Board of Studies in Physics

FACULTY OF SCIENCE

GONDWANA UNIVERSITY, GADCHIROLI

Syllabus of

M.Sc.First Year (Semester pattern) (Choice Based Credit System)

SUBJECT - PHYSICS

Semester I & Semester II

Syllabus for M. Sc. Physics

Choice Based Credit System (Semester Pattern)
Gondwana University, Gadchiroli
Effective from 2016-2017

Scheme of teaching and examination under semester pattern Choice Based Credit System (CBCS) for M.Sc. Program in subjects Physics

Semester I;

Core	Theory / Practical	Teaching Scheme			Credit	Examination Scheme						
		Hrs/ week				Duration in hrs.	Max. Marks			Minimum Marks	
		Theory	Practical	Total			External	Internal	Total	Theory	Practical
Core 1 (PSCPHYT01)	Paper 1 Mathematical Physics	4	-	4	4	3	80	20	100	40	
Core 2 (PSCPHYT02)	Paper 2 Complex Analysis and Numerical method	4	-	4	4	3	80	20	100	40	
Core 3 (PSCPHYT03)	Paper 3 Electronics	4	-	4	4	3	80	20	100	40	
Core 4(PSCPHYT04)	Paper 4 Electrodynamics I	4	-	4	4	3	80	20	100	40	
Pract. Core 1 & 2 (PSCPHYP01 & P02)	Practical 1 (Paper 1 & 2)	-	8	8	4	3-8*	80	20	100	40	40
Pract. Core 3 & 4 (PSCPHYP03 & P04)	Practical 2 (paper 3 & 4)	-	8	8	4	3-8*	80	20	100	40	40
Seminar 1	Seminar 1	2	-	2	1			25	25	10	
TOTAL		**18**	**16**	**34**	**25**		**480**	**145**	**625**	**170**	**80**

Semester II:

Core	Theory / Practical	Teaching Scheme Hrs/ week			Credit	Duration in hrs.	Examination Scheme Max. Marks			Minimum Marks	
		Theory	Practical	Total			External	Internal	Total	Theory	Practical
Core 5 (PSCPHY T05)	Paper 5 Quantum Mechanics I	4	-	4	4	3	80	20	100	40	
Core 6 (PSCPHY T06)	Paper 6 Statistical Physics	4	-	4	4	3	80	20	100	40	
Core 7(PSCPH YT07)	Paper 7 Classical Mechanics	4	-	4	4	3	80	20	100	40	
Core 8 (PSCPHY T08)	Paper 8 Electrodynamics II	4	-	4	4	3	80	20	100	40	
Pract. Core 5 & 6 (PSCPHY P05 & P06)	Practical 3 (Paper 5 & 6)	-	8	8	4	3-8*	80	20	100	40	40
Pract. Core 7 & 8 (PSCPHY P07 & P08)	Practical 4 (Paper 7 & 8)	-	8	8	4	3-8*	80	20	100	40	40
Seminar 2	Seminar 2	2	-	2	1			25	25	10	
TOTAL		**18**	**16**	**34**	**25**		**480**	**145**	**625**	**170**	**80**

Seminar
Guidelines for Students, Supervisors and Examiners

In each semester, the student will have to deliver a seminar on any topic relevant to the syllabus / subject encompassing the recent trends and development in that field / subject. The topic of the seminar will be decided at the beginning of each semester in consultation with the supervising teachers. The student has to deliver the seminar which will be followed by discussion. The seminar will be open to all the teachers of the department, invitees, and students.

The students should submit the seminar report typed and properly bound in one copy to the head of the department. The said shall be evaluated by the concerned supervisor / head of the department. The marks of the seminar shall be forwarded to the university within due period through head of the Department. The record of the seminar should be preserved till the declaration of the final result.

