MASTERS DEGREE PROGRAM IN PHYSICS

MODULE DESCRIPTION FORMS

1. Module Code: MPH6161

2. Module Title: CLASSICAL MECHANICS

3. Level: 6 **Semester:** 1 **Credits:** 15

4. First year of presentation: 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH

5. Pre-requisite modules, excluded combinations: N/A

6. Allocation of study and teaching hours

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim:

The aim of the course is to give to students a complete solid understanding of Classical Mechanics at an advanced level. The course provides indispensable preparation for all advanced courses in theoretical physics. Techniques learned have wide use in advanced quantum mechanics, classical and quantum field theory, general relativity, particle physics and statistical mechanics that the student would learn in the subsequent semesters.

Content:

- Lagrangian Formulation of Mechanics: Calculus of Variations, Action Integral, Principle of

Least Action, Euler-Lagrange Equation, Generalized Co-ordinates and Momenta, Constraints, Normal Modes, Conservation Laws: energy, linear momentum, angular momentum; the virial theorem, integration of the equations of movement: problems with one degree of freedom, two body problem, movement in a central field, scattering in a central field;

- Dynamics of Rigid Bodies: Moment of Inertia tensor, Principal Moments and Principal Axes of Inertia, Euler Angles;
- Hamiltonian Formulation of Mechanics: Hamilton's Equations, Poisson Brackets, Canonical Transformations, Liouville theorem, Hamilton-Jacobi theorem, Hamilton-Jacobi theorem, separation of variables, action-angle variables, adiabatic invariants, Continuous Symmetries and Conservations Laws.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to show knowledge and understanding of:

A.1. The Lagrangian and Hamiltonian formulations of classical mechanics;

A.2. The motion of isotropic gyroscope, symmetric gyroscope, asymmetric gyroscope.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1 Formulate and solve problems related to motion of holonomic and non holonomic systems with the newtonian formalism;

B.2. Apply variational principles in real-world examples of mechanics;

B.3. Define the Hamiltonian function for different systems;

B.4. Find and analyze solutions of canonic equations describing the motion of simple systems;

B.5. Define the integrals of motion of systems;

B.6. Define different canonic transformations;

B.7. Demonstrate the theorem of Liouville;

B.8. Apply mathematical methods for problems in mechanics and solve standard problems in theoretical mechanics;

B.9. Relate theoretical models to their applications;

B.10. Transfer expertise between different topics in mathematics.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Communicate with clarity and collaborate effectively with other students;

C.2. Work effectively, independently and under direction;

Demonstrate an enhancement of problem solving abilities, particularly mathematical approaches to problem solving;

C.3. Use appropriate sources as part of directed self-learning;

C.4. Make effective use of IT.

D. Key Transferable Skills

On completion of the module, students will be able to:

D.1. Justify conclusions using mathematical arguments with appropriate rigour;

D.2. Use appropriate sources as part of directed self-learning;

D.3. Accomplish projects and team tasks, and to collaborate in the group carrying out her/his part of the job;

D.4. Communicate results using appropriate styles, conventions and terminology;

D.5. Exercise initiative and personal responsibility;

D.6. Work independently and present effectively technical information in both written and oral forms;

D.7. Tackle material which is given both unfamiliar and complex;

D.8. Have a sense of self-organization, self-discipline and self-knowledge;

D.9. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

LAGRANGIAN MECHANICS

Generalized Coordinates, Hamilton’s Principle, Invariance of the equations of motion, Calculus of Variation, Derivation of Lagrange’s Equation form Hamilton’s Principle, Extension of Hamilton’s Principle to non-holonomic Systems, Advantage of Variational Principal Formulation, Noether’s

Theorem, Symmetries and conservation laws: Conservation of momentum, angular momentum and energy, virial theorem, central force motion: Kepler problem, Scattering in a central potential, Rutherford formula. Example #1: A sliding point mass on a sliding wedge, Example #2: A pendulum attached to a mass on a spring, Example #3: Double pendulum, Example #4: The thingy. Constraints: Constraints and Variational Calculus, Constrained Extremization of Functions, Extremization of Functionals: Integral Constraints; Extremization of Functionals: Holonomic Constraints; Examples of extremization with constraints; Constraints and Conservation Laws. Application to Mechanics: Example #5: One cylinder rolling off another, Example #6: Frictionless motion along a curve, Example #7: Frictionless motion along a curve, Example #8: Disk rolling down an inclined plane, Example #9: Pendulum with non-rigid support, Example #10: Falling ladder, Example #11: Point mass inside rolling hoop.

DYNAMICS OF RIGID BODY

Kinematics of rigid body: infinitesimal rotations, Euler's angles, rigid system of particles, Tensor of Moments of Inertia. Dynamics of Solid: Euler's Equations, Euler-Lagrange Equations, theorem of the kinetic resultant, theorem of kinetic energy. Torque Free Motion, Stability, Symmetric Top, Asymetric Top. Systems under liaisons: holonomic and non holonomic systems, reaction forces, d'Alembert and Lagrange methods, Euler-Poinsot's problem, Lagrange-Poisson's problem. Equilibrium and stability. Stationary systems. Symetric fields. Gravitation Field: Law of Gravitation, Field surrounding a solid, Precession of the Moon. Heavy gyroscope: general study, gyroscopic effect, gyroscopic compass.

HAMILTONIAN MECHANICS

Canonical Equations of Hamilton

Legendre Transformations and the Hamiltonian Equations; Hamilton's Principle, Modified Hamilton's Principle; Cyclic Coordinates and Conservation Theorems; Derivation of Hamilton's

Equations from a Variational Principe; Poisson Brackets; the Principal of Least Action; Principal of Maupertuis, Poincare Recurrence Theorem; Canonical Transformations: the Equation of Canonical Transformation (Function of Routh), Examples of Canonical Transformations, the Harmonic Oscillator, The Symplectic Approach to Canonical Transformations, Generating Functions for Canonical Transformations, Equation of Motion, Infinitesimal Canonical Transformations and Conservation Theorems in the Poisson Bracket Formulation, the Angular Momentum Poisson

Bracket Relations, Symmetry Groups of Mechanical Systems, Liouville's Theorem.

Hamilton-Jacobi Theory and Action Angle Variables

The action as a function of coordinates and time, The Hamilton-Jacobi Equations for Hamilton's Principal Function, Example #1: the Harmonic Oscillator, Example #2: Particle in a Box, the Hamilton-Jacobi Equation for Hamilton's Characteristic Function, Time-independent Hamiltonians, Example #3: one-dimensional motion, Separation of Variables in the Hamilton-Jacobi Equations, Example #4: point charge plus electric field, Example #5:: Charged Particle in a Magnetic Field; Ignorable Coordinates and the Kepler Problem, Action-Angle Variables, Action-Angle Variables for Completely Separable Systems, Example #6: Kepler Problem in Action-Angle Variables, Example #7: Motion on Invariant Tori.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information.

The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the black board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and black board for solving problem.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.

- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A2, B1-B10, C1-C4**
CA II: Mid-Semester Examination	30	**A1-A2, B1-B10, C1-C4, D1-D9**
End Semester Examination	40	**A1-A2, B1-B10, C1-C4, D1-D9**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Text

- Goldstein H., C. P. Poole, and J. L. Safko, Classical Mechanics, 3rd ed., Addison-Wesley, 2001.

Background Texts

- De Lange O.L. and J. Pierrus, Solved Problems in Classical Mechanics: Analytical and numerical solutions with comments, Oxford University Press, 2010.
- Goldstein H., Classical Mechanics. 3rd ed. San Francisco, CA: Addison-Wesley, 2002.
- Hand L.N. and J. D. Finch, Analytical Mechanics, Cambridge University Press, Cambridge, England, 1998.
- Jorge V. J. and E.J. Saletan, Classical Dynamics, A contemporary approach, Cambridge Univ. Press, 1998.

- Landau L. D. and E. M. Lifshitz, Mechanics, Course of Theoretical Physics, Volume 1, 3rd ed., Pergamon Press, New York, 1976.
- Landau L. D. and E. M. Lifshitz, Mechanics. 3rd ed. Translated by J. B. Sykes and J. S. Bell. Oxford, UK: Butterworth-Heinemann, 1982.
- Landau L. D. and E. M. Lifshitz, The Classical Theory of Fields: Volume 2 (Course of Theoretical Physics Series), Butterworth-Heinemann.
- Marion J. B. and S.T. Thornton, Classical Dynamics. 4th ed. Fort Worth, TX: Saunders College Pub., 1995.
- Morin D., Introduction to Classical Mechanics, with problems and solutions, Cambridge Univ. Press, 2008.
- Percival I. and R. Derek, Introduction to Dynamics, Cambridge University Press, 1987.
- Scheck F., Mechanics: From Newt's Laws to Deterministic Chaos, 5th ed., New York, NY: Springer-Verlag, 1999.
- Taylor E. F. and J. A. Wheeler, Spacetime Physics, W. H. Freeman, San Francisco, 1992.
- **Module Team:**

  Module Leader: Prof. Bonfils Safari

  Team members: another Lecturer to be identified

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1. **Module Code:** MPH6162
2. **Module Title**: MATHEMATICAL METHOD FOR PHYSICS
3. **Level:** 6 **Semester:** 1 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36

Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim:

The course will cover some mathematical techniques commonly used in theoretical physics. This is not a course in pure mathematics, but rather on the application of mathematics to problems of interest in the physical sciences.

Content:

Depending on your initial preparation, to be assessed by a preliminary test that will not count for your final grade, we will cover some or all of the following topics: • Vector calculus in curvilinear coordinates; • The theory of analytic functions; • Linear algebra, vectors and tensors in physics; • Special functions and their physical applications; • Partial and ordinary differential equations; analytical and numerical methods for their solution. This is a course in mathematical physics, so the emphasis will always be on physical applications.

8. Learning Outcomes

A. Knowledge and Understanding

By the end of the course, the student must demonstrate good knowledge and understanding of:

A.1. Vector calculus in curvilinear coordinates;

A.2. The theory of analytic functions;

A.3. Linear algebra, vectors and tensors in physics;

A.4. Special functions and their physical applications;

A.5. Partial and ordinary differential equations;

A.6. Analytical and numerical methods for their solution.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1 Apply vector calculus in curvilinear coordinates and tensors in physical problems;

B.2. Find and analyze solutions of partial differential equations and their physical applications;

B.3. Apply mathematical methods for problems in physics and solve standard problems in theoretical physics;

B.4. Relate theoretical models to their applications;

B.5. Transfer expertise between different topics in mathematical physics.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

Having successfully completed the module, students should be able to:

C.1. Analyze and solve complex problems in Mathematical Physics;

C.2. Give a clear presentation on a chosen subject matter related to Mathematical Physics.

D. Transferrable skills

Having successfully completed the module, students should demonstrate the ability to:

D.1. Solve both unfamiliar and complex problems and to present written report;

D.2. Tackle material which is given both unfamiliar and complex;

D.3. Learn independently, actively and reflectively and to develop intuition;

D.4. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.5. Construct clearly logical arguments;

D.6. Have a sense of self-organization, self-discipline and self-knowledge;

D.7. Pursue further studies in this and related areas.

9. Indicative Content

LINEAR VECTOR SPACES

- *Basic Linear Algebra:* Definition of a Linear Vector space; the Scalar Product; Dual vectors and the Cauchy-Schwartz Inequality; Real and complex Vector Spaces; Metric spaces; Linear Operator; the Algebra of Linear Operator; Some Special Operators; Linear Independence of Vectors; Eingenvalues and Eingenvectors (Ordinary and Generalized Eingenvectors); Orthogonalization Theorem; N-Dimensional Vector Space; Matrix Algebra; The Inverse of a

Matrix; Change of Basis in an N-Dimensional Space. Exercises and Problems

THEORY OF ANALYTICAL FUNCTION

- *Basic Complex Analysis:* Elementary Notions of Set Theory and Analysis; Function of a Complex Argument; the Differential Calculus of Functions of a Complex Variable. Exercises and Problems
- *Integration: t*he Cauchy Riemann Conditions; the Integral calculus of Function of a Complex Variable: Cauchy and Stokes. Exercises and Problems
- *Applications:* the Darboux Inequality; Examples of Analytic Functions: Polynomial-Power Series-Exponential and Related Functions; Conformal Transformations: Conformal Mapping-Homographic Transformation-Change of Integration Variable; a simple application of Conformal Mapping; the Cauchy Theorem. Exercises and Problems
- *Applications of Cauchy's Theorem:* Cauchy's Integral Representation; The Derivatives of an Analytic Function; Local behaviour of an Analytic Function; the Cauchy-Liouville Theorem; the Theorem of Morera; Manipulations with Series of Analytical Function; the Taylor Series; Zeros and Isolated Singular Points of Analytic Functions: Zeros, Isolated Singular Points; Calculus of Residues: Theorem of Residues-Evaluation of Integrals; the Principal value of an Integral; Multivalued Functions; Riemann Surfaces: The Logarithmic Function and Its Riemann Surface-The Functions $f(z)=z^{1/n}$ and Their Riemann Surface-The Functions $f(z)=(z^2-1)^{1/2}$ and Its Riemann Surface; Example of the Evaluation of an Integral Involving a Multivalued Function; Meromorphic functions and the Winding-Number: the Mittag-Leffer Expansion-A Theorem on Meromorphic Function; Analytic Continuation; Contour Integration Technology; The Shwartz Reflection Principle; Dispertion Relations; the Fundamental theorem of Algebra; Partial-Fraction and Product Expansions; the Method of Steepest Descent; Asymptotic Expansion; Wiener-Hopf Equations; Function of Several Complex variables; the Gamma Function. Exercises and Problems.

FUNCTION SPACE, ORTHOGONAL POLYNOMIALS, AND FOURIER ANALYSIS

- *Basics in Calculus:* Space and Continuous Function; Metric Properties of the Space Functions; Elementary Introduction to the Lebesgue Integral; the Riesz-Ficher Theorem; expansions in Orthogonal Functions; Hilbert Space; the generelization of the Notion of a basis; the

Weirstrass Theorem. Exercises and Problems.

- *The Classical Orthogonal Polynomials:* the Generalized Rodriguez Formula; Classification of the Classical Polynomials; the recurrence relations; Differential Equations Satisfied by the Classical Polynomials; the Classical Polynomials. Exercises and Problems.
- *Trigonometrical Series:* an Orthonormal Basis in $L_1^2(-\pi, \pi)$, the Convergence Problem. Exercises and Problems.
- *The Fourier Transform:* An Introduction to the Theory of Generalized Functions: Definition of a Generalized Function; Handling Generalized Functions; The Fourier Transform of a Generalized Function; the Dirac δ Function. Exercises and Problems.

DIFFERENTIAL EQUATIONS

- *Basics in Ordinary Differential Equations:* Second Order Differential Equations: Preliminaries; the Transition from Linear Algebraic Systems to Linear Differential Equations-Difference Equations. Exercises and Problems.
- *Green's Function Theory*: Generalized Green's Identity; Green's Identity and Adjoint Boundary Conditions; Second-Order Self Adjoint Operators; Green's Functions; Construction and Uniqueness of Green's Function; Generalised Green's Function; Second Order Equation with inhomogeneous Boundary Conditions, The Sturn-Liouville Problem; Eingenfunction Expansion of Green Function. Exercises and Problems.
- *Series Solutions of Linear Differential Equations of the Second Order that depend on a Complex Variable*: Classification of Singularities; Existence and Uniqueness of the Solution of Differential Equation in the neighborhood of an Ordinary Point; Solution of Differential Equation in the neighborhood of a Regular Singular Point. Exercises and Problems
- *Solution of Differential Equation Using the Method of Integral Representation:* General Theory; Kernels of Integral representations. Exercises and Problems.
- *Fuchsian Equations with three Regular Singular Points.* Exercises and Problems.

SPECIAL FUNCTIONS

- *The Hypergeometric Function:* Solutions of the Hypergeometric equation; Integral Representation of the Hypergeometric Function; Some further Relations Between Hypergeometric Functions. Exercises and Problems.

- *Functions Related to the Hypergeometric Function:* The Jacobi Function; The Gegenbauer Function; The Legendre Functions. Exercises and Problems.
- *The Confluent Hypergeometric Function and related:* Parabolic Cylinder Functions; Hermite and Laguerre Polynomials, The Error Function; The Bessel Function; Hankel functions, Elliptic Functions, elliptic modular function. Exercises and Problems.

