gravitation and cosmology: principles and applications of the general theory of relativity. New York: Wiley, 1973
3. Lambourne, Robert J. Relativity, gravitation and cosmology. Cambridge University Press, 2010.
4. Puri, Satya Pal. General theory of Relativity. Pearson Education India, 2013.
5. Shipman, Harry L. Black holes, quasars, and the universe. No. 523.8 SHI. Boston: Houghton Mifflin, 1976.
6. Pickover, Clifford A. Black holes: A traveler's guide. 1998.
7. Roos, Matts. Introduction to cosmology. John Wiley & Sons, 2015.

PHYS-626: CLASSICAL AND QUANTUM FIELD THEORIES **4 Credits**

Unit-I : Non-Gravitational Fields **15 Hours**

Classical Field Theories – Lagrangian and Hamiltonian Formulations – Noether Theorem and Conservation Laws – Generators of Poincaré Group and Poincaré algebra – Klein-Gordon Fields – Dirac Field – Schrödinger Field – Electromagnetic Field – Abelian Gauge Symmetry – Nonabelian Gauge Theories.

Unit-II: Gravitational Field **15 Hours**

Principle of Equivalence – Gravity as Space-time Curvature – Curved Spaces – Contravariant and Covariant Tensors – Geodesics – Christoffel Symbols – Parallel Transport – Covariant Differentiation – Curvature Tensor – Ricci Tensor – Curvature Scalar – Bianchi Identities – Einstein Tensor – Sources of Curvature and Stress-Energy Tensor – Einstein's Field Equations.

Unit-III: Introduction to Quantization **15 Hours**

Quantization of Klein-Gordon Field – Equal-Time Commutation Relations – Heisenberg's Equations – Fourier Decomposition of Field Operators – Invariant Commutation Relations – Scalar Feynman Propagator – Interaction Picture – Time Ordered Evolution Operator – Scattering Matrix – Wick's Theorem – Quartic Interaction – Feynman Rules and Diagrams.

Unit-IV: Field Theories in Noncommutative Spacetime **15 Hours**

Noncommutative Spacetime – Action Integrals for Noncommutative Field Theories – Space-Time Symmetry as Diffeomorphism Symmetry – Space-Time Symmetries in Noncommutative Minkowski and Curved Spaces – Noncommutative Gauge Symmetries – Seiberg-Witten Map – Emergent Gravity Phenomena in Noncommutative Gauge Theories.

References:

1. W.Greiner and J. Reinhard, *Field Quantization*, Springer.
2. M.E. Peskin and D.V.Schroeder, *An Introduction to Quantum Field Theory*.
3. Sean Carroll, *Spacetime and Geometry – An Introduction to General Relativity*.
4. Seiberg and Witten, *String Theory and Noncommutative Geometry*, JHEP **09**(1999)032.
5. R.Szabo, *Quantum Field Theory on Noncommutative Spaces*, Phys.Rept.**378**(2011) 207.
6. M. Chaichian, P. Presnajder and A. Tureanu, *New Concept of Relativistic Invariance in NC Space-Time: Twisted Poincaré Symmetry and its Implications*, Phys.Rev.Lett.**94** (2005) 151602.
7. P. Aschieri, C.Blohmann, M.Dimitrijevic, F.Meyar, P.Schupp and J.Wess, *A Gravity Theory on Noncommutative Spaces*, Class.Quant.Grav. **22** (2005) 3511-3532, arXiv:hep-th/0504183.
8. V.O.Rivelles, *Noncommutative Field Theories and Gravity*, Phys.Lett. **B558** (2003) 191-196; arXiv:hep-th/0212262.
9. B. Muthukumar, Journal of High Energy Physics **1501** (2015) 123, arXiv:1408.5478.

PHYS 627 - MICRO MANIPULATION USING OPTICAL TRAPS

Forces of a single beam Gradient laser trap on a dielectric sphere in Ray optics regime- Light ray in a trap – Optics regime- Force of gradient trap of spheres- Effect of mode profiles and index of refraction on trapping forces

Basic Laser Tweezer Setup-Microscope- laser-Optics and layout- System setup- Alignment- Translation- Video recording and analysis Optical Trap design Considerations- Choke of trapping laser- Optical Layout- Imaging- High resolution Position measurement- Noise Sources- feedback- Calibration- Analysis

Laser scissors and Tweezers- Mechanism of interaction- Biological studies- Optical Force Microscopy- AFM like application- Experimental Design Optical Chopsticks- digital synthesis of multiple optical Traps- Trapping Configurations- Mechanical deflection (Mirror)- Acousto-Optic deflection- Position Control and noise

Holographic Optical Tweezers with Fluidic Sorting- Nanofabrication with Holographic Tweezers- Dynamic Holographic Tweezers Sorting by periodic potential Landscapes- Optical peristalsis- Micro fluidic sorting in Optical lattice

Femtosecond pulse laser trapping and tweezers- Morphology dependent resonance under femtosecond laser illumination- Morphology dependent resonance coupling- Cavity photon confinement lifetime- Simultaneous femtosecond single beam trapping and morphology dependent resonance excitation- Resonant particle trapped microscopy

Single Molecule Imaging and Micro- manipulation of biomolecule- Signal and noise in micromechanical measurements use of Optical Tweezers to study Single Motor molecules- Rotation of particles by radiation pressure

Reference:

1. Femtosecond Biophysics: Core Technology and Applications by MIN GU, DAMIAN BIRD DANIEL DAY, LING FU, DRU MORRISH Cambridge University Press 2010.

2. Optical Trapping and Manipulation of Neutral Particles Using Laser- Arthur Ashkin.

3. Methods in cell Biology Ed Leslie Wilson, Paul Matsudaira Academic press.