Internal Assessment:

1. The internal assessment marks shall be awarded by the concerned teacher.
2. The internal assessment marks shall be sent to the University after the Assessment in the prescribed format.
3. For the purpose of internal assessment the University Department / College shall conduct any three assignments described below. Best two scores of a student in these tests shall be considered to obtain the internal assessment score of that student.
4. If the student does not appear for the Practical Exam he shall be declared failed in Practical Examination irrespective of marks obtained in Internal Practical Assessment. However the Internal Practical Assessment marks will be carried forward for his next supplementary Practical Exam.
5. General guidelines for Internal Assessment are:
    a) The internal assessment marks assigned to each theory paper as mentioned in Appendix 1 shall be awarded on the basis of assignments like class test, attendance, home assignments, study tour, industrial visits, visit to educational institutions and research organizations, field work, group discussions or any other innovative practice / activity.
    b) There shall be three assignments (as described above) per course.
    c) There shall be no separate / extra allotment of work load to the teacher concerned. He/ She shall conduct the internal assessment activity during the regular teaching days / periods as a part of regular teaching activity.
    d) The concerned teacher / department / college shall have to keep the record of all the above activities until six months after the declaration of the results of that semester.
    e) **At the beginning of each semester, every teacher / department / college shall inform his / her students unambiguously the method he / she propose to adopt and the scheme of marking for internal assessment. (Prescribed in syllabus of respective Subjects).
    f) Teacher shall announce the schedule of activity for internal assessment in advance in consultation with HOD / Principal.

Practical Examination

1. Each practical carries 100(80 Pr+20 Int) marks. The scheme of marking shall be as per given in the syllabi of respective subjects.
2. Practical performance shall be jointly evaluated by the External and Internal Examiner. In case of discrepancy, the External Examiner's decision shall be final.
3. Duration of practical examination will be as per given in the syllabi of respective subjects.

4. The Practical Record of every student shall carry a certificate as shown below, duly signed by the teacher-in-charge and the Head of the Department. If the student fails to submit his / her certified Practical Record duly signed by the Teacher-In-Charge and the Head of the Department, he / she shall not be allowed to appear for the Practical Examination and no Marks shall be allotted to the student.
5. The certificate template shall be as follows:

<center>**C E R T I F I C A T E**</center>

Name of the college / institution _
Name of the Department: _

This is to certify that this Practical Record contains the bonafide record of the Practical work of Shri / Shrimati / Kumari _ of M. Sc. _ _ _ _ _ _ _
_ _ _ _ _ _ _ Semester _ _ _ _ _ _ _ _ _ during the academic year _ _ _ _ _ _ _. The candidate has satisfactorily completed the experiments prescribed by Gondwana University Gadchiroli for the subject _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Dated _ _ _ / _ _ _ / _ _ _ _ _

Signature of the teacher who taught the examinee   Head of the Department
1. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
2. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

General Rules and Regulations regarding pattern of question paper for the semester end examination:

A) Pattern of Question Paper
1. There will be four units in each paper.
2. Maximum marks of each theory paper will be 80.
3. Question paper will consist of five questions, each of 16 marks.
4. Four questions will be on four units with internal choice (One question on each unit).
5. Fifth question will be compulsory with questions from each of the four units having equal weightage and there will be no internal choice.

Revised Syllabus to be implemented from 2016-17 Choice Based Credit System (CBCS)
M.Sc. Physics Semester I
1. (Core 1) Paper 1: Mathematical Physics
2. (Core 2) Paper 2: Complex Analysis and Numerical Methods
3. (Core 3) Paper 3: Electronics
4. (Core 4) Paper 4: Electrodynamics I

M.Sc. Physics Semester II
1. (Core 5) Paper 5: Quantum Mechanics-I
2. (Core 6) Paper 6: Statistical Physics
3. (Core 7) Paper 7: Classical Mechanics
4. (Core 8) Paper 8: Electrodynamics II

Semester I Paper 1 (Core 1) (PSCPHYT01) Mathematical Physics

Unit I

Curvilinear co-ordinate Systems, Physical ideas about gradient, divergence and Curl,

Fourier Series : Definition, Dirichlet's condition, Convergence, Fourier Integral and Fourier transform, Convolution theorem, Parseval's identity, Applications to the solution of differential equations.

Unit II

Elementary ideas about tensors, Cartesian tensors, differential of Cartesian tensors, gradient, divergence and curl , Laplacian of Cartesian tensors. Non-Cartesian tensors.Tensor densities and capacities. Differentiation of Non-Cartesian tensors, Chrisoffel symbols. gradient, divergence and curl , Laplacian of Non-Cartesian tensors Laplace transform of elementary functions

Unit III

Linear vector spaces - linear independent bases, Dimensionality, inner product, matrices, linear transformation, Matrices- Inverse, Orthogonal and Unitary matrices, Cayley Hamilton theorem, eigen vectors and eigen value problem, Diagonalization, Complete orthonormal sets of function.