The part on partial differential equations can be given in seminars or a separate module early before the stating of the program.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information.

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Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the black board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and black board for solving problem.

Teaching material: students will be provided with Reference Textbooks and or handouts notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

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Absence to examination:

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Grading:

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Total	100	

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13. Strategy for Feedback and Student Support during Module

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14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Arfken G.B. and H.J. Weber**,** Mathematical Methods for Physicists, 7th ed., Academic Press, 2012.
- Byron F.W and R.W. Fuller, Mathematics of Classical and Quantum Physics, Reprint edition, Dover Publications, 1992.
- Dennery P. and A. Krzywicki, Mathematics For Physics, Dover Publications, 1996.

Background Texts:

- Bender C.M. and S.A. Orszag, Advanced Mathematical Methods for Scientists and Engineers: Asymptotic Methods and Perturbation Theory, Springer-Verlag New York Inc., 1999.
- Boas M.L., Mathematical Methods in the Physical Sciences, 3rd ed., John Wiley & Sons, 2005.
- McCord P. M. and H. Feshbach, Methods of Theoretical Physics, Part I, McGraw-Hill Science/Engineering/Math, 1953.
- McCord P. M. and H. Feshbach, Methods of Theoretical Physics, Vol.2, McGraw-Hill, 1953.
- Press W.H., S.A. Teukolsky, W.T. Vetterling and B.P. Flannery, Numerical Recipes: The Art of Scientific Computing, 3rd ed., Cambridge University Press, 2007.
- R. Courant and D. Hilbert, Methods of Mathematical Physics, Vol.1, Wiley-VCH, 1989.

15. Module Team:

Module Leader: Dr. Emmanuel Nshingabigwi

Team members: Assistant Lecturers to be identified

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1. **Module Code:** MPH6163
2. **Module Title**: ADVANCED ELECTROMAGNETISM
3. **Level:** 6 **Semester:** 1 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim:

The aim of the course is to give students a strong foundation in the fundamental parts of Advanced Electromagnetism and Special Relativity. This course is basic to an understanding of all modern physics and is prerequisite for all the courses to be followed in the High Energy and Condensed Matter second year Masters programs.

Content:

The first part covers advanced topics in electrodynamics, from Maxwell's equations, gauge transformations, the energy and momentum in electromagnetic fields, multipole expansions and dipole radiation, to electromagnetic fields in macroscopic media and relativistic field theory. We will introduce the scalar and vector potential, complex fields, spherical harmonics and Legendre polynomials, as well as four-vector notation and index notation. The second part of the module introduces Special Relativity of Einstein with emphasis on the coordinate transformations between coordinate systems moving at constant velocities.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Establish and solve the Maxwell Equations in vacuum and in matter;

A.2. Describe the propagation of electromagnetic waves in isotropic dielectric media, in conducting media;

A.3. Describe and explain the experiments which led to the abandonment of Galillean Relativity;

A.4. State and apply the principle of Relativity of Einstein;

A.5. Obtain Lorentz transformation from Einstein's postulates.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Apply Lorentz transformations on the electromagnetic field;

B.2. Find and analyze solutions of Maxwell Equations and their physical applications;

B.3. Apply mathematical methods for problems in physics and solve standard problems in electromagnetism theory;

B.4. Relate theoretical models to their applications;

B.5. Transfer expertise between different topics in electromagnetism.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

Having successfully completed the module, students should be able to:

C.1. Analyze and solve complex problems in electromagnetism;

C.2. Give a clear presentation on a chosen subject matter related to electromagnetism.

D. Transferrable skills

Having successfully completed the module, students should demonstrate the ability to:

D.1. Solve both unfamiliar and complex problems and to present written report;

D.2. Tackle material which is given both unfamiliar and complex;

D.3. Learn independently, actively and reflectively and to develop intuition;

D.4. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.5. Construct clearly logical arguments;

D.6. Have a sense of self-organization, self-discipline and self-knowledge;

D.7. Pursue further studies in this and related areas.

9. Indicative Content

PART I: ELECTRODYNAMICS

Review of the Coulomb, Gauss's laws and surface integral, Bio-Savart law, Ampere's law and line integral, Faraday law. The Divergence Theorem. Conservation of charge and the equation of continuity. Stokes' Theorem and the meaning of the curl. Simple examples of curl in cylindrical polar coordinates. The displacement current. A more comprehensive study of Lorentz force, Electrostatics, Magnetostatics and Faraday's law. Maxwell's equations (non-relativistic form). Conservation laws. Then solving Maxwell's equations: Retarded solutions, Radiating Systems and Plane waves. This would include boundary problems in electrostatics ; the green function ; momentum of distributed charges. Electromagnetic waves and their propagation. Generation of electromagnetic waves, Hertz' experience, qualitative and quantitative transport of electromagnetic waves. Electric and magnetic fields in matter : vector fields **E, B, H, D, P** and **M**. Retarded potential. Electrodynamics in relativistic notation. Lorentz transformation for electromagnetic field. Energy and momentum fields. The electromagnetic mass. The dynamics of relativistic particles and fields and the radiation of moving charges once more. Energy transport and the vector electromagnetic energy transport (Poynting Vector).

PART II: SPECIAL RELATIVITY

Given the transformation properties of Maxwell's equations one introduces the concept of

Lorentz transformations in general and shows that they preserve the Minkowski metric. Consequences of this are elaborated including: simultaneity of events, length contraction, time dilatation, composition of velocity, transformation of acceleration. These are corroborated by the experiments of Fizeau and Michelson-Morley.

Relativistic properties of particles including the differences between rest mass and relativistic mass are explained, transformations of energy and momentum are given, and relativistic equations of motion the relativistic expression of energy, particle with zero proper mass and conservation laws of energy and momentum are discussed.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the black board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning

outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A5, B1-B5, C1-C2**
CA II: Mid-Semester Examination	30	**A1-A5, B1-B5, C1-C2, D1-D7**
End Semester Examination	40	**A1-A5, B1-B5, C1-C2, D1-D7**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The main source is a set of Lecture Notes supplied by the lecturer at the start of the course. However, there are many good books on quantum mechanics which one may recommend.

Core Texts:

- Griffiths D., Introduction to Electrodynamics, 4th ed., Addison-Wesley, 2012;
- Jackson, J.D, Classical Electrodynamics, 3rd ed., Wiley, 1998

Background Texts:

- Landau L., E. Lifchitz, L. Pitaevskii, V. B. Berestetskii, Physique Théorique, Tome 4, Electrodynamique Quantique, Ed. MIR Moscou, 1982.
- Hugh D. Young and Roger A. Freedman, University Physics (extended with Mastering Physics) 11th ed., Pearson/Addison Wesley, 2004.
- Hugh D. Young, Roger A. Freedman, A. Lewis Ford, University Physics With Modern Physics, 13th ed., Addison-Wesley, 2011.

15. Module Team:

Module Leader: Prof. Yadav Lakhan Lal

Team members: Senior Lecturer to be identified

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1. **Module Code:** MPH6164
2. **Module Title**: QUANTUM MECHANICS I
3. **Level:** 6 **Semester:** 1 **Credits:** 15

4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH

5. **Pre-requisite modules, excluded combinations:** N/A

6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim:

The aim of the module is to give students a strong grounding in the foundational parts of Quantum Mechanics. This course is basic to an understanding of all modern physics and is prerequisite for all the courses to be followed in the High Energy and Condensed Matter second year Masters programs.

Content:

The module gives a description and analysis of classical and modern experiments that show that classical mechanics, electromagnetism and statistical physics are not valid at small enough scales. The module makes a review of initial attempts to understand this situation by Plank, Einstein, Bohr and others, culminating in the `old quantum theory'. Then comes the introduction to modern quantum mechanics and its probabilistic interpretation due to Born. The relationship between operators and observables is explained as well as how uncertainty relations arise. A complete analysis of the Simple Harmonic Oscillator and the Hydrogen bound states in various dimensions is given. This shows that the quantization of energy naturally arises from quantum mechanics. In order to perform the analysis a complete study of the rotation group is made in 2 and 3 dimensions. This leads to an understanding of spin states.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Explain why one must go beyond classical physics- and cite examples

A.2. Describe the old quantum theory and explain its limitations

A.3. Show a complete understanding of the physical and mathematical foundations of quantum mechanics

A.4. Completely determine the spectra of the simple harmonic oscillator and of Hydrogen like atoms in various dimensions.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Formulate quantum mechanical models given their classical counterparts including associating operators to classical observables

B.2. Understand how to apply rotational symmetry for central potentials to factorize the Schrödinger equation.

B.3. Identify certain second order differential equations and give their solutions in terms of known functions.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:

C.1. Analyze and solve complex problems in Quantum Mechanics;

C.2. Give a clear presentation on a chosen subject matter related to electromagnetism.

C.3. Communicate with clarity

C.4. Work effectively, independently and under direction

C.5. Analyze and solve complex problems accurately.

D. Key Transferable Skills

On completion of the module, students will be able to:

D.1. Solve both unfamiliar and complex problems and to present written report;

D.2. Tackle material which is given both unfamiliar and complex;

D.3. Justify conclusions using mathematical arguments with appropriate rigour;

D.4. Communicate results using appropriate styles, conventions and terminology;

D.5. Learn independently, actively and reflectively and to develop intuition;

D.6. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.7. Construct clearly logical arguments;

D.8. Have a sense of self-organization, self-discipline and self-knowledge;

D.9. Pursue further studies in this and related areas.

9. Indicative Content

The course begins with experimental facts. Black Body Radiation including Classical Formulae for Black Body Radiation, Theories of the Atom including Thomson's Model and Rutherford's Model. Potential Barrier Penetration or Tunneling. Issues with classical formulae of Specifc Heat, the Photoelectric Effect. Spectral Lines of Hydrogen and the Zeeman and Stark Effects. Compton Effect. The Stern-Gerlach Experiment. Double Slit Experiments with electrons and with classical objects.

This is followed by an overview of the `old quantum' theory which was created to explain

the above phenomena. Plank's Constant and Discrete Energy Levels. Continuous Versus Discrete Energy Levels. Specific Heat. Einstein's Theory of Photons and the Photoelectric Effect. The Theory of Photons Applied to Compton Scattering. The Bohr Atom and Energy levels of Hydrogen like Atoms. Sommerfeld-Wilson Quantization. de Broglie's Postulate and Matter Waves. A discussion on the existence of Particles and Waves? Correspondence Principle. Short comings of the old quantum theory.

The Schroedinger equation and modern quantum mechanics is introduced. The Born Interpretation. Conservation of Probability. Probabilistic. Physical Quantities and Operators. Commutators and Ordering of Operators. Representations. Linear Operators and Wavefunctions. Bras and Kets. Linear Operators and Matrices. Projection Operators. Adjoints and Hermitian Operators. Complete Set of Commuting Operators. The Position and Momentum Basis. Continuous and Discrete Infinite Dimensional Vector Spaces. Hermitian Operators and Completeness. The Schroedinger Equation in the Position Representation. Square Integrable Functions Form A Vector Space. Hermitian

Operators and Observables. A mathematical derivation of the Heisenberg Uncertainty Relations. Minimum Uncertainty states. When Does a Physical Quantity Have a Definite Value? Time and Energy uncertainty?

It is shown how the Quantization of Energy arises through the consideration of the simple harmonic oscillator and the Hydrogen atom in various dimensions. The Simple Harmonic Oscillator. Classical Theory. An approach to Solve the Schroedinger Equation. The Energy or {N} Representation. Thermodynamic Equilibrium. The {q} Representation and Hermite Polynomials. Tunneling and Forbidden Regions. Time Dependent Solutions. Creation and Destruction Operators. Two Dimensional Central Potential and Angular Momentum. The Two Dimensional Hydrogen Atom. Three Dimensional Central Potentials. Ladder Operators and Angular Momentum. Integers and half Integer states. Spherical Harmonics. Legendre Polynomials. The Radial Equation Schroedinger equation. The Simple Harmonic Oscillator in d Dimensions. The Two Dimensional Simple Harmonic Oscillator and Angular Momentum. Three Dimensional Simple Harmonic Oscillator. Differential Solution to the 3-dimensional Simple Harmonic Oscillator. Bound States of the Hydrogen Atom. Separation of Variables for Two Distinguishable Particles. Hydrogen Like Atoms.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the black board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks	30	**A1-A4, B1-B3, C1-C5**

(quizzes and homework)		
CA II: Mid-Semester Examination	30	**A1-A4, B1-B3, C1-C5, D1-D9**
End Semester Examination	40	**A1-A4, B1-B3, C1-C5, D1-D9**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The main source is a set of Lecture Notes supplied by the lecturer at the start of the course. However, there are many good books on quantum mechanics which one may recommend.

Core Texts:

- Cohen-Tannoudji C., B. Diu and F. Laloë, Quantum Mechanics, Wiley, 1977.
- Merzbacher E., Quantum Mechanics, 3rd ed., Wiley, 1998.
- Shankar C., Principles of Quantum Mechanics, 2nd ed., Plenum, 1994.

15. Module Team:

Module Leader: Prof. Karemera Marembo P.C.

Team members: George Thompson

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1. Module Code : MPH6261

2. **Module Title:** STATISTICAL PHYSICS
3. **Level:** 6 **Semester:** 2 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim:

The aim of the module is to give to students a complete solid understanding of Statistical Physics at an advanced level. Students will acquire fundamental knowledge of Classical and an introduction to Quantum Statistical Mechanics; construct a bridge between macroscopic thermodynamics and microscopic Statistical Mechanics, by using mathematical methods and fundamental physics, for individual particles. The module provides indispensable preparation for Quantum Mechanics and Solid State, Nuclear and Particle Physics and Astronomy and Astrophysics modules that the student would learn in the subsequent semesters. Problem solving is stressed as a means of imparting physical understanding and intuition.

Content:

This module develops concepts in classical laws of thermodynamics and their application, postulates of statistical mechanics, statistical interpretation of thermodynamics, microcanonical,

canonical and grand canonical ensembles; the methods of statistical thermodynamics, kinetics, and the theory of phase transitions are used to develop the statistics for Bose, Fermi and photon gases; selected topics from low temperature physics and electrical and thermal properties of matter are discussed.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to show knowledge and broad understanding of:

A.1. Statistics of particles and statistics of fields

A.2. Statistical Mechanics, and show a critical awareness of the significance and importance of the topics, methods and techniques discussed in the lectures and their relationship to concepts presented in other courses.

A.3. The concepts of universality and scaling laws.

A.4. Renormalization group theory.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Demonstrate thorough mastery at an advanced level of extensive knowledge and skills required for attaining all the course learning outcomes.

B.2. Work with the different statistical formalisms: microcanonical (e.g. study lattice specific heat - Einstein model), canonical (e.g. Debye model), and grand-canonical (e.g. to derive Fermi-Dirac and Bose-Einstein statistics);

B.3. Describe and analyze quantitatively processes, relationships and techniques relevant to the topics included in the course outline;

B.4. Applying these ideas and techniques to analyze critically and solve advanced or complex problems which may include unseen elements;

B.5. Relate theoretical models to their applications;

B.6. Transfer expertise between different topics in mathematics.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:

C.1. Writing down and, where appropriate, either prove or explain the underlying basis of physical laws relevant to the course topics, and discuss their applications;
C.2. Working effectively, independently and under direction;
C.3. Analyzing and solve complex problems accurately;
C.4. Making effective use of IT.

D. Key Transferable Skills

On completion of the module, students will be able to:
D.1. Solve both unfamiliar and complex problems and to present written report;
D.2. Tackle material which is given both unfamiliar and complex;
D.3. Justify conclusions using mathematical arguments with appropriate rigour;
D.4. Communicate results using appropriate styles, conventions and terminology;
D.5. Learn independently, actively and reflectively and to develop intuition;
D.6. Demonstrate a sense of self-organization, self-discipline and self-knowledge;
D.7. Construct clearly logical arguments;
D.8. Have a sense of self-organization, self-discipline and self-knowledge;
D.9. Pursue further studies in this and related areas.

9. Indicative Content

- *Thermodynamics:* Introduction; the zeroth law; the first and second laws; the Carnot engine; the Entropy; Approach to equilibrium and thermodynamic potential; Useful mathematics results; Stability conditions; the third law. Exercises and problems.
- *Probability:* General definitions; Random variables; Some important distributions; Many random variables and the Central Limit Theorem; Laws of large numbers and typical behavior; Information and entropy; Large deviation theory and the Legendre transform. Exercises and problems.
- *Kinetic theory of gases:* General definitions; Liouville's theorem; the Bogoliubov-Born-Green-Kirkwood-Yvon hielarch; the Boltzman equation; the H-theorem and irreversibility; Equilibrium properties; Conservation laws. Exercises and problems.
- *Classical statistical mechanics:* General definitions; the microcanonical ensemble; the two-level systems; the ideal gas; Mixing entropy and the Gibbs paradox; the canonical ensemble;

the grand canonical ensemble. Exercises and problems.

- *Interacting particles:* The cumulant expansion; the cluster expansion; the second viral coefficient and van der waals equation; Breakdown of the van der waals equation; Mean field theory of condensation; Variation methods; Corresponding states; Critical point behavior. Exercises and problems.
- *Quantum statistical mechanics:* Dilute polyatomic gases; Vibrations of a solid; Black-body radiation; Quantum microstates; Quantum macrostates. Exercises and problems.
- *Ideal quantum gases:* Hilbert space of identical particles; canonical formulation; grand canonical formulation; non-relativistic gas; the degenerate Fermi gas; the degenerate Bose gas; Photon gas; Superfluid He^4. Exercises and problems.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
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- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulations.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted.

All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

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Component	**Weighting (%)**	**Learning objectives covered**
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CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B6, C1-C4**
CA II: Mid-Semester Examination	30	**A1-A4, B1-B6, C1-C4, D1-D9**
End Semester Examination	40	**A1-A4, B1-B6, C1-C4, D1-D9**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts

- Landau L.D. and E.M. Lifshitz, Statistical Physics I, II, Pergamon Press (Oxford), 1980.
- Landau L.D. and E.M. Lifshitz, Statistical Physics, Vol. 5, Butterworth-Heinemann, 1980.
- Kardar M., Statistical Physics of Particles, Cambridge University Press, 2007.

Background Texts

- Binder K. (ed.), Monte-Carlo methods in statistical physics, Springer-Verlag (New York), 1986.
- Binney J.J., N.J. Dowrick, A.J. Fisher, and M.E. Newman, The Theory of Critical Phenomena, Oxford University Press (Oxford), 1992.
- Cardy J., Scaling and Renormalization in Statistical Physics, Cambridge University Press (Cambridge), 1996.

- Cover T.M., J.A. Thomas, Elements of Information Theory, 2nd ed. (Wiley Series in Telecommunications and Signal Processing), 2006.
- Greiner W., L. Neise, and H. St¨ocker, Thermodynamics and Statistical Mechanics, Springer-Verlag (New York), 1995.
- Huang K., Statistical Mechanics, J. Wiley (New York), 1987.
- Kubo R., Statistical Mechanics, North Holland (Amsterdam), 1967.
- Ma S.-k., Modern Theory of Critical Phenomena, Benjamin (Reading), 1976.
- McCoy B.M. and T.T.Wu, The Two-Dimensional Ising Model, Harvard (Cambridge), 1973.
- Pathria R.K., Statistical Mechanics, Butterworth-Heinemann, 1996.
- Plischke M. and B. Bergersen, Equilibrium Statistical Mechanics, World Scientific (Singapore), 1994.
- Schwabl F., Statistical Mechanics, Springer, 2005.
- Stanley H.E., Phase Transitions and Critical Phenomena, Oxford University Press (London), 1971.
- Wilson K.G., Scientific American, 241, 140, 1979.
- Yeomans J.M., Statistical Mechanics of Phase Transitions, Clarendon (Oxford), 1992
- Feller W., An Introduction to Probability Theory and its Applications, Vol.1, John Wiley & Sons Inc., 1957.

Advanced texts:

- Landau L.D. and E.M. Lifshitz: Statistical Physics II, Vol. 9, Pergamon Press. Modern Theory of quantum gases and liquids, magnetic systems.
- Chaikin P. and T. Lubensky, Principles of Condensed Matter Physics, Cambridge University Press, 1995. Phase transitions, rich on applications to condensed matter.
- Feynman R.P., Statistical Mechanics – A set of lectures, Frontiers in Physics, Benjamin/Cummings, Reading Massachusetts, 1982. Path integrals, chosen subjects in statistical mechanics.
- Goldenfeld N., Lectures on Phase transitions and the Renormalization Group, Frontiers in Physics, Addison Wesley, Reading Massachusetts, 1994: Phase transitions, RG.

15. Module Team:

Module Leader: Prof. Scandolo Sandro

Team members: Dr. Emmanuel Nshingabigwi

1. **Module Code:** MPH6262
2. **Module Title:** QUANTUM MECHANICS II
3. **Level:** 6 **Semester:** 2 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

This module follows the introductory course of Quantum Mechanics I. It aims to continue the development of non-relativistic quantum mechanics as a complete theory of microscopic dynamics, capable of making detailed predictions, with a use of the mathematical methods learnt in previous courses.

Content

The module covers fundamental concepts of quantum mechanics: wave properties, uncertainty principles, Schrödinger equation, and operator and matrix methods. Basic applications of the following are discussed to investigate the rules of quantum mechanics in a more systematic fashion by showing how quantum mechanics is used to examine: the motion of a single particle in one dimension, many particles in one dimension, and a single particle in three dimensions, and angular momentum and spin. The course also examines approximation methods: variational principle and perturbation theory.

8. Learning Outcomes

The students are expected to master the basic mathematical skills that will be required throughout the course, such as the use of complex numbers and complex valued functions, simple differential equations, Gaussian integrals and basic linear algebra. If necessary, some of the most important math will be refreshed at the beginning of the course by some tutors.

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Discuss and interpret experiments displaying wavelike behavior of matter, and how this motivates the need to replace classical mechanics by a probabilistic wave equation of motion for matter (the Schrödinger equation).

A.2. Understand the central concepts and principles of quantum mechanics: the Schrödinger equation, the wave function and its physical interpretation, stationary and non-stationary states, time evolution and expectation values.

A.3. Interpret and discuss physical phenomena in light of the Heisenberg uncertainty principle.
Basically understand the formalism and 'language' of quantum mechanics and how it relates to linear algebra.

A.5. Understand the concepts of spin (Stern-Gerlach experiment) and angular momentum, as well as their quantization into states- and addition rules e.g. Explain the Zeeman affect and spin orbit coupling.

A.6. Understand from the perspective view of symmetry aspects of the problem how to construct, without using perturbation theory, the appropriate combinations of orbital and spin states, which make the effect of the $\boldsymbol{L}\cdot\boldsymbol{S}$ term in the Hamiltonian.

B. Cognitive/Intellectual skills/Application of Knowledge/ Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

B.1. Solve independently the Schrödinger equation for simple one-dimensional systems-the ones explicitly taught (e.g. square well, harmonic oscillator, potential barrier), as well as similar, new ones.

B.2. Use the solution to compute probabilities, expectation values, uncertainties and time evolution.

B.3. Solve simple problems in two and three dimensions in various coordinate systems, e.g. by using separation of variables in the Schrödinger equation.

B.4. Perform calculations on systems of identical particles, e.g. determine the symmetry properties of the wave function, and the total spin.

B.5. Give concise physical interpretations, and arguments for the validity of the mathematical solutions.

B.6. Communicate results easily orally and written.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

Having successfully completed the module, students should be able to:

C.1. Analyze and solve complex problems in electromagnetism;

C.2. Give a clear presentation on a chosen subject matter related to electromagnetism;

C.3. Communicate with clarity;

C.4. Work effectively, independently and under direction;

C.5. Analyze and solve complex problems accurately.

D. Key Transferable Skills

On completion of the module, students will be able to:

D.1. Solve both unfamiliar and complex problems and to present written report;

D.2. Tackle material which is given both unfamiliar and complex;

D.3. Justify conclusions using mathematical arguments with appropriate rigour;

D.4. Communicate results using appropriate styles, conventions and terminology;

D.5. Learn independently, actively and reflectively and to develop intuition;

D.6. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.7. Construct clearly logical arguments;

D.8. Have a sense of self-organization, self-discipline and self-knowledge;

D.9. Pursue further studies in this and related areas.

9. Indicative Content

- *Introduction*
- *Schrödinger's Equation Solved- one dimensional problems:* The Free Particle, A Large Step Potential, A Large Step Potential, A Small Step Potential, The Potential Barrier, The Large Hat Potential, Small Hat Potential, The Potential Well, Shallow Potential Well, In the Potential Well, Delta function potential, Coulomb Scattering, Periodic Potentials and the Kronig-Penney Model.
- *Tunnelling and the WKB Approximation:* This is a brief introduction to the WKB method. Wave functions and Overalps, The WKB Method: Validity of the Assumption.
- *Spin:* Stern-Gerlach experiment: the spin operators and states; Experiments with Stern-Gerlach apparatus, A single spin -1/2 in a uniform field: Larmor precession; Heisenberg representation.
- *Spin-orbit and addition of angular momenta:* Relativistic effects; The origin of spin-orbit; Construction of J-states out of p-states, Generalization: addition of *L* and *S*.
- *Density matrices:* The density matrix for a pure state, the density matrix for a mixed state; Density matrices and statistical mechanics, Density matrices by tracing out the universe.
- *Time-independent perturbation theory:* Two-state problem, Non-degenerate case: general solution.
- *Degenerate case:* first order; Application: the fine-structure of Hydrogen.
- *Time-dependent perturbation theory:* General case, First-order solution, Electromagnetic radiation on an atom.
- *Many particle systems:* Many-particle basis states for fermions and bosons, Two-electrons: the example of Helium.
- *A Second quantization:* Brief Outline-Why a quadratic Hamiltonian is easy.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B3, C1-C5**
CA II: Mid-Semester Examination	30	**A1-A6, B1-B6, C1-C5, D1-D9**
End Semester Examination	40	**A1-A6, B1-B6, C1-C5, D1-D9**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The main source is a set of Lecture Notes supplied by the lecturer at the start of the course. However, there are many good books on quantum mechanics which one may recommend.

Core Texts:

- Cohen-Tannoudji C., B. Diu and F. Laloë, Quantum Mechanics, Wiley, 1977.
- Dirac P.A.M., The Principles of Quantum Mechanics, 4th ed., (revised), Oxford University Press, Oxford UK, 1958.
- Griffiths D.J., Introduction to Quantum Mechanics, 2nd ed., Pearson Prentice Hall, Upper Saddle River NJ, 2005.
- Merzbacher E., Quantum Mechanics, 3rd ed., Wiley, 1998.
- Park D., Introduction to the Quantum Theory, 2nd ed., McGraw-Hill, New York NY, 1974.

Background Texts:

- Bohm D., Quantum Theory, Dover, New York NY, 1989.
- Harris R., Non-classical Physics, Addison-Wesley, Menlo Park CA, 1998.
- Sakurai J.J., Modern Quantum Mechanics, Benjamin/Cummings, Menlo Park CA, 1985.
- Shankar R., Principles of Quantum Mechanics, 2nd ed., Plenum, 1994.
- Squires G.L., Problems in Quantum Mechanics, Cambridge University Press, Cambridge UK, 1995.
- Gasiorowicz S., Quantum Physics, 2nd ed., John Wiley & Sons, New York NY, 1996.

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Prof. Karemera Marembo P.C.

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1. **Module Code :** MPH6263
2. **Module Title:** SOLID STATE PHYSICS
3. **Level:** 6 **Semester:** 2 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24

Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim:

The aim of the course is to give students an introduction to the fundamental aspects of Solid State Physics. It is a prerequisite for all the courses to be followed in the Condensed Matter Physics second year Masters program. It is an elective course for all other Physics Masters programs.

Content:

A large number of macroscopic phenomena in solids can be understood by microscopic theories that are based on classical and quantum mechanics. Examples include whether a solid conducts electricity, whether it is transparent to light, what is its ultimate mechanical strength, etc. At the basis of most microscopic theories of solids and crystals is the concept of periodic lattice and of "reciprocal" lattice. Vibrations in crystals are discussed as an example of extended classical excitations in a periodic lattice. The mathematical framework developed to describe vibrations can be formalized into a theorem (Bloch's theorem) and can in turn be used to describe also the extended quantum states of electrons in a periodic lattice. Depending on the type of solid considered, calculations of electronic states in solids require different levels of approximations, from the choice of the basis set (in this context both tight-binding and quasi-free-electron models will be discussed) to the way the interaction between electrons is included. The results of different models can be compared with realistic examples of solids.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Explain the properties of periodic lattices and determine their reciprocal lattices

A.2. Determine the normal modes of vibration of crystals

A.3. Understand the different approximations relevent for the determination of electronic states in crystals, and know their range of applicability

A.4. Understand the microscopic reasons which make solids insulating, conductive, transparent, opaque, strong, weak, etc.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Recognize crystals structures and understand their properties

B.2. Know how to apply rotational symmetry for central potentials to factorize the Schroedinger equation.

B.3. Make educated guesses about properties like hardness, conductivity, reflectivity and magnetism of any solid, starting from its chemical formula.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:

C.1. Writing down and, where appropriate, either prove or explain the underlying basis of physical laws relevant to the course topics, and discuss their applications;

C.2. Working effectively, independently and under direction;

C.3. Analyzing and solve complex problems accurately;

C.4. Making effective use of IT.

D. Key Transferable Skills

On completion of the module, students will be able to:

D.1. Solve both unfamiliar and complex problems and to present written report;

D.2. Tackle material which is given both unfamiliar and complex;

D.3. Justify conclusions using mathematical arguments with appropriate rigour;

D.4. Communicate results using appropriate styles, conventions and terminology;

D.5. Learn independently, actively and reflectively and to develop intuition;

D.6. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.7. Construct clearly logical arguments;

D.8. Have a sense of self-organization, self-discipline and self-knowledge;

D.9. Pursue further studies in this and related areas.

9. Indicative Content

- The microscopic structure of matter / the building blocks of solid state physics: electrons, atoms, electromagnetism, quantum mechanics
- Basic atomic structure / hydrogen atom / core and valence electrons
- Atomic bonding: covalent, ionic, hydrogen bond, Van der Waals, etc
- Potential of interaction between atoms / equilibrium structures / vibrations
- Crystal structures / Bravais lattices / symmetry / packing / packing fraction
- Vibrations in a periodic lattice / phonons / sound waves
- Electrons in a periodic lattice / Bloch's theorem
- The tight binding method
- Band structures / metals / insulators / optical properties
- Semiconductors / magnetism / superconductors

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

Academic honesty:

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12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B3, C1-C4**
CA II: Mid-Semester Examination	30	**A1-A4, B1-B3, C1-C4, D1-D9**
End Semester Examination	40	**A1-A4, B1-B3, C1-C4, D1-D9**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Ashcroft N.W. and N. D. Mermin, Solid State Physics, Harcourt, 1976.

- Kittel C., Introduction to Solid State Physics, 7th ed., John Wiley & Sons, 1996.

15. Module Team:

Module Leader: Prof. Scondolo Sandro

Team members: Dr. Emmanuel Nshingabigwi, Prof. Karemera Marembo P.C.

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1. **Module Code :** MPH6264
2. **Module Title:** NUMERICAL METHODS I
3. **Level:** 6 **Semester:** 2 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim:

The aim of this module is to introduce students to simple numerical techniques using computers to solve basic problems, which students have never used during their undergraduate studies.

Content:

The first part of this module will introduce students to scientific computing and the role of numerical methods in modeling complicated physical processes on the computer. The structure of this course will involve both lectures and computational hands-on labs to complement the theory learnt in the lectures. Topics, described in detail below, will include numerical recipes (algorithms) for integration, differentiation, differential equations and a gentle introduction to computer programming. The students will learn the basics of FORTRAN programming, which will include hands-on exercises in basic/simple FORTRAN codes. Advanced topics such as numerical linear algebra, Monte Carlo and molecular dynamics will be touched on very briefly in preparation for the second year.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to demonstrate knowledge and understanding of:

A.1. Using with confidence and comfort Linux Operating systems for programming, shell scripting and word processing in general.