Unit-IV

Linear differential equations, Special Function- Laguerre, Hermite, Legendre polynomials, Special Bessel's function, Spherical harmonics, Generating Function and recursion relations, differential and integral form.

Text and Reference Books

1.Matrices and Tensor in Physics: A.W.Joshi

2. Mathematical Physics: H.K.Dass

3. Tensors in Mechanics and Elasticity Brillouin.

4. Vector analysis – Newell

5. Rajput B S, Mathematical Physics, PragatiPrakashan (Meerat) 1999

Semester I Paper 2 (Core 2) (PSCPHYT02) Complex Analysis and Numerical Methods

Unit I
Definition of Complex Numbers, Equality of Complex Number, Complex Algebra, Conjugate Complex Numbers, Geometrical representation of Complex Number, Geometrical representations of the sum, difference, product and quotient of Complex Number, Cauchy-Rieman Conditions, Analytic functions, Multiply connected regions, Cauchy Theorem, Cauchy Integration formula, Derivatives, problems.

Unit II
Singularities- Poles, Branch Points, Calculus of Residues-Residues Theorem, Cauchy Principle value, Pole Expansion of Meromorphic Functions, Product expansion of entire Functions, problems .

UNIT III
Methods for determination of zeros and linear and non-linear single variable algebraic and transcendental equations, (Bisection method, false position method, iteration method, Newton-Raphson method, secant method), Finite differences. Newton's formulae (no proofs)

Unit IV
Lagrange's interpolation, Divided differences. Numerical integration, trapezoid rule, simpson's 1/3rd rule, Simpson's 3/8th rule, Linear least squares.
Euler and RungeKutta methods for solving ordinary differential equations. (No proofs)

References:
1. Rajput B S, Mathematical Physics, PragatiPrakashan (Meerat) 1999
2. Introductory Methods of Numerical Analysis: S Sastry
3. Computer Oriented Numerical Methods: V Rajaraman
4. R. V. Churchill, Complex variables and Applications, 7th Edition McGraw Hill
5. Computer oriented Numerical Methods: R.S.Salaria
6. Mathematical Physics: H.K.Dass
7. Higher Engineering Mathematics : B. S. Grewal

Semester I Paper 3 (Core 3) (PSCPHYT03) Electronics

Unit I
Electronics Semiconductor discrete devices (characteristic curves and physics of p-n Junction), Schottky, Tunnel and MOS diodes, Bipolar junction transistor, junction field effect transistor (JFET),Metal-oxide-Semiconductor Field effect transistor (MOSFET), unijunction transistor(UJT) and sillicon controlled rectifier (SCR), Opto-electronic devices (Photo-diode, solar cell, LED, LCD and photo transistor

Unit II
Applications of semiconductor devices in linear and digital circuits- Zener regulated power supply, Transistor (bipolar, MOSFFT, JFET) as amplifier, coupling of amplifier stages (DC, RC and Transformer coupling), RC-coupled amplifier.
Feedback in amplifiers and oscillators (phase shift, Hartley, Colpitts and crystal controlled) clipping and clamping circuits. Transistor as a switch OR, AND and NOT gates (TIL and CMOS gates).

Unit III
Digital integrated circuits- NAND and NOR gates building block, X-OR gate, simple combinational Circuits -Half and full address, Flip-Flops, Multivibrators (using transistor) and sweep geneator (using transistors, UJT and SCR). shift registers, counters, A/D and D/A coverters. Linear integrated circuits-Operational amplifier and its applications-Inverting and noninverting amplifier, adder, integrator, differentiator, waveform generator, comparator and Schmitrigger.

Unit IV
Communication Electronics-Basic principle of amplitude frequency and phase modulation. Simple circuits for amplitude modulation and demodulation, digital (PCM) modulation and demodulation. Fundamentals of optical communication, Microwave Oscillators (reflex, klystron, megnetron and Gunn diode), Cavity resonaters. Standing wave detector.