A.2. Thorough numerical algorithms associated with integration, differentiation, differential equations.

A.3. Origins of the differences in errors between different algorithms.

A.4. The importance and logic of computer programming – being able to take problems that cannot be solved via paper and pen and how they can be translated into numerical problems that can be solved on the computer. In essence, developing an understanding of how to take problems and translating them into pseudocode or algorithms.

A.5. Programming in FORTRAN. This will involve writing both simple and more complicated FORTRAN programs in a clean and elegant way.

A.6. Higher-level mathematical packages such as Mathematica and its applications to scientific computing.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Apply their knowledge of numerical algorithms to solve real physical problems that they will encounter during their research. More importantly, they should be able to identify and synthesize the information that they learnt in this class to attack problems that they may encounter during their research.
B.2. Debug FORTRAN programs that they may write in the future. This will involve being able to identify sources of errors in their computer programs and hopefully the logic and process behind fixing these types of problems.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:
C.1 Technical skills associated with computer programming and the general usage of computers for scientific computing: scripting, editing computer programs with different types of editors. Proficiency in using Linux computing environment.
C.2 Being able to work in collaboratory/group projects which involves different people implementing various aspects of the code.
C.3 Being able to use higher level scientific computational tools like Mathematica which is often used by scientists doing numerics. This is very relevant for skills needed for their research during the Masters or PhD.

D. Key Transferable Skills

D.1. At the end of this course, students should have the basic programming skills that will hopefully allow them to learn other languages such as C, C++, Python, etc…
D.2. After this course, students will choose sections to specialize in such as Condensed Matter, Earth Systems Physics and High Energy. This course should give students the minimal necessary skills to begin to use or understand more complicated codes/packages that they will encounter in their respective areas of specialty.

9. Indicative Content

PART I: NUMERICAL ANALYSIS: LECTURE

In all cases below, lectures will involve introduction/motivation of physical problems so that students can make connections to practical situations that they will encounter for example in their research.

- *Introduction:* error analysis, representation of data on the computer, decimal & binary numbers. Decimal, double-precision, floating precision (numerical representation).
- *Why numerical algorithms:* introduction to types of physical problems requiring efficient numerical algorithms
- *Error Analysis:* Approximations and round off errors, Truncation errors and Taylor Series
- *Solving Polynomial Equations:* Determination of roots of polynomials and transcendental equations by Newton-Raphson, Bisection, Secant, Bairstow, and Regula Falsi methods.
- *Integration:* Numerical Integration: Trapezoidal rule, Newton-Cotes, Gaussian Quadrature.
- *Numerical Linear Algebra:* Introduction to Matrix Algebra, Eigenvalue problems, Single-Value decomposition, Solutions of linear simultaneous linear algebraic equations by Gauss Elimination, Cholesky factorization and Gauss- Siedel iteration methods.
- *Fitting:* Curve fitting- linear and nonlinear regression analysis; Euclidean Fit
- Differentiating noisy data
- *Numerical Differentiation:* Finite difference methods: Backward, Forward and Central difference relations and their uses in Numerical differentiation and integration.
- *Numerical Ordinary differential equations* (initial value problems): Numerical solution of ordinary differential equations by Euler, Modified Euler, Heun's method Runge-Kutta and Predictor-Corrector method.
- *Numerical partial differential equations:* Applications of difference relations in the solution of partial differential equations.
- *Introduction to pseudocode*.

PART I: LAB LECTURES

These lectures/hands-on sessions take place after the first part which is mostly theoretical.

- Linux Operating System, Unix Commands, bash shell.
- FORTRAN 90 programming: basic operations, input/output, flow control, functions/subroutines, array/matrices
- Introduction to visualization/plotting tools: Gnuplot, Xmgrace etc

- Introduction to mathematical software for scientists.

PART II: PROGRAMMING: LECTURE

In the second part, students will be introduced to the very basics of computer programming in FORTRAN.

- Introduction to computer programming: motivation for writing programs – realistic examples to be discussed. Designing a program, algorithm, pseudocode. logic of programming.
- Understanding a programming language syntax. Fundamentals of basic programming: variable declaration, Boolean types, constants, assignments, reading and writing from and to a file.
- Logical operations and control constructs: IF statement, IF-ELSE-IF construct, loops: do loop, for loops.
- Introduction to complex data structures: arrays. Procedures: functions, subroutines.
- Random number generators.
- Brief introduction to advanced topics: Monte Carlo and Molecular Dynamics.

PART II: LAB LECTURES

These lectures/hands-on sessions take place after the first part which is mostly theoretical.

- Hands-on exercise on variable declaration, assignment: simple addition, subtraction, multiplication, reading/writing from/to a file;
- Hands-on exercise on IF-ELSE-IF construct;
- Hands-on exercise on loops in FORTRAN (do/for loops);
- Hands-on exercise on using complex data structures such as arrays;
- Hands-on sessions illustrating common mistakes made in programming using real examples of FORTRAN programs written by other people;
- Hands-on exercises for algebraic problem, polynomial equations, differential and integral equations.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A6, B1-B2, C1-C3**
CA II: Mid-Semester Examination	30	**A1-A6, B1-B2, C1-C3, D1-D2**
End Semester Examination	40	**A1-A6, B1-B2, C1-C3, D1-D2**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Chivers I. and J. Sleighthome, Introduction to Programming with FORTRAN: With Coverage of FORTRAN 90, 95, 2003, 2008 and 77, 2nd ed., Springer, 2012
- Cormen T.H., Introduction to Algorithms, 3rd ed., The MIT Press.
- Gould H., Jan Tobochnik and Wolfgang Christian, An Introduction to Computer Simulation Methods: Applications to Physical Systems, 3rd ed., Addison Wesley, 2006.
- Smith I.M., Programming in FORTRAN 90: A first course for Engineers and Scientists, Wiley, 1995.

Background Texts:

- Knuth D., The Art of Computer Programming, Volumes 1-4 A Boxed Set, Addison Wesley, 2011.
- Press W., S. Teukolsky, W. Vetterling, B. Flannery Numerical Recipes: The Art of Scientific Computing, 3rd ed., Cambridge University Press, 2007.
- Stroustrup B., The C++ Programming language, 4th ed., Addison-Wesley Professional, 2013.

Computer Requirements

FORTRAN compilers, Python, Mathematica/Matlab, Xmgrace, gnuplot.

15. Module Team:

Module Leader: Dr. Hassan Ali

Team members: Another lecturer to be identified

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1. **Module Code :** HEP6361
2. **Module Title:** RELATIVISTIC QUANTUM MECHANICS
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** A thorough grounding in relativity, quantum

mechanics, electromagnetism and electrodynamics is assumed.

6. Allocation of study and teaching hours

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim

The aim of this module is to learn how quantum mechanics and relativity need to be mutually consistent.

Content

The Klein Gordon and Dirac equations are derived as relativistic generalizations of Schrödinger and Pauli equations respectively. The Dirac equation will be analyzed in depth and its successes and limitations will be stressed.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to demonstrate:

A.1. An understanding of the basic tools of relativistic quantum Mechanics;

A.2. An understanding of the origin of the Klein Gordon and Dirac equations, their significance and their transformation properties;

A.3. An appreciation of the general nature of Relativistic Quantum Mechanics;

A.3. An appreciation of the role of relativistic quantum effects in other areas of science;

A.4. An appreciation of the rich variety of physics dependent on relativistic quantum theory.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. be able to explain how some physical phenomena including spin, the gyromagnetic ratio of the electron and the fine structure of the hydrogen atom can be accounted for using relativistic quantum mechanics;

B.2. Demonstrate an enhancement of the ability to interpret theory of relativistic quantum mechanics;

B.3. Solve analytic problems in relativistic quantum theory.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Communicate and collaborate effectively with other students;

C.2. Demonstrate an enhancement of problem solving abilities, particularly mathematical approaches to problem solving;

C.3. Use appropriate sources as part of directed self-learning.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Use appropriate sources as part of directed self-learning;

D.2. Demonstrate a deeper appreciation of the connection of the role played by relativistic quantum theory in the world at large;

D.3. Accomplish projects and team tasks, and to collaborate in the group carrying out her/his part of the job;

D.4. Exercise initiative and personal responsibility;

D.5. Work independently and present effectively technical information in both written and oral forms;

D.6. Tackle material which is given both unfamiliar and complex;

D.7. Have a sense of self-organization, self-discipline and self-knowledge;

D.8. Justify conclusions using mathematical arguments with appropriate rigour;

D.9. Communicate results using appropriate styles, conventions and terminology;

D.10. Learn independently, actively and reflectively and to develop intuition;

D.11. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.12. Construct clearly logical arguments;

D.13. Have a sense of self-organization, self-discipline and self-knowledge;

D.14. Pursue further studies in this and related areas.

9. Indicative Content

PART I

- *Mathematical Tools for Quantum Mechanics:* Kets and bras. Inner Products. Linear operators. Hermitian operators and observables. Representations in state space: orthonormal basis, completeness relation, representations of kets and bras, and of operators, change of representation, unitary operators, transformation matrix. Eigenvalue equation and diagonalisation. Definition of observable, commuting observables, unitary equivalent observables, noncommuting observables.
- *Physical Postulates of Quantum Mechanics:* Description of the state of the system, physical quantities, measurement of physical quantities, spectral decomposition, and probability interpretation. Expectation values. Heisenberg uncertainty relation. Pure and Mixed States, Density Matrix. Example: the Spin 1/2 system.
- *Position, Momentum and Translations:* Continuous spectra, Dirac delta function. Position eigenkets and position measurement. Momentum as generator of infinitesimal translations, in quantum and classical mechanics. Finite translations. Canonical commutation relations. Wave functions in position and momentum space.
- *Quantum Dynamics:* Time evolution. The Schrödinger equation for the time evolution of a state ket. Schrödinger versus Heisenberg picture: state kets and observables in the Schrödinger and Heisenberg pictures. Schrödinger wave equation, conservation of probability. Main example: the Harmonic Oscillator. Operator Method , the Fock space and Coherent States.

PART II

- *Relativistic Wave equations:* The Lorentz Group. Klein-Gordon equation, The Dirac equation and its Lorentz covariance, Dirac and Weyl Spinors. Probability current. Bilinear covariants.

Minimal Coupling to Electromagnetism. Nonrelativistic limit of the Dirac equation and gyromagnetic ratio of the electron. Solutions of the free Dirac equation: plane wave solutions, polarised electrons in relativistic theory. Projection operators for energy and spin.

- *Discrete Symmetries in the Dirac theory and the zero mass limit:* Charge conjugation and Hole Theory. Parity transformation and Time reversal transformations of Spinors. Chirality and Helicity. Neutrino's two components equation.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning

outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B3, C1-C3**
CA II: Mid-Semester Examination	30	**A1-A4, B1-B3, C1-C3, D1-D14**
End Semester Examination	40	**A1-A4, B1-B3, C1-C3, D1-D14**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The main source is a set of Lecture Notes supplied by the lecturer at the start of the course.

Core Texts:

- Bjorken J.D. and S. D. Drell, Relativistic Quantum Mechanics, McGraw-Hill (New York), 1964.
- Feynman R., Quantum Electrodynamics, page xxv, Princeton University Press, 1985, 2006.

Background Texts:

- Anderson C.D., The Apparent Existence of Easily Deflectable Positives. *Science,* New Series, Vol. 76, No. 1967, pp. 238-239, 1932.
  Published by American Association for the Advancement of Science.
  Stable URL: http://www.jstor.org/stable/1658257
- Dirac P.A.M., The Quantum Theory of the Electron. Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character. Vol. 117, No. 778, pp. 610-624, 1928, Published by The Royal Society.
  Stable URL: http://www.jstor.org/stable/94981
- Feshbach H. and F. Villars, Elementary Relativistic Wave Mechanics of Spin 0 And Spin 1/2 Particles. Rev. Mod. Phys. 30, 24, 1958.
- From Nobel Lectures, Physics 1922-1941, Elsevier Publishing Company, Amserdam, 1965

- Hess V.F., C.D. Anderson, The Nobel Prize In Physics 1936, The Production And Properties Of Positrons
- Stable URL: http://www.nobelprize.org/nobel_prizes/physics/laureates/1936/anderson-lecture.html
- Schrödinger E., P.A.M. Dirac, The Nobel Prize In Physics 1933, Theory Of Electrons And Positrons

  Stable URL: http://www.nobelprize.org/nobel_prizes/physics/laureates/1933/dirac-lecture.html

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited (see budget)

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1. **Module Code :** HEP6362
2. **Module Title:** LIE GROUPS AND LIE ALGEBRAS
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – revision and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

This module introduces the student to Lie groups and Lie algebras in general. These are fundamental to the formulation of modern particle physics. In order to discuss modern theories one must understand both the representation theory and structure theory of Lie algebras. Indeed this is the language in which fundamental physics theories are written.

Content

This module starts with a complete introduction to the representations of SU(2) including the tensor products and Young Tableaux. Then the Lie algebra of SU(3) is studied together with some relevant representation theory. These two groups form the basis of the Standard Model and so this knowledge is essential for a particle physicist. A complete description of the classical groups follows as this is important for physics beyond the Standard Model. The next half of the course is devoted to structure theory of semi-simple Lie algebras in order for the student to appreciate the construction of the Lie algebras of the classical groups and because this has relevance to their representation theory as well as to more modern theories such as string theory.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to demonstrate knowledge and understanding of:

A.1. Basic concepts of Lie group theory;

A.2. A general background in representation theory;

A.3. Different types of Lie groups and Lie algebras;

A.4. The role played by Lie Groups and algebras in at least one application area in details;

A.5. The nature of symmetries;

A.6. Structure theory of semi-simple Lie algebras;

A.7. The representations of SU(2) including the tensor products and Young Tableaux;

A.8. Lie algebra of SU(3) and some relevant representation theory.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Develop structure theory of Lie groups and Lie algebras and derive various classification results;

B.2. Appreciate how the subject relates to the formulation of modern particle physics;

B.3. Apply results from the unit to problems in these areas.

C. Communication /ICT/ Numeracy / Analytic Techniques/Practical skills

Having successfully completed the module, students will be able to:

C.1. Demonstrate a comprehensive understanding of techniques for the application of Lie algebra;

C.2. Apply Lie theory approach to analyze of systems with symmetries;

C.3. Use the relationship between Lie groups and Lie algebras in concrete mathematical problems;

C.4. Perform basic computations involving matrix Lie groups;

C.5. Discuss the role played by Lie groups and algebras in at least one application area in detail.

D. Transferable skills

Having successfully completed the module, students should be able to:

D.1. Have developed intuition for the structure of the main examples of Lie groups and Lie algebras that arise in applications;

D.2. Evaluate and apply the contents of the specialized literature on these topics;

D.3. Work independently (including work with the literature);

D.4. Accomplish projects and team tasks, and to collaborate in the group carrying out her/his part of the job;

D.5. Exercise initiative and personal responsibility;

D.6. Work independently and present effectively technical information in both written and oral forms;

D.7. Tackle material which is given both unfamiliar and complex;

D.8. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.9. Justify conclusions using mathematical arguments with appropriate rigour;

D.10. Communicate results using appropriate styles, conventions and terminology;

D.11. Learn independently, actively and reflectively and to develop intuition;

D.12. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.13. Construct clearly logical arguments;

D.14. Pursue further studies in this and related areas.

9. Indicative Content

- Introduction
- Basics of Groups
- Infinitesimal Transformations, Symmetries and Conserved Charges
- The Groups SU(2) and SO(3; R)
- More about representations
- Ladder operators
- Representations of the Lie Algebra of SU(2)
- Spin and angular distributions
- Isospin
- The Hydrogen Atom
- SU(3) and its Lie Algebra
- Tensor Representations of SU(N); Young Tableaux
- SU(3) and its Lie Algebra
- Lie Algebras, Sub-Algebras and Ideals
- Matrix Groups and their Lie Algebras
- The Cartan-Killing Form and Root Spaces
- Simple and Semi-Simple Lie Algebras
- The Classical Lie Groups
- The Cartan Matrix and Dynkin Diagrams

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A8, B1-B3, C1-C5**
CA II: Mid-Semester Examination	30	**A1-A8, B1-B3, C1-C5, D1-D14**
End Semester Examination	40	**A1-A8, B1-B3, C1-C5, D1-D14**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Aitchison I.J.R. and A. J. G. Hey, Gauge Theories in Particle Physics, Adam Hilger, Bristol, 1989
- H. Georgi H., Lie algebras in particle physics: from isospin to unified theories, Benjamin, Reading, 1982.

Background Texts

- Cheng T.P. and L.F. Li, Gauge Theory of Elementary Particle Physics, Clarendon (Oxford), 1984.
- Quigg C., Gauge Theories of the Strong, Weak, and Electromagnetic Interactions, Benjamin, Menlo Park, 1983.

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited

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1. **Module Code :** HEP6363
2. **Module Title:** INTRODUCTION TO PARTICLE PHYSICS
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – revision and attendance		4	6
Other:			
Invigilation	-	-	4

Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim

This course is designed to give students a working understanding of the field of particle physics.

Content

The module starts by considering the composition of matter in terms of its most elementary constituents. This is followed by a briefly discussion on particle accelerators and detectors. Next, the properties of the elementary particles are explained, and they are classified according to these properties into two broad categories known as quarks and leptons. Next, follows the discoveries of the gauge bosons and Higgs boson. These particles interact with each other via three forces known as the electromagnetic, the weak and the strong forces, whose features and mechanism of action are explained. Next, the relationship between conservation laws and symmetries of the fundamental interactions is discussed. This relationship turns out to be the key to understanding how elementary particles behave.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to demonstrate knowledge and understanding of:

A.1. The composition of matter in terms of its most elementary constituents;

A.2. Particle accelerators and detectors

A.3. The properties of the elementary particles and their classification according to these properties into quarks and leptons;

A.4. The fundamental concepts in advanced topics of theoretical particle physics;

A.5. The origin the gauge bosons and Higgs boson and how these particles interact with each other via three forces known as the electromagnetic, the weak and the strong;

A.6. The relationship between conservation laws and symmetries of the fundamental interactions

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.2. Develop highly specialized and advanced mathematical skills in the areas studied;

B.2. Solve complex, novel and specialized problems, draw conclusions and deploy physical intuition, with minimal guidance.

B.3. Develop their mathematical self-sufficiency and be able to read and understand advanced theoretical physics independently.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Analyze and solve complex problems in Elementary Particle Physics;

C.2. Give a clear presentation on a chosen subject matter related to Elementary Particle Physics

D. Transferrable skills

Having successfully completed the module, students should demonstrate the ability to:

D.1. Solve complex problem and to present written report;

D.2. Tackle material which is given both unfamiliar and complex;

D.3. Learn independently, actively and reflectively and to develop intuition;

D.4. Exercise initiative and personal responsibility;

D.5. Work independently and present effectively technical information in both written and oral forms;

D.6. Tackle material which is given both unfamiliar and complex;

D.7. Have a sense of self-organization, self-discipline and self-knowledge;

D.8. Justify conclusions using mathematical arguments with appropriate rigour;

D.9. Communicate results using appropriate styles, conventions and terminology;

D.10. Learn independently, actively and reflectively and to develop intuition;

D.11. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.12. Construct clearly logical arguments;

D.13. Have a sense of self-organization, self-discipline and self-knowledge;

D.14. Pursue further studies in this and related areas.

9. Indicative Content

I. INTRODUCTION

Defining elementary particles. Units and scales. Observations of elementary particles.

II. DISCOVERIES OF PARTICLES AND MAIN CONCEPTS

- *Early discoveries*: Electron, proton, neutron, photon. Neutrino. Fermi theory of the weak interactions.
- *Detection of particles*. Principles of detection of particles. Radiation and ionization. Scintillations and Cherenkov radiation.
- *Cosmic rays and discoveries of particles*: Cosmic rays. Positron. Muon. Pion. Pion decay. Strange particles. Kaons. Strangeness
- *Acceleration of particles:* Linear accelerators. Cyclic accelerators. First accelerator experiments. Muon neutrino. LEP, Tevatron, LHC.
- *Quarks:* Classification of hadrons. SU(3)-symmetry. Eightfold way. u, d and s quarks. Introduction of color. Quark jets. Cross-section of the electron - positron annihilation to hadrons. Cabibbo mixing.
- *Deep inelastic scattering:* Form factors. Structure functions. Scaling. Partons. Violation of scaling.
- *Heavy leptons and quarks:* Observations of resonances. Charmed particles. Discovery of J/ psi. tau-lepton. CKM-mixing. Bottom quark. Top quark. Tau neutrino.
- *Discoveries of the gauge bosons and Higgs boson:* Intermediate bosons W, Z. Gluons. Higgs boson.
- *Resonances:* Evolution matrix and S-matrix. Optical theorem. Total decay rate and total cross-section. Resonances.

III. SYMMETRIES AND INTERACTIONS

- *Symmetries at classical and quantum level:* Symmetries and transformations. Conservation laws. Properties of matrix elements.
- *Parity:* P-transformations. Parity conservation. Parity of pion and other particles. Parity violation.

- *Charge conjugation:* C-transformation. C-parity. Violation of C-symmetry.
- *CP-violation:* CP- properties of neutral K mesons. Discovery of CP - violation. Direct CP - violation. CP - violation in B-meson system.
- *U(1) – symmetries:* Baryon number. Lepton number. Neutrinoless double beta decay. Individual leptonic numbers. Neutrino oscillations. MSW – effect. B-L quantum number.
- *SU(2)-symmetry:* Isospin, Isospin symmetry in nucleon-nucleon scattering. Isospin symmetry in pion-nucleon scattering. Isospin and electric charge. Hypercharge. G-parity.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and

assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A6, B1-B3, C1-C2**
CA II: Mid-Semester Examination	30	**A1-A6, B1-B3, C1-C2, D1-D14**
End Semester Examination	40	**A1-A6, B1-B3, C1-C2, D1-D14**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The main source is a set of Lecture Notes supplied by the lecturer at the start of the course.

Core Texts:

- Bettini A., Introduction to particle physics, Cambridge University Press, 2012.
- Bryan J.C., Introduction to Nuclear Science, CRC Press, Taylor & Francis Group, 2008.
- Fukugita M. and T. Yanagida, Physics of Neutrinos, Springer-Verlag, Berlin Heidelberg, 2003
- Griffiths D., Introduction to particle physics, 2nd ed., Wiley-VCH, 2008.
- Hughes S., Elementary particle physics, 3rded., Cambridge University Press, 1991.
- Kane G., Modern elementary particle physics, Addison Wesley, 1993.
- Martin B.R. and G. Shaw, Particle physics, ed., 3rd John Wiley & Sons, 2008.
- Ne'eman Y., The particle hunter, 2nd ed., Cambridge University Press, 1996.
- Particle Physics, Phys. Lett. B592, 1 (2004), as updated for edition 2006.
- Perkins D., Introduction to High Energy Physics, 4th ed., Cambridge University Press, 2000.
- Quigg C., Gauge theories of the strong, weak and electromagnetic Interaction, Westview Press, 1997.

Recommended reading books

- Barger V.D. and R.J.N. Phillips, Collider Physics, Addison-Wesley, Reading, 1997.
- Commins E.D. and P. H. Bucksbaum, Weak interactions of leptons and quarks, Cambridge, New York, 1983.- Still the classic reference.

- Okun L.B., Particle physics– the quest for the substance of substance, Harwood, New York, 1985.
- Perkins D.H., Introduction to high energy physics, Addison-Wesley, Menlo Park, 1987. - Experimentally oriented.

Web Resource:

- URL: http://pdg.lbl.gov

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited

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1. **Module Code :** HEP6365
2. **Module Title:** QUANTUM ELECTRODYNAMICS
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules:** Advanced Electromagnetism (MPH6163), Quantum Mechanics II (MPH6164), and Quantum Mechanics II (MPH6262).
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – revision and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

The module aims to provide a detailed understanding non-relativistic introduction to quantum electrodynamics (QED). In addition, electromagnetic interactions within the framework of the Dirac equation are also studied. This provides to students the ability to perform concrete perturbative calculations of elementary processes.

Content

The module covers the following topics: Canonical quantization, Klein-Gordon and Dirac fields, gauge principle and QED Lagrangian, S-matrix, Feynman rules, basic QED processes, and radiative corrections.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Demonstrate knowledge and understanding of non-relativistic quantum mechanics and of classical electromagnetism;

A.2. Write down the wave equations of QED and exhibit their gauge invariance;

A.3. Understand the derivation of the scattering amplitude and Feynman Rules.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Demonstrate some familiarity with concepts of modern physics (elementary particles, astrophysics). Thorough working knowledge of mathematical techniques and calculus is essential;

B.2. Apply the Feynman rules to simple QED diagrams;

B.3. Show that $g = 2$ for the electron at tree level in the Dirac equation;

B.4. Describe the form of QED cross sections and decay rates.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Explain why the QED coupling runs and how;

C.2. Analyze and solve complex problems in QED.

C.3. Calculate autonomously electromagnetic processes in different branches of modern;

C.4. Give a clear presentation on a chosen subject matter related to QED

D. Transferrable skills

Having successfully completed the module, students should:

D.1. Have a coherent overview of electromagnetic processes in elementary particle physics, nuclear physics, atomic and molecular physics and astrophysics;

D.2. Evaluate and apply the contents of the specialized literature on these topics;

D.3. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.4. Learn independently, actively and reflectively and to develop intuition;

D.5. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.6. Be able to construct clear, logical arguments;

D.7. Have a sense of self-organization, self-discipline and self-knowledge.

D.8. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- *Classical Field Theory:* Poincarre Transformation properties of Fields-Least Action Principle-Equations of Motion-Hamiltonian Density-Solutions of free equations of motion and with external sources-Green Functions.
- *Noether Theorem*: Conserved Currents-Energy Momentum Tensor-Angular Momentum Tensor.
- *Quantum Field Theory for free Spin-0 Fields:* Microcausality and Commutation Relations. Quantization of Klein Gordon Equations. Creation and Annihilation operators and algebra. Hamiltonian and Momentum operators. Vacuum state, particles and Fock space. Boson Statistics from QFT. Poincarre Transformations in QFT. Complex Scalar Fields. Normal Ordering. Time Ordering. 2- and n- point functions
- *Quantization of Spin-1/2 Fields:* Spinorial Representation of the Lorentz Group. Fermi-Dirac and Weyl representation of spinors. Dirac Equation and solutions. Quantization of Spin-1/2 Fields. Anticommutation Relation and Causality. Fermi Statistics. Spin and Helicity Operators. 2- and n- point functions. Conserved current and Charge. C, P (and T) symmetries
- *Quantization of Spin-1 fields:* Physical polarization. Gauge redundancy and Lorentz invariance. Gauge invariant Lagrangian and Gauge Fixing. Quantization of Massless Spin-1 fields, physical

and unphysical polarizations. Spin-1 propagator and physical interpretation. Coupling to other fields, Gauge invariance and Covariant Derivatives

- *Interactions:* Interacting Lagrangian and particle non-conservation. Scattering Amplitudes and S-Matrix. Optical Theorem. Dyson Series and perturbation theory. Wick Theorem, Feynman Rules and Diagrams. QED to first and second order. Cross Section: 2 to n. Unstable Particles: Decay rates. Phase Space integrals
- *QED at tree level:* e+e- -> mu+mu- cross section: polarized and unpolarized. Compton Scattering: unpolarized
- *Introduction to Effective Field Theories:* Relevant, Marginal and Irrelevant Interactions. Low Energy Limit and decoupling of Heavy Particles.
- *Examples:* Euler-Heisenberg Lagrangian and Reyleigh scattering.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.

- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A3, B1-B4**
CA II: Mid-Semester	30	**A1-A3, B1-B4, C1-C4, D1-D8**

Examination		
End Semester Examination	40	**A1-A3, B1-B4, C1-C4, D1-D8**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Halzen F.and M.D. Alan, Quarks and Leptons: An Introductory Course in Modern Particle Physics, Wiley & Sons, 1984.
- Feynman R., Quantum Electrodynamics, page xxv, Princeton University Press, 1985, 2006.

Background Texts:

- Dudley, J.M.; and A.M. Kwan, "Richard Feynman's popular lectures on quantum electrodynamics: The 1979 Robb Lectures at Auckland University". American Journal of Physics 64 (6), 1996.
- Greiner W. and J. Reinhart, Quantum Electrodynamics, Springer-Verlag, 1992, 1994, 2002.

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited

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1. **Module Code :** HEP6364
2. **Module Title:** QUANTUM FIELD THEORY
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** Advanced Electromagnetism (MPH6163), Quantum Mechanics II (MPH6164), and Quantum Mechanics II (MPH6262).
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – revision and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

The aims of this module are: to provide an introduction to classical and quantum field theory, to provide an introduction to elementary particles and their interactions, to further enhance the mathematical skills of the student, to introduce the student to some open problems in theoretical physics. This module is a pillar for any physicist and mathematician interested in the latest developments in high energy physics and the interplay of physics and advanced mathematics.

Content

This module introduces the students to the physics and mathematical tools that they need in order to understand and to follow modern developments in theoretical physics. The module introduces field theory - both classical and quantum - as a natural extension of classical and quantum mechanics. The module gives essentially an introduction to the Feynman path integral. It starts with a derivation of the path integral in the context of quantum mechanics which is then followed by the path integral for field theory. The classical action of the path integral is studied in depth. Important properties that arise from global and local continuous symmetries of the action are studied. Particular attention is given to spontaneous symmetry breaking and what this means for the path integral as well as its role in the Standard Model (the Weinberg-Salam model together with Quantum chromodynamics). In following sections this formulation is applied to Perturbation Theory and Diagramatics (a loop expansion). The important concepts of renormalization and in particular the renormalization group are introduced.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Master a coherent body of knowledge and understanding of mathematical tools that they need in order to understand and to follow modern developments in theoretical physics.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Interpret the classical action of the path integral for global and local continuous symmetries;

B.2. Apply the Feynman path integral to Perturbation Theory and Diagramatics;

B.3. Apply the important concepts of renormalization and in particular the renormalization group.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1.Use advanced techniques learned in Quantum Field Theory in Quantum Electro Dynamics and in Elementary Particle Physics such as:

1. Derive the Feynman rules for bosons and fermions
2. Compute tree-level and radiative corrections for, e.g. e+ e- in μ+ μ-

3. Compute the renormalization of the electromagnetic, weak and strong charge
4. Compute critical exponents and its applications to quantum and thermal phase transitions
5. Compute Deep Inelastic Scattering
6. Use novel High Energy Dedicated computer packages, to derive the Feynman diagrams automatically.

C.2. Analyze and solve complex problems in Quantum Field Theory;

C.3. Give a clear presentation on a chosen subject matter related to Quantum Field Theory.

D. Transferrable skills

Having successfully completed the module, students should:

D.1. Evaluate and apply the contents of the specialized literature on these topics;

D.2. Be able to present good written report;

D.3. Be able to learn independently, actively and reflectively and to develop intuition;

D.4. Be able to tackle material which is given both unfamiliar and complex;

D.5. Have a sense of self-organization, self-discipline and self-knowledge;

D.6. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- *Introduction*
- *Path Integrals and Quantum Mechanics:* Schrödinger and Heisenberg Pictures, The Kernel, The Kernel for small Time, Convolution, Convolution, The Path Integral, Convolution Again, Dependence On ε, Matrix Elements, Generating Functional of Correlation Functions, An aside on $h = 1$, The Correlation Functions, Remarks and Further Reading. Exercises.
- *Many Degrees of Freedom and Field Theory Path Integrals:* Generalization to more than one degree of freedom, Quantum Field Theory, Euclidean Space, Remarks and further reading. Exercises.
- *Perturbation Theory:* Gaussian Path Integrals: Finite Dimensional Integrals, Passing to the Field Theory, Turning on the Interaction' The Feynman propagator' Leading order calculation of Z[J]: The Normalization' Relation to the standard perturbation theory and Wick's theorem: No Vacuum Bubbles. Exercises.
- *Path Integrals for Fermions:* Grassmann variables, Apples and Pears, Integration, Generating

Functionals, Quantum field theory of fermions. Exercises.