Textbooks:
1. A. Malvino and D. J. Bates: Electronic Principles (Mc Graw Hill Education, India)
2. Boylstad&Neshishkey, "Electronic devices & circuits" , PHI
3. Milliman, J. Halkias, "integrated elctronics", Tata McGraw Hill
4. J. J. CatheySchaum's Outlines "Electronic Devices & Circuits" Tata McGraw Hill.
5. J. D. Ryder," Electronics Fundamentals and Applications", John Wiley-Eastern Publications.
6. A. P. Malvino, D.P. Leach, "Digital Principles and Applications", McGraw Hill Book Co., 4th Edition (1986).
7. Ramakant A. Gayakwad, "Op-amps and Linear Integrated Circuits" PHI
8. Anil Maini, Varsha Agrawal, " Electronic Devices and acircuits" Wiley
9. George Kennedy, " Electronic Communication Systems", Tata McGraw Hill.
10. Dennis Roddy, John Coolen, "Electronic Communication Systems ", Pearson

Semester I Paper 4 (Core 4) (PSCPHYT04) Electrodynamics I

Unit I
Electrostatics: Coloumb's law, Electric field, Charge distribution, Dirac delta function, Field lines, Gauss's law and applications, Differential form of Gauss's law, Electric potential, Poisson and Laplace's equations, Electrostatic potential energy.

Unit II
Electrostatics: Boundary value problems, Uniqueness theorems, Green's theorem, Method of images, Method of separation of variables (Cartesian Coordinates, Spherical and Cylindrical Coordinates), Multipole expansion.

Unit III
Magnetostatics: Biot-Savart law, Ampere's law, Differential form of Ampere's law, Vector potential, Magnetic field of a localized current distribution, magnetic moment, Magnetostatics boundary conditions, Magnetic Shielding.

Unit IV
Time varying fields: Faraday's law, Maxwell's displacement current, Maxwell's equations, Maxwell's equations in matter, Scalar and vector potentials, Gauge Transformation, Wave equations, Poynting's theorem, Conservation laws.

Text Books:
1.Introduction to Electrodynamics, David J. Griffith, Prentice Hall of India Private Limited.
2. Classical Electrodynamics, John D. Jackson, Wiley Eastern Limited.
3. Classical Electrodynamics, Tung Tsang, World Scientific Publishing Private Limited.

Semester I Practical 1 and 2   Practical 1 (core 1 and 2) (PSCPHYP01&P02)
1. To find the largest or smallest of a given set of numbers.
2. Bubble sort.
3. To generate and print first hundred prime numbers.
4. Matrix multiplication.
5. To generate and print an odd ordered magic square.
6. Other exercises involving conditions, loop and array
7. Lagrange Interpolation.
8. Method of successive approximation
9. Bisection Method
10. Newton-Raphson Method.
11. Gaussian Elimination
12. Linear Least Squares Fit.
13. Simpson's rule integration.
14. Computation of special functions

Practical 2 (Core 3 and 4) (PSCPHYP03&P04)

1. Design of a regulated power supply.
2. Characteristics and applications of silicon controlled rectifier.
3. Design of common emitter Power transistor amplifier.
4. Experiments on bias stability.
5. Negative feedback (Voltage series / shunt and current series / shunt).
6. Astable, Monostable and Bistable multivibrator.
7. Experiment on FET and MOSFET characterization and application as an
8. amplifier.
9. Experiment on Uni-junction transistor and its application.
10. Digital – I: Basic, TTL, NAND and NOR.
11. Digital – II: Combinational logic.
12. Flip-Flops.
13. Study of modulation (FM, AM, etc.).
14. Operational Amplifier.
15. Differential Amplifier.
16. Microprocessor.
17. Verification of Biot-Savart law.
18. Verification of Faraday's Law

Semester II Paper 5 (Core 5) (PSCPHYT05) Quantum Mechanics I

Unit- I

Time dependent and time-independent Schrodinger equation, continuity equation, wave packet, admissible wave functions, stationary states.

Formalism of wave mechanics, expectation values, quantum mechanical operators for position and momentum in the coordinate representation, Construction of quantum mechanical operators for other dynamical variables from those of position and momentum, Ehrenfest's theorem, momentum eigen functions in the coordinate representation, box normalization and Dirac delta function.