- *Gauge Theories:* Local Gauge Symmetry; Vector potentials and covariant derivatives: A Question of Labels, Gauge Covariance, Gauge invariant action and field equations, Coupling of fermions. Exercises.
- *Path Integrals for Gauge Theories:* Need for a Gauge Choice for the Photon, A Simple Model: Determining $\Delta_G(x, y)$, Gauge Choice Independence, Gauge Theory: The Faddeev-Popov Trick; Faddeev-Popov Ghosts: Remarks. Exercises.
- *The Standard Model:* The Lagrangian of the Standard Model, The electroweak interaction of leptons, QCD Lagrangian and the electroweak interaction of quarks. Exercises.
- *The Effective Action:* A Compact Notation; Generating Function $W[J]$ for Connected Graphs, The Effective Action $\Gamma[\phi_c]$, Effective Equations of Motion, Leading Order Corrections to Classical Dynamics. Exercises.
- *Perturbation Theory and Diagramatics:* Diagramatics, Γ up to the order of 2-loops, Determining ϕ_c. Exercises.
- *The Effective Action and Low Energy Physics:* The Effective Potential, The 1-loop Effective Lagrangian, Goldstone's theorem, The Mass Matrix. Exercises.
- *Divergences in Proper Vertices:* 11.1 Recalling The Diagrammatic Rules, 1-loop diagrams and expressions: $\Gamma^{(2)}(x_1, x_2)$, $\Gamma^{(4)}$, 1-Loop Renormalization.
- *Renormalization in ϕ^4 Theory:* $\Gamma^{(2)}$ to 2-loop order, Renormalized n-point vertices, The Renormalized Action And Counter-Terms, 1-Loop Calculation, 2-Loop Calculation. Exercises.
- *Dimensional Regularization:* 1-loop $\Gamma_R^{(4)}$ in ϕ^4 Theory, Systematics of Dimensional Regularization, 1-Loop Renormalization n The MS Scheme: 1-Loop $\Gamma_R^{(4)}$, 1-Loop $\Gamma_R^{(4)}$.
- *Power Counting in Field Theory:* Canonical Dimensions for a Scalar Field Theory, Superficial Degree of Divergence, Renormalizable Field Theories, Theories With Spinors, Theories With Vector Fields. Exercises.
- *Renormalization Group (RG) Equations:* The RG Equations in ϕ^4 Theory, The Solution Of The RG Equation, A Scaling Argument, High Energy Behaviour. Exercises.
- *Analysis of the RG Equations in The minimal subtraction (MS) Scheme:* Behavior of The

Solutions of The RG Equations, The Scaling Behavior of $\tilde{\Gamma}_R^{(N)}$ at $g = g_f$, μ Independence of Physical Quantities, Scheme Independence. Exercises.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
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CA II: Mid-Semester Examination	30	**A1, B1-B3, C1-C3, D1-D6**
End Semester Examination	40	**A1, B1-B3, C1-C3, D1-D6**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The main source is a set of Lecture Notes supplied by the lecturer at the start of the course. However, there are many good books on Quantum Field Theory:

Core Texts:

- Dirac P.M., Physikalische Zeitschrift der Sowjetunion 3, No 1, 1933.
- Feynman R., Rev. Mod. Phys. 20, 367, 1948.
- Feynman R. and A. Hibbs, Quantum Mechanics and Path Integrals, McGraw-Hill, New York, 1965.
- Schulman L., Techniques and Applications of Path Integration, J. Wiley and Sons, Brisbane, 1981.

Background Texts:

- Cheng T. and L. Li, Gauge Theory of Elementary Particle Physics, Oxford University, Press, Melbourne, 1984.
- Huang K., Quarks, Leptons and Gauge Fields, World Scientific, Singapore, 1982.
- Mandl F. and G. Shaw, Quantum Field Theory, Wiley, Chichester, 1984.
- Peskin M.E. and D. V. Schroeder, An introduction to quantum field theory, Addison-Wesley, Menlo Park, 1995.
- Ryder L.H., Quantum Field Theory, Cambridge University Press, 1996.
- Srednicki S., Quantum Field Theory, Cambridge University Press, 2007.
- Sterman G., An Introduction to Quantum Field Theory, Cambridge University Press, 1993.

Reading articles:

- de Rafael E. and J.L. Rosner, Ann. Phys. 82, 369, 1974.

- Gross G. and F. Wilczek, Phys. Rev. D8, 3633, 1973.
- Machacek M.E. and M.T. Vaughn, Nucl. Phys. B236, 221, 1984.
- Politzer E., Phys. Rev. Lett. 30, 1346, 1973.
- Vladimirov A.A., Theor. Math. Phys. 25, 1170, 1975.
- Zee A., Phys. Rev. D7, 3630, 1973.

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited

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1. **Module Code :** HEP6366
2. **Module Title:** GENERAL RELATIVITY AND COSMOLOGY
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** Classical Mechanics (MPH6161), Advanced Electromagnetism (MPH6163), Quantum Mechanics II (MPH6164), and Quantum Mechanics II (MPH6262).
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – revision and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

The aim of this module is learn the physical basis of General Relativity (GR) as well as the most important gravitational phenomena that are described with it. This requires mastering tonsorial calculus. The classical tests of GR and the familiarization with the most important spacetimes are also included as part of the course.

The main sections of the module include: Equivalence principles-Motion in the gravitational field-Tensors and differential forms-Riemannian Geometry-Einstein's field equations-Schwarzschild solution and black holes-Tests of the general theory of relativity. Gravitational waves-Cosmology.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should (be able to):

A.1. Describe experimental evidence in favor of general relativity and the principle of equivalence in terrestrial and astrophysical observations.

A.2. Know how to calculate curvature tensor.

A.3. Know the meaning of basic concepts like the equivalence principles, inertial frames and how gravity is understood as a manifestation of a curved space-time.

A.4. Know how to calculate particle trajectories in gravitational fields solving the geodesic equation.

A.5. Know how to calculate the simple-distribution energy-momentum tensor for matter.

A.6. Be familiar with the fundamental principles of the general theory of relativity.

A.7. Be familiar with some of the main contents of the theory: motion in the gravitational field, time dilation and frequency shifts, bending of light, gravitational waves and cosmological models with expanding space.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should:

B.1. Master calculating with tensors and differential forms.

B.2. Be able to describe physical phenomena in different coordinate systems and to transform from one coordinate system to another.

B.3. Be familiar with covariant derivative and covariant Lagrangian dynamics, geodesic curves, and be able to calculate the components of the Riemann curvature tensor from a given line element.

B.4. Be able to solve Einstein's field equations for static spherically symmetric problems and for isotropic and homogeneous cosmological models.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Use differential geometry to implement the principle of equivalence.

C.2. Use Einsteins equations in a linearized manner so as to describe weak gravitational fields, including the generation, propagation and detection of gravitational waves.

C.3. Use space-time symmetries for solving problems of dynamics and relativistic kinematics C.4. Master calculating the relativistic frequency shifts for sources moving in a gravitational field, as well as the bending of light passing a spherical mass distribution.

C.5. Give a mathematical description of gravitational waves, as well as cosmological models in the context of general relativity.

C.6. Relate general relativity and electromagnetism establishing their similarities and differences.

C.7. Use critical reasoning, show analytical skills, correctly use technical language and develop logical arguments

C.8. Develop critical thinking and reasoning and communicate orally and on written ideas effectively.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Work independently, take initiative itself, and be able to organize to achieve results and to plan and execute a project.

D.2. Develop independent learning strategies

D.3. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.3. Evaluate and apply the contents of the specialized literature on these topics;

D.4. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.5. Learn independently, actively and reflectively and to develop intuition;

D.6. Generate innovative and competitive proposals for research and professional activities;

D.7. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.8. Be able to construct clear, logical arguments;

D.9. Have a sense of self-organization, self-discipline and self-knowledge;

D.10. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

PART I: TOWARDS THE EINSTEIN EQUATIONS

- *From the Einstein Equivalence Principle to Geodesics*

  Introduction, caveats and omissions, motivation: the Einstein equivalence principle, geodesics, metrics and coordinate transformation, Christoffel symbols, geodesics and coordinate transformations.
- *The Physics and Geometry of Geodesics*

  The geodesic equation from a variational principle, Newtonian limit, gravitational redshift, locally inertial and Riemannian normal coordinates, more on geodesics and the variational principle, affine and non-affine parameterizations.
- *Tensor Algebra*

  From the Einstein equivalence principle to the principle of general covariance, tensors, tensor algebra, tensor densities, a coordinate-independent interpretation of tensors.
- *Tensor Analysis*

  Preliminary remarks, covariant derivative for vector fields, invariant interpretation of the covariant derivative, extension of the covariant derivative to other tensor fields, main properties of the covariant derivative, principle of minimal coupling, tensor analysis – some special cases, covariant differentiation along a curve, parallel transport and geodesics, generalizations.
- *Physics in a Gravitational Field*

  Particle mechanics in a gravitational field revisited, electrodynamics in a gravitational field, conserved quantities from covariantly conserved currents. conserved quantities from covariantly conserved tensors?
- *Curvature I: The Riemann Curvature Tensor*

  Curvature: preliminary remarks, the Riemann curvature tensor from the commutator of covariant derivatives, symmetries and algebraic properties of the Riemann tensor, the Ricci tensor and the Ricci scalar. An example: the curvature tensor of the two-sphere, Bianchi identities, another look at the principle of general covariance.

- *Curvature II: Geometry and Curvature*

  Intrinsic geometry, curvature and parallel transport. Vanishing Riemann tensor and existence of flat coordinates. The Geodesic deviation equation.

- *Towards the Einstein Equations*

  Heuristics. A more systematic approach. The weak-field limit. The Einstein equations. Significance of the Bianchi identities. The cosmological constant.

PART II: SELECTED APPLICATIONS OF GENERAL RELATIVITY

- *The Schwarzschild Metric*

  Introduction, Static isotropic metrics, solving the Einstein equations for a static isotropic metric. Basic properties of the Schwarzschild metric - the Schwarzschild radius. Measuring length and time in the Schwarzschild metric.

- *Particle and Photon Orbits in the Schwarzschild Geometry*

  From conserved quantities to the effective potential. Timelike geodesics. The anomalous precession of the perihelia of the planetary orbits. Null geodesics, bending of light by a star.

- *Approaching and Crossing the Schwarzschild Radius*

  Infinite gravitational redshift. Vertical free fall. Tortoise coordinates. Eddington-Finkelstein coordinates, black holes and event horizons. The Kruskal metric.

- *Einstein-Hiebert action*

  Derivation of the Einstein equations. Definition of the stress-energy tensor. Example of the scalar field.

- *Linearised Gravity and Gravitational Waves.*

  Preliminary remarks. The linearised Einstein equations. Gauge freedom and coordinate choices. The wave equation. The polarisation tensor. Physical effects of gravitational waves, detection of gravitational waves. Quadrupole formula. Energy and momentum emission.

- *Cosmology I: Maximally Symmetric Spaces*

  Isometries and killing vectors. Conserved quantities. Homogeneous, isotropic and maximally symmetric spaces, the curvature tensor of a maximally symmetric space. The Robertson-Walker metric.

- *Cosmology II: Basics*

  The Hubble expansion. Area measurements in a Robertson-Walker metric and number counts. The cosmological red-shift, the red-shift distance relation (Hubble's law).

- *Cosmology III: Basics of Friedman-Roberton-Walker Cosmology*

  The Ricci tensor of the Robertson-Walker metric. The matter content: a perfect fluid. Conservation laws. The Einstein and Friedman equations.

- *Cosmology IV: Qualitative Analysis*

  The critical density. The big bang, the age of the Universe. Long term behaviour. Density and pressure of the present universe.

- *Cosmology V: Exact Solutions*

  Preliminaries. The Einstein universe. The matter dominated era, age and life-time of the Universe, the radiation dominated era, the vacuum dominated era.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered

In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A7, B1-B4, C1-C8**
CA II: Mid-Semester Examination	30	**A1-A7, B1-B4, C1-C8, D1-D10**
End Semester Examination	40	**A1-A7, B1-B4, C1-C8, D1-D10**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. But students will have to make the best of their time by having identified specific questions that they need answered before coming to see the lecturer. This because often by well identifying the issues they need help with, students will be able to find the answer themselves. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Carroll S., Spacetime and Geometry: An Introduction to General Relativity, Addison Wesley, 2003.
- Hartle J., Gravity. An Introduction to Einstein’s General Relativity, Addison-Wesley, 2003.
- Hawking S. and G. Ellis, The Large-Scale Structure of Space-Time, Cambridge University Press, 1973.

- Schutz B.F., A First Course in General Relativity, 2nd ed., Cambridge University Press, 2009.
- Wald R., General Relativity, University Of Chicago Press, 1984.
- Weinberg S., Gravitation and Cosmology, John Wiley & Sons , 1972.

Background Texts:

- D'Inverno R., Introducing Einstein's Relativity, Clarendon Press, 1992.
- de Felice F. and C. Clarke, Relativity on Curved Manifolds, Cambridge University Press, 1990.
- Guillemin V. and A. Pollack, Differential Topology, Prentice-Hall, 1974.
- Lightman A.P. and W.H. Press, R.H. Price, and S.A. Teukolsky, Problem Book in Relativity and Gravitation, Princeton University Press, 1975.
- Misner, K. Thorne and J.Wheeler, Gravitation, W. H. Freeman, 1973.
- Nash and S. Sen, Topology and Geometry for Physicists, Academic Press, 1983.
- Poisson E., A Relativist's Toolkit: the Mathematics of Black Hole Mechanics, Cambridge University Press, 2007.
- Sachs R. and H. Wu, General Relativity for Mathematicians, Springer-Verlag, 1977.
- Schutz B.F., Geometrical Methods of Mathematical Physics, Cambridge University Press, 1980.
- Straumann N., General Relativity and Relativistic Astrophysics, Springer-Verlag, 1984.
- Taylor E. and J. Wheeler, Spacetime Physics, 2nd ed., W. H. Freeman, 1992.
- Warner F.W., Foundations of Differentiable Manifolds and Lie Groups, Springer-Verlag, 1983
- Zee A., Einstein Gravity in a Nutshell, Princeton University Press, 2013.

Web Resource:

Sean Carroll's on-line lecture notes: http://pancake.uchicago.edu/~carroll/notes/

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited

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1. **Module Code:** HEP6367
2. **Module Title:** THE STANDARD MODEL
3. **Level:** 6 **Semester:** 3 **Credits:** 10

4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH

5. **Pre-requisite modules, excluded combinations**: N/A

6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – revision and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

This module gives a basic introduction to the Standard Model (SM) of particle physics. It provides at present our best fundamental understanding of the phenomenology of particle physics.

Content

The module starts with some field-theoretic calculation techniques on symmetries and spontaneously broken non-abelian gauge theories, followed by the construction of the Standard Model Lagrangian I for Electro Weak Gauge Interactions-EWGI. Next comes the spontaneous symmetry breaking and the Construction of The Standard Model Lagrangian II for Electro Weak Symmetry Breaking-EWS. Next, an exploration of the structure of the Standard Model, the associated phenomenology is discussed followed by some discussion of beyond the Standard Model possibilities.

8. **Learning Outcomes**

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Demonstrate knowledge and understanding of some field-theoretic calculation techniques on symmetries and spontaneously broken non-abelian gauge theories;

A.2. Construct the Standard Model Lagrangian I for Electro Weak Gauge Interactions-EWGI;

A.3. Demonstrate knowledge and understanding of spontaneous symmetry breaking;

A.4. Construct the Standard Model Lagrangian II for Electro Weak Symmetry Breaking-EWS

A.5. Be familiar with collider phenomenology and tests of the Standard Model, especially with Higgs boson phenomenology at present and future colliders like LHC (Large Hadrons Collider at CERN)

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Explore the structure of the Standard Model and its associated phenomenology;

B.2. Discuss beyond the Standard Model possibilities.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Analyze and solve complex problems related to the Standard Model and beyond the Standard Model possibilities;

C.2. Give a clear presentation on a chosen subject matter related to the Standard Model.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Have a coherent overview of the Standard Model and its associated phenomenology;

D.2. Work independently and take initiative itself

D.2. Be organized to achieve results and to plan and execute a project.

D.3. Develop independent learning strategies

D.4. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.5. Evaluate and apply the contents of the specialized literature on these topics;

D.6. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.7. Learn independently, actively and reflectively and to develop intuition;

D.8. Generate innovative and competitive proposals for research and professional activities;

D.9. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.10. Be able to construct clear, logical arguments;

D.11. Have a sense of self-organization, self-discipline and self-knowledge;

D.12. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

PART I TECHNICAL TOOLS I (symmetries)

This part is mostly dedicated to collect the relevant tools given in previous courses and their extension to the Standard Model-SM.

SM = spontaneously broken non-abelian gauge theories.

- Non-abelian gauge theories (see Quantum Field Theory-QFT) - with fermions
- Gauge theories (see Quantum Electrodynamics-QED) - non-abelian
- Chiral fermions

a. QFT

b. Continuous symmetry groups (Lie groups) - mainly SU(N), U(1)

1. Global symmetries (isospin)
2. Gauge symmetries (QED, Quantum Chromodynamics-QCD)

a. Representations of the Lorentz group on fermions, L and R fermions + P, C, T

b. Explicit form of a generic gauge theory with scalars and femions

c. [renormalization]

PART II CONSTRUCTION OF THE SM LAGRANGIAN I (EW gauge interactions)

1. The starting point: QED + QCD + Fermi interaction for weak interactions
2. The unitarity problem and renormalizability
3. Inferring the gauge structure the SM - the electroweak (EW) symmetry
4. Anomalies

PART III TECHNICAL TOOLS II (Spontaneous Symmetry Breaking-SSB)

1. SSB of global symmetries - abelian + non-abelian?

2. SSB of gauge symmetries (Higgs mechanism) - abelian + non-abelian?

PART IV CONSTRUCTION OF THE SM LAGRANGIAN II (ElectroWeak Symmetry Breaking-EWSB, terms involving Higgs)

1. The Higgs quantum numbers from Yukawas
2. The Higgs sector
3. The Yukawa sector

PHENOMENOLOGICAL ANALYSIS OF THE SM LAGRANGIAN

Find the mass eigenstates-Find interactions- Linear terms-Bilinear terms-Trilinear and higher order terms

PART V EWSB

1. Vacuum
2. The spontaneous breaking of the SM group into QED+QCD
3. Goldstones

PART VI SYMMETRIES

0. Parity (P), Charge conjugation (C), and time-reversal (T), CP.PC.CPT
1. U(3)^5
2. Custodial symmetry and exact U(1)
3. Accidental symmetries

PART VII GAUGE BOSONS (spin 1)

1. Gauge boson spectrum
2. Gauge self-interactions
3. The covariant derivative
4. Gauge interactions
5. Tests (EWPT)

PART VIII FERMIONS (spin 1/2)

1. Fermion masses
2. The lagrangian in terms of fermion mass eigenstates
3. The CKM matrix, neutral currents

PART IX HIGGS (spin 0)

1. Higgs spectrum
2. Higgs self-interactions

3. Unitarity bounds on the Higgs mass
4. Perturbativity and stability bounds
5. Experimental bounds

PART X BEYOND THE STANDARD MODEL

1. The need of extending the SM
2. Neutrinos
3. The hierarchy problem
4. Nice features of the SM and challenges for NP

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A5, B1-B2, C1-C2**
CA II: Mid-Semester Examination	30	**A1-A5, B1-B2, C1-C2, D1-D12**
End Semester Examination	40	**A1-A5, B1-B2, C1-C2, D1-D12**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Donoghue J.F., E. Golowich, B. R. Holstein, Dynamics of the Standard Model, Cambridge, Cambridge, 1992. -Symmetries, current algebra, etc.
- Langacker P., Precision Tests of the Standard Electroweak Model, World Scientific Pub Co Inc, 1995. -Structure of the Standard Model.
- Renton P., Electroweak Interactions: An Introduction to the physics of Quarks and Leptons, Cambridge University Press, Cambridge, 1990.

Background Texts:

- Aitchison J.R., Anthony, J.Hey, Gauge Theories in Particle Physics: A Practical Introduction: From Relativistic Quantum Mechanics to QED, Vol. 1, 4th ed., CRC Press, Taylor &Francis Group (Vols. 1 & 2), 2013.
- Aitchison J.R., Anthony, J.Hey, Gauge Theories in Particle Physics: A Practical Introduction: Non-Abelian Theories: QCD and the Electroweak Theory, Vol.2, 3rd ed., The Institute of Physics, London IOP, 2004.
- Cheng T., Li L., Gauge Theory of Elementary Particle Physics: Problems and Solutions, Oxford University Press, 1988.
- Guidry M., Gauge Field Theories: An Introduction with Applications, Wiley-VCH, 2004.

- Halzen F., A.D. Martin, Quarks and Leptons: An Introductory Course in Modern Particle Physics, John Wiley & Sons, 1984.
- Nachtmann O., Elementary Particle Physics: Concepts and Phenomena, Springer-Verlag, 1990.
- Renton P., D. Bailin, A. Love, Introduction to Gauge Field Theory, Taylor and Francis Group, 1993.

Reference Articles:

- Amsler C. et al. [Particle Data Group], Phys. Lett. B 667 (2008) 1.
- Englert F. and Brout R., Phys. Rev. Lett. 13 (1964) 321.
- Fermi E., Z. Phys. 88 (1934) 161.
- Gamow G. and Teller E., Phys. Rev. 49 (1936) 895.
- Glashow S.L., Nucl. Phys. 22 (1961) 579.
- Goldstone J., A. Salam and S. Weinberg, Phys. Rev. 127 (1962) 965.
- Guralnik G.S., C. R. Hagen and T. W. B. Kibble, Phys. Rev. Lett. 13 (1964) 585.
- Hambye T. and K. Riesselmann, Phys. Rev. D 55 (1997) 7255 [arXiv:hepph/9610272].
- Higgs P.W., Phys. Rev. Lett. 13 (1964) 508.
- Nambu Y., Phys. Rev. 117 (1960) 648. J. Goldstone, Nuovo Cim. 19 (1961) 154.
- Salam A., Originally printed in "Svartholm: Elementary Particle Theory, Proceedings of the Nobel Symposium Held 1968 at Lerum, Sweden", Stockholm 1968, 367-377
- Sudarshan E.C.G. and R. e. Marshak, Phys. Rev. 109 (1958) 1860.
- Weinberg S., Phys. Rev. Lett. 19 (1967) 1264.

Web Resources:

- http://lepewwg.web.cern.ch/
- http://pdg.lbl.gov/, The Review of Particle Properties, 2002, especially the review articles on QCD, Electroweak Theory, and other Standard Model topics.
- http://www.hep.man.ac.uk/u/forshaw/NorthWest/QFT.html: Introduction to Quantum Field Theory, J. Forshaw webpage.

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited

1. **Module Code:** HEP6368
2. **Module Title:** SUPERSYMMETRY (SUSY) FIELD THEORY
3. **Level:** 6 **Semester:** 3 **Credits:** 0
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations**: N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – revision and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

Supersymmetry is the most compelling scenario for physics beyond the Standard Model (BSM). Understanding how supersymmetry can be realized (and then spontaneously broken) in Nature is therefore the most important challenges theoretical high energy physics has to confront with. This module aims to providing an introduction to such fascinating subject.

Content

This module gives a brief overview on "what is supersymmetry ?" and "why is it interesting to study it". In the rest of the module, (much) more detailed answers to these two basic questions are provided.

8. **Learning Outcomes**

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Demonstrate knowledge and understanding of the usefulness of supersymmetry its formulation and the corresponding supersymmetry algebra starting with the Lorentz and Poincarre groups, Spinors and representations of the Lorentz group;

A.2. Demonstrate knowledge and understanding of the Representations of the supersymmetry algebra;

A.3. Demonstrate knowledge and understanding of the Superspace and superfields, supersymmetric actions (minimal supersymmetry), theories with extended supersymmetry and Supersymmetry breaking;

A.4. Demonstrate knowledge and understanding in the main field of study, including both broad knowledge of the field and a considerable degree of specialised knowledge in certain areas of the field as well as insight into current research and development work;

A.4. Demonstrate specialised methodological knowledge in the main field of study applied to the Standard Model and beyond.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Demonstrate the ability to critically and systematically integrate knowledge and analyse, assess and deal with complex phenomena, issues and situations even with limited information.

B.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods, undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work.

B.3. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences, and

B.4. Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

B.5. Demonstrate the ability to pursue further studies within this research field.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Perform calculations based on Supersymmetry

C.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods;

C.3. Undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

C.4. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of Supersymmetry and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of Supersymmetry concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

Supersymmetry: a bird eyes view:

- What is supersymmetry?
- What is supersymmetry useful for?
- Some useful references

The supersymmetry algebra:

- Lorentz and Poincarre groups
- Spinors and representations of the Lorentz group
- The supersymmetry algebra
- Exercises

Representations of the supersymmetry algebra:

- Massless supermultiplets
- Massive supermultiplets
- Representation on fields: a first try
- Exercises

Superspace and superfields:

- Superspace as a coset
- Superfields as fields in superspace
- Supersymmetric invariant actions - general philosophy
- Chiral superfields
- Real vector superfields
- Exercises

Supersymmetric actions: minimal supersymmetry:

- N = 1 Matter actions
- N = 1 SuperYang-Mills
- N = 1 Gauge-matter actions

- Exercises

Theories with extended supersymmetry:

- N = 2 supersymmetric actions
- N = 4 supersymmetric actions
- On non-renormalization theorems

Supersymmetry breaking:

- Vacua in supersymmetric theories
- The goldstone theorem and the goldstino
- F-term breaking
- Pseudomoduli space: quantum corrections
- D-term breaking
- Exercises

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

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Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

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Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

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CA II: Mid-Semester Examination	30	**A1-A4, B1-B5, C1-C4, D1-D16**
End Semester Examination	40	**A1-A4, B1-B5, C1-C4, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Bilal, Introduction to supersymmetry, Chapter 6, arXiv:hep-th/0101055.
- Intriligator K.A., N. Seiberg and D. Shih, Supersymmetry Breaking, RSymmetry Breaking and Metastable Vacua, Section 3, JHEP 0707 (2007) 017 [arXiv:hep-th/0703281].
- Intriligator K.A., N. Seiberg, D. Shih, Dynamical SUSY breaking in meta-stable vacua, Appendix A, JHEP 0604 (2006) 021 [hep-th/0602239].
- Intriligator K.A., N. Seiberg, Lectures on Supersymmetry Breaking, Section 2, Class. Quant. Grav. 24 (2007) S741-S772 [hep-ph/0702069].
- Sohnius M.F., Introducing Supersymmetry, Chapters 6 and 11, Phys. Rept. 128 (1985) 39.

Background Texts:

- Coleman S.R., The Fate Of The False Vacuum. 1. Semiclassical Theory, Phys. Rev. D 15 (1977) 2929 [Erratum-ibid. D 16 (1977) 1248].

- Duncan M.J. and L. G. Jensen, Exact tunneling solutions in scalar field theory, Phys. Lett. B291 (1992) 109-114.

15. Module Team:

Module Leader: Prof. George Thompson

Team members: Senior Lecturer to be recruited

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1. **Module Code:** AST6361
2. **Module Title:** COSMOLOGY
3. **Level:** 6 **Semester: 3** **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
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Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim:

The course aims at presenting, to a graduate level audience, a theoretical framework of cosmology based on observations.

Brief content:

The emphasis will be on building a physical picture of cosmic evolution of our universe using some mathematical arguments that support and interpret the observed universe. The course is roughly divided into three parts: Classical Cosmology, the Physics of the Early Universe, and Elements of Structure Formation.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to demonstrate knowledge and understanding of:

A.1. The laws and principles of Classical cosmology;

A.2. The history of the evolution of the universe;

A.3. The equations describing the expansion of the Universe, and its predicted expansion rate for a variety of circumstances;

A.4. The structures of the universe;

A.5. The evidence supporting key elements of the Cosmology models including for dark matter, dark energy and inflation.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Apply knowledge of core concepts of general relativity and astrophysics to understand cosmology;

B.2. Describe Hubble's Law and the Big Bang; the cosmic background radiation; Big Bang nucleosynthesis etc;

B.3. Apply basic cosmological models to predict the age and structure of the universe for various geometries.

B.4. Derive the equations describing the expansion of the Universe, and find its predicted expansion rate for a variety of circumstances.

B.5. Explain the nature of the inflationary universe; the origin of cosmic structure; the cosmological constant, dark energy, and the accelerating universe; and the ultimate fate of our universe.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:

C.1. Explain concepts/principles of Cosmology using different representations: words and symbols, pictures, diagrams, graphs, formulas, equations etc;

C.2. Analyze and solve conceptual and numerical problems related to Cosmology;

C.3. Make precise observations, correlate experiment to theory and modify experiment, if need arises;

C.4. Demonstrate report-writing skills.

D. Key Transferable Skills

On completion of the module, students will be able to:

D.1. Communicate concepts and principles of Cosmology concisely, accurately and informatively to specialist and non-specialist audiences;

D.2. Formulate solutions to problems in cosmology involving new concepts with limited guidance;

D.3. Demonstrate knowledge of the frontiers of the discipline, for example, through cases where current theories fail to explain a set of observational data;

D.4. Locate and make use of detailed information on current topics in cosmology in the primary research literature;

D.5. Summarize current thinking in cosmology in a variety of written and oral forms, both alone and in collaboration with others;

D.6. Communicate concepts and principles of Cosmology concisely, accurately and informatively to specialist and non-specialist audiences;

D.7. Develop new skills and understanding of high level

D.8. Work independently and take initiative itself

D.9. Be organized to achieve results and to plan and execute a project.

D.10. Develop independent learning strategies

D.11. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.12. Evaluate and apply the contents of the specialized literature on these topics;

D.13. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.14. Learn independently, actively and reflectively and to develop intuition;

D.15. Generate innovative and competitive proposals for research and professional activities;

D.16. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.17. Construct clear, logical arguments;

D.16. Have a sense of self-organization, self-discipline and self-knowledge;

D.17. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

CLASSICAL COSMOLOGY

Cosmic Homogeneity and Isotropy:

- Introduction
- The Hubble Law
- Newtonian Cosmology
- Friedmann-Robertson-Walker (FRW) Cosmology
- The Anthropic Principle

Horizons and distance scales

- Light geodesics
- Horizons
- Conformal diagrams
- Redshift
- Redshift and observations in Cosmology

THE EARLY UNIVERSE

Thermal history of the universe

- Thermodynamics in the big bang

- Relics of the big bang
- The physics of recombination
- CMB
- Primodial nucleosynthesis
- Baryogenesis

Inflation

- -Arguments for inflation
- Inflation (an overview)
- Inflation field dynamics
- Inflation models
- Relics from inflation

STRUCTURE FORMATION

Dynamics of structure formation

- Dynamics of Linear perturbations
- Peculiar velocity field
- Coupled perturbations
- Full treatment of perturbations
- Transfer function
- N-body models
- Non-linear models

Cosmic Background Fluctuations

- Mechanisms for primary fluctuations
- CMB anisotropies (characteristics)
- CMB anisotropies (observations)

Cosmic structures and Dark matter

- Structure Formation
- Galaxy clustering
- The Evidence for Dark Matter

- Dark Matter Candidates
- The Cold Dark Matter Paradigm
- The Accelerating Universe

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information.

The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will provide the means to give a concise, focused presentation of the subject matter of the module. The lecture material will be explicitly linked to the contents of recommended textbooks for the module, thus making clear where students can begin independent study. When appropriate, the lectures will also be supported by the distribution of written material, or by information and relevant links. During lectures, the efforts will be made to link the new knowledge to prior knowledge of the students. Efforts will be made to address the misconceptions of the students. Analogy and examples related to the module will be used. The concepts/principles related to the module will be presented in a well-organized way and conceptual links will be provided. The organization of presented knowledge will be made as clear as possible by frequent summaries, as well as by concept-map diagrams.

Exercises: problems for the exercises will be handed out on a weekly basis in order to give students the chance to develop their theoretical understanding and problem solving skills and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the black board. Efforts will be made for active participation of students, by inviting questions, reactions and suggestions from the students, asking questions to them, etc Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and black board for solving problem.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement. Summative assessment of students' performance will be made through in course Assessment Tests and final examination. The frequent formative assessment will be used in various forms to monitor learning progress during instruction. The conceptual questions will be an integral part of the lectures/tutorials. The diagnostic test/home assignment can help to diagnose learning difficulties and misconceptions of students.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A5, B1-B5**
CA II: Mid-Semester Examination	30	**A1-A5, B1-B5, C1-C4, D1-D17**
End Semester Examination	40	**A1-A5, B1-B5, C1-C4, D1-D17**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

Core Text:

- Mukhanov V., Physical Foundations of Cosmology, Cambridge University Press, 2008.
- Peacock J., Cosmological Physics, 8th ed., Cambridge University Press, 2007.
- Peebles P.J.E., Principles of Physical Cosmology, Princeton University Press, 1993.

Background Texts:

- Hawking S.W. and G. F. R. Ellis, The Large Scale Structure of Space-time, Cambridge University Press, 1975.
- Liddle A., An Introduction to Modern Cosmology, Wiley-Blackwell, 2003.
- Roos M., Introduction to Cosmology, 3rd ed., Wiley, 2003.

- Weinberg S., Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity, John Wiley & Sons, 1972.

Journals: N/A

Key websites and on-line resources: N/A

Software: N/A

Computer requirements:

There will be computer simulations, data reduction using specific astrophysical software which will be installed on computers in the departmental postgraduate computer lab. A computer lab is required. These computers will run both in Windows and Linux and will be connected to a local or a university computer server (which will be in charge of keeping useful software of science in general).

Please add anything else you think is important

Video films or computer simulations related to the content will be shown to the students.

15. Module Team:

Module Leader: Dr. Ravi Seth

Team members: Prof. Manasse Mbonye, Dr. Isidore Mahara

Senior Lecturer: to be recruited

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1. **Module Code:** AST6362
2. **Module Title:** EXTRAGALACTIC ASTRONOMY
3. **Level:** 6 **Semester: 3** **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-

Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim:

The main objective of this module is to be able to appreciate the various aspects of galaxy formation and evolution, and apply them to outcomes of modern extragalactic research activities.

Content:

This module introduces the basic elements of extragalactic astronomy and observational cosmology. This includes the morphology, structural and spectral properties of star-forming and quiescent galaxies along the Hubble sequence. In this module we describe how galaxy populations change and how the distant galaxies in the early Universe evolve in the galaxies we observe today in our local neighborhood. The growth of the super massive black holes in the centers of galaxies as well as their phases as Active Galactic Nuclei is studied. This module also includes a look at main surveys and instruments, used in modern extragalactic research.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to show knowledge and understanding of:

A.1. The structure and properties of galaxies, galaxy groups and clusters;

A.2. The process of galaxy formation and their subsequent evolution and interactions with the intergalactic medium;

A.3. Techniques which telescopes and instruments use to observe different astrophysical processes in distant galaxies.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Obtain galaxy properties from observational evidence;

B.2. Describe the differences in galaxy populations and properties over the course of the Universe in terms of galaxy evolution;

B.3. Describe the formation of galaxies;

B.4. Apply basic physical principles to galaxy evolution and formation processes;

B.5. Apply material covered in the lectures to current research activities in extragalactic Astrophysics;

B.6. Describe the basic functioning of the optical/UV/IR telescope and spectrograph, and radio interferometer.

B.7. Describe the concepts of expanding space-time and cosmological red shift.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:

C.1. Communicate with clarity;

C.2. Work effectively, independently and under direction;

C.3. Explain concepts/principles of Extragalactic Astrophysics using different representations: words and symbols, pictures, diagrams, graphs, formulas, equations etc;

C.4. Analyze and solve conceptual and numerical problems related to Extragalactic Astrophysics;

C.5. Make precise observations, correlate experiment to theory and modify experiment, if need arises;

C.6. Demonstrate report-writing skills

C.7. Write a clear, technically accurate, and convincing proposal aimed at securing observing time on a telescope.

D. Key Transferable Skills

On completion of the module, students will be able to:

D.1. Demonstrate knowledge and expertise of basic experimental skills such as handling astronomy instruments, coordination, etc.;

D.2. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.3. Communicate concepts and principles of Extragalactic astrophysics concisely, accurately and informatively to specialist and non-specialist audiences;

D.4. Develop new skills and understanding of high level

D.5. Work independently and take initiative itself

D.6. Be organized to achieve results and to plan and execute a project.

D.7. Develop independent learning strategies

D.8. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.9. Evaluate and apply the contents of the specialized literature on these topics;

D.10. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.11. Learn independently, actively and reflectively and to develop intuition;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Be able to construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- The Milky Way as Galaxy: Galactic coordinates, Determination of distances within our Galaxy, the structure of the Galaxy, Kinematics of the Galaxy, the Galactic Microlensing effect, the Galactic Centre;
- Galaxies: Morphological classification, stellar population, Spectral energy distribution, Scaling relations, Black holes in the centres of galaxies;
- Statistical properties of the galaxy population: luminosity function; mass function; star-formation history of the Universe;
- Active Galactic Nuclei: Introduction, Classification of AGN, the Central Engine, Components of AGNs, AGNs and Cosmology;
- Clusters and Group of Galaxies: the Local group, Galaxies in Clusters and Groups;

- The Universe at High Red Shift: Galaxy Formation and Evolution (Red, blue and the green 'valley' galaxies), Galaxies at High Red shift;
- Elements of Cosmology: content of the Universe, current evidence for Dark Matter and Dark Energy; evolution and eventual fate of the Universe; cosmic microwave background radiation; nucleosynthesis.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information.

The material in this module is delivered through a combination of *formal lectures and exercises:*

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12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
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Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

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14. Indicative Resources

Core Text:

- Elmegreen D., Galaxies and Galactic Structure, , Prentice Hall, 1997.
- Schneider P., Extragalactic Astronomy and Cosmology: An Introduction, Springer, 2006.Sparke L.S. and J.S. Gallagher, Galaxies in the Universe, Cambridge University Press, Cambridge 2000.

Background Texts:

- Binney & M. Merrifield, Galactic Astronomy, Princeton University Press, 1998.
- Bradley W. Carroll and Dale A. Ostlie, An Introduction to Modern Astrophysics, Addison-Wesley, 2006.

Journals:

- *The NASA Astrophysics Data System:* http://adswww.harvard.edu/

The SAO/NASA Astrophysics Data System (ADS) is a Digital Library portal for researchers in Astronomy and Physics, operated by the Smithsonian Astrophysical Observatory (SAO) under a NASA grant. The ADS maintains three bibliographic databases containing more than 8.3 million records: Astronomy and Astrophysics, Physics, and arXiv e-prints. The main body of data in the ADS consists of bibliographic records, which are searchable through highly customizable query forms, and full-text scans of much of the astronomical literature which can be browsed or searched via our full-text search interface. Integrated in its databases, ADS provides access and pointers to a wealth of external resources, including electronic articles, data catalogs and archives.

- *Astrophysical Journal*

The Astrophysical Journal (APJ) is a peer-reviewed scientific journal covering astronomy and astrophysics. It was founded in 1895 by the American astronomers George Ellery Hale and James Edward Keeler. It publishes three 500-page issues per month. The journal is published by the Institute of Physics Publishing.

- *Astronomy and Astrophysics*

The Astronomy and Astrophysics(abbreviated as A&A in the astronomical literature, or else Astron. Astrophys.) is a European Journal, publishing papers on theoretical, observational and instrumental astronomy and astrophysics. It is published by EDP Sciences. The journal copyright is owned by the European Southern Observatory.

- *Monthly Notices of the Royal Astronomical Society*

The Monthly Notices of the Royal Astronomical Society (MNRAS) is one of the world's leading scientific journals in astronomy and astrophysics. It has been in continuous existence since 1827 and publishes peer-reviewed letters and papers reporting original research in relevant fields. MNRAS is published by Blackwell Scientific Publications (later Wiley-Blackwell) on behalf of the Royal Astronomical Society(RAS).

- *Publications of the Astronomical Society of the Pacific*

"Publications of the Astronomical Society of the Pacific" is a monthly scientific journal which publishes astronomy research and review papers, instrumentation papers and dissertation summaries. It is managed by the Astronomical Society of the Pacific, and published by the University of Chicago Press. It has been published monthly since 1899, and along with the Astrophysical Journal, Astronomical Journal, Astronomy and Astrophysics and MNRAS is one of the primary journals for the publication of astronomical research.

Key websites and on-line resources

- *Imagine the Universe!*

http://imagine.gsfc.nasa.gov/

This is an educational resource for students, teachers, and the general public. "Imagine the Universe!" provides information on topics in astrophysics about the Structure and Evolution of the Universe. If you don't find your questions answered, you can "Ask an Astrophysicist". Material is written at a variety of reading levels from middle school to college. Teacher resources includes information on resources at the Laboratory for High-Energy Astrophysics, "Adopt an Astronomer", summer intern programs, and lesson plans. We also maintain a list of other astronomy education resources on the WWW, as well as search facilities with our site to find specific topics.

- *StarChild*

http://starchild.gsfc.nasa.gov/docs/StarChild/StarChild.html

This is a learning center for young astronomers. It is an educational resource for younger readers (from kindergarten to junior high school). StarChild has information at multiple reading levels on astronomy and space exploration.

- *WebStars: Astrophysics in Cyberspace*

http://heasarc.gsfc.nasa.gov/docs/outreach/webstars.html

The website lists astronomical resource sites for users who have a general interest in astronomical topics.

- *The AstroWeb Consortium (NRAO site)*

http://www.cv.nrao.edu/fits/www/astroweb.html

Several institutions around the world maintain closely related links to Astronomy resources called the AstroWeb Consortium. The following links are excellent starting points for browsing for astronomy resources.

- *The Galaxy Page*

http://www.dmoz.org/Science/Astronomy/

The University of Arizona Students for the Exploration and Development of Space (SEDS) has a truly impressive list of resources through the WWW. These include resources lists on the solar system, astronomy and astrophysics (including amateur astronomy, date sources, news, periodical, software, celestial events, observatories, and more!), aerospace and astronautics (including launch vehicles, current and future satellites, shuttle schedules, etc), and future exploration (including forthcoming launch systems, the new International Space Station, and the human exploration of space).

Here you'll find links to NASA Education News, with information on upcoming events and recent projects. Also, links are provided to NASA's educational programs, services, and curriculum support products. This site is mainly intended for educators.

- *NASA Education resource:*
  http://www.nasa.gov/offices/education/about/index.html
- *StarDate Online:*
  http://stardate.org/

General information on the night sky is provided and updated daily.

- *A Guide to Astronomy Careers and Resources:*
  (http://www.guidetocareereducation.com/tips-and-tools/astronomy-careers

The following are links to the best resources on the web for pursuing an education and career in astronomy. All of the links will direct you to resources from universities, government agencies, and respectable independent organizations.

- *MIT courses:*

http://ocw.mit.edu/courses/physics/

- *Free astrophysics/astronomy e-books:*

http://www.e-booksdirectory.com/listing.php?category=167

http://www.e-booksdirectory.com/listing.php?category=165

Software

Astrophysics/Astronomy software (online and downloadable):

http://www.midnightkite.com/software.html

Students will be indicated useful software to download during exercises and practices, some important are with (*) for very needed:

On Windows PC:

- ASTRONOM: planetary information software

- Astronomer's Digital Clock: displays time, date, and Julian day
- CLEA (*): Windows Software Modern Laboratory Exercises in Astronomy
- Cartes du ciel: Free sky atlas for windows that provides access to catalogs and photographs (Sky charts in English
- Celestia (*): A free real-time space simulation that lets you experience our universe in three dimensions
- CyberSky: Colorful, easy-to-use planetarium program
- Maxclock 3.1: High-precision clock, displays sidereal and solar times, equation of time, Julian dates, Delta-T, equatorial and ecliptic coordinates of sun and moon
- Stellarium (*): Freeware that renders 3D photo-realistic skies in real time (or here http://www.stellarium.org/)
- Celestia (*): A scientifically accurate 3D space simulation (uses OpenGL), contains 3D positions of everything from stars to asteroids and artificial satellites (also a large amount of expansion ad dons are available).

On LUNIX PC:

- Fchart: Draws practical, well-readable deepsky finder charts in Postscript (EPS) and Adobe PDF format.
- IRAF (*): Image Reduction and Analysis Facility.

Java, JavaScript, and Active Server Pages:

- Aladin: Sky atlas allowing the user to visualize digitized images of any part of the sky, to superimpose entries from astronomical catalogs or personal user data files, and to access related data and information from the SIMBAD, NED, VizieR, etc.
- DeepSkyLive: A free web-based star charting java-applet: draws stars to mag 11.5, can display all NGC objects.
- Picosky: Sideral time calculator.

Teaching/Technical Assistance

One Assistant Lecturer is needed to help in tutorial sessions, some being run in computer labs.

Laboratory space and equipment

A small telescope will be needed for demonstration of basic principles of observing objects in the sky. However, in the future with more students in postgraduate levels, there will be a need of a research optical telescope for students who will choose to do further research in Astrophysics.

Computer requirements

There will be computer simulations, data reduction using specific astrophysical software which will be installed on computers in the departmental postgraduate computer lab. A computer lab is required. These computers will run both in Windows and Linux and will be connected to a local or a university computer server (which will be in charge of keeping useful software of science in general).

Please add anything else you think is important

Video films or computer simulations related to the content will be shown to the students.

15. Module Team:

Module Leader: Dr. Ravi Sheth

Team members: Prof. Manasse Mbonye, Dr. Pheneas Nkundabakura

Senior Lecturer to be recruited

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1. **Module Code:** AST6363
2. **Module Title:** HIGH ENERGY ASTROPHYSICS
3. **Level:** 6 **Semester: 3** **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6

Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

This module aims at giving an introduction to a wide range of topics of modern astrophysics involving high energy processes and/or observable at high energies, in particular at X-ray and Gamma-ray frequencies.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to show knowledge and understanding of:

A.1. The sky as seen across the electromagnetic spectrum and in particular with high-energy detectors;

A.2. The basic physical processes involving high energy particles and/or creating high energy emission;

A.3. The basic physics in accretion processes observed for a variety of sources;

A.4. The methods and observing techniques to study high energy emission;

A.5. The wide range of astrophysical sources visible at high energies and to relate them to relevant emission processes;

A.6. The relative importance of high energy processes for a variety of sources;

A.7. The current research going on in high energy astrophysics;

A.8. The prospects given by future high energy observatories.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:

B.1. Describe the sky as seen across the electromagnetic spectrum and in particular with high-energy detectors;

B.2. Explain the basic physical processes involving high energy particles and/or creating high energy emission;

B.3. Demonstrate an understanding of the basic physics in accretion processes observed for a variety of sources;

B.4. Learn the methods and observing techniques to study high energy emission;

B.5. Identify the wide range of astrophysical sources visible at high energies and to relate them to relevant emission processes;

B.6. Demonstrate an understanding of the relative importance of high energy processes for a variety of sources;

B.7. Have an insight into current research going on in high energy astrophysics;

B.8. Describe the prospects given by future high energy observatories.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:

C.1. Explain concepts/principles of High Energy Astrophysics using different representations; words and symbols, pictures, diagrams, graphs, formulas, equations etc;

C.2. Analyze and solve conceptual and numerical problems related to High Energy Astrophysics;

C.3. Make precise observations, correlate experiment to theory and modify experiment, if need arises;

C.4. Demonstrate report-writing skills;

C.5. Write a clear, technically accurate, and convincing proposal aimed at securing observing time on a telescope.

D. Key Transferable Skills

On completion of the module, students will be able to:

D.1. Communicate concepts and principles of High energy astrophysics concisely, accurately and informatively to specialist and non-specialist audiences;

D.2. Demonstrate knowledge and expertise of basic laboratory skills such as handling instruments, coordination of work, etc.

D.3. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.4. Communicate concepts and principles of High Energy Astrophysics concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level

D.6. Work independently and take initiative itself

D.7. Be organized to achieve results and to plan and execute a project.

D.8. Develop independent learning strategies

D.9. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.10. Evaluate and apply the contents of the specialized literature on these topics;

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Learn independently, actively and reflectively and to develop intuition;

D.13. Generate innovative and competitive proposals for research and professional activities;

D.14. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.15. Be able to construct clear, logical arguments;

D.16. Have a sense of self-organization, self-discipline and