Unit-II

Brief revision of linear vector spaces, inner or scalar product, Schwarz inequality, state vectors, general formalism of operator mechanics vector, operator algebra, commutation relations, eigen values and eigen vectors, hermitian operators degeneracy, orthogonality eigenvectors of Hermitian operators, noncommutativity of two operators and uncertainty in the simultaneous measurements of the corresponding dynamical variables, the fundamental expansion postulate, representation of state vector, Dirac's bra-ket notations.

Matrix representation of operators, change of basis, unitary transformations, quantum dynamics, Schrodinger, Heisenberg and interaction picture.

Unit-III

Solution of Schrodinger equation for simple problems, 1-D Square well, step and barrier potentials, 1-D harmonic oscillator, zero point energy. harmonic oscillator problem by operator method.

Angular momentum operator, commutation relations, expression for L2 operator in spherical polar coordinates, Role of L2 operators in central force problem, eigen value problem for L2 , separation of Schrodinger equation in radial and angular parts, solution of radial equation for hydrogen atom, 3-d square well potential, parity of wave function, parity operator

Unit-IV

Generalized angular momentum, raising and lowering operators, matrices for J2, Jx, Jy, Jz operators,Pauli spin matrices, Addition of angular momenta, Clebich-Gordon Co-efficient, spin angular momentum, spin momentum functions.

Text and Reference Books:

1. Quantum mechanics: E. Merzbacher
2. Quantum mechanics: L.I.Schiff
3. Quantum mechanics: Mathews and Venkatesan
4. Quantum mechanics :Ghatak and Loknathan
5. Quantum mechanics: B.Craseman and J.D.Powell
6. Modern quantum mechanics: J.J.Sakurai
7. Quantum Theory D. Bohm, (Asia Publishing House)
8. Quantum Mechanics: 500 problems with Solutions: Aruldhas (PHI)

Semester II Paper 6 (Core 6) (PSCPHYT06) Statistical Physics

Unit I
Fundamentals of classical statistical mechanics, microstate and macrostate, distribution function, Liouville's theorem, Gibbs Paradox, ensembles (micro-canonical, canonical and grand-canonical), partition function, free energy and connection with thermodynamic quantities, energy and density fluctuations

Unit II
Fundamentals of quantum statistical mechanics, BE and FD Statistics, Symmetry of wave functions, Boltzmann limit of Bosons and Fermions, Ideal Bose system: Bose-Einstein condensation, Behaviour of ideal Bose gas below and above Bose temperature, Photons and liquid helium as bosons.

Unit III
Ideal Fermi system: Weak and strong degeneracy, Fermi function, Fermi energy, Behaviour of ideal Fermi gas at absolute zero and below Fermi temperature, Fermionic condensation, Free electrons in metals as fermions, Electronic specific heat,
Cluster expansion for classical gas, Virial equations of states.

Unit IV
Phase transition: Phase transition of first and second order, Landau theory of phase transition, Ising model, Order parameter, Critical exponents, Scaling hypothesis, Random walk, Brownian motion, Langevin theory, Correlation function and fluctuation-dissipation theorem, Fokker-Planck equation. Weiss theory of ferromagnetism.

Text and Reference Books:
1. Fundamentals of Statistical Physics: B. B. Laud
2. Statistical Mechanics: R. K. Pathria
3. Statistical Mechanics: S. K. Sinha
4. Statistical and Thermal Physics: F. Reif
5. Statistical Mechanics: K. Huang
6. Statistical Mechanics: Loknathan and Gambhir
7. Statistical mechanics: R. Kubo
8. Statistical Physics: Landau and Lifshitz

Semester II Paper 7 (Core 7) (PSCPHYT07) Classical Mechanics

Unit-I
Survey of elementary principles of mechanics of a particle, Dynamical systems, Phase space dynamics, stability analysis, constraints & their classifications, D'Alemberts Principle, Variational Principle, Lagrange's equation, Hamilton's Principle.

Unit-II
Conservation theorems and symmetry properties, Hamiltonian formalism, Hamiltons equations, Routh's procedure for cyclic coordinates, conservation laws
Canonical transformations, Poisson brackets and Poisson theorems, Hamilton-Jacobi Theory

Unit-III
Central force motion, reduction to one body problem, equations of motions and first integrals , classification of orbits for inverse square central forces. Two body collisions, Rutherford scattering in laboratory and centre-of-mass frames.

Unit-IV
Rigid body dynamics, Euler's angles, Euler's theorem, moment of inertia tensor, eigen values and principal axis transformation, non-inertial frames and Pseudo forces, Periodic motion,: small oscillations, normal modes.

Text and Reference books:
1. Classical Mechanics: H. Goldstein
2. Classical Mechanics: N.C.Rana and P.S.Joag
3. Classical Mechanics : J. C. Upadhyaya (Himalaya Publishing House)

Semester II Paper 8 (Core 8) (PSCPHYT08) Electrodynamics II

Unit-I
Scalar waves : Plane waves, spherical waves, phase and group velocities and wave packets Vector waves : Electromagnetic plane waves, harmonic plane waves, elliptic linear and circular polarization, Stokes parameters, Reflection and refraction of plane waves, Fresnel polarization on reflection and refraction, Propagation in dielectric films.

Unit-II
Symmetries of Maxwell equations : Lorentz transformations, Covariance of electrodynamics, Lorentz gauge condition, equation of continuity and Maxwell equations, electrodynamics field tensor and its transformation. Relativistic field theory, Lagrangian for EM field conservation laws, conformal invariance.

Unit-III
Motion of a charge in EM fields : Lorentz force, motion in uniform, static, electric and magnetic fields and combined static EM fields. Wave equation : Electric dipole, electric quadrupole and magnetic dipole radiation, half wave and full wave antenna. Radiation by a moving charge :Lienard-Wiechert potentials of a point charge, Larmor's formula, Angular distribution of radiation.

Unit-IV
Wave guides: Cylindrical cavities, fields on the surface and within a hollow metallic conductor,TE, TM, TEM modes in a rectangular and cylindrical wave guide, fields and radiation of a localized oscillating source, electric dipole, magnetic dipole and electric quadrupole fields. Bremsstarhlung : virtual quanta, synchrotron radiation.

Reference Books
1. Introduction to Electrodynamics: David Griffiths (PHI)
2. Electrodyanamics J. D. Jackson
3. Introduction to Electrodynamics, A. Z. Capri and P. V. Panat (Narosa)
4. Classical theory of fields, Landau &Lifshitz
5. Electrodynamics, W. Panofsky and M. Phillips
6. Principles of Optics, M. Born & E. Wolf Pergamon Press
7. Electromagnetism and Classified Theory, A. D. Barut, Dover

Semester II Practical 3 and 4
Practical 3 (C5 and C6) (PSCPHYP03&P04)

1. Study of B-H Curve
2. Determination of e/m of electron by normal Zeeman effect using Febry Perot Etalon.
3. Determination of Lande's factor of DPPH using ESR spectrometer
4. Determination of e/m by Thomson method.
5. Determination of e/m by Busch's helical beam method.
6. Study of paramagnetic to ferromagnetic phase transition.
7. Study of Paramagnetic salt by Guoy's balance
8. Differential scanning Calorimetry
9. Determination of Plank's constant.
10. Determination of Stephan's constant.
11. Simulation of Ising model.
12. Location of critical point in Ising model using Binder cumulant.
13. Simulation of random walk.
14. Simulation of mean field model of para-ferro transition.
15. Numerical solution of particle in a box.
16. Simulation of Maxwell's velocity distribution.
17. Construction and determination of dielectric constant.

Practical 4 (core 7 and 8) (PSCPHYP07&P08)

1. Study of Focault pendulum
2. Study of Bifilar pendulum
3. Fibre optics
4. Study of waveguide
5. Thickness of thin wire with lasers
6. Measurement of wavelength of He-ne laser light using ruler.
7. To study Faraday effect using He-Ne laser.
8. Simulation of simple pendulum
9. Simulation of compound pendulum
10. Simulation of planetary motion.
11. Study of emission spectra of iron (Iron arc).
12. Determination of Dissociation Energy of Iodine (Molecule by photography of the absorption band of Iodine in the visible region.
13. Determination of wavelength of monochromatic source using MICHELSON Interferometer.
14. Measurement of resistivity of a semiconductor by four probe method at different temperatures and determination of band gap energy.
15. Study of Hall Effect in semiconductors.
16. Ultrasonic velocity of liquid mixtures- Interferometer
17. Thermistor characteristics-Band gap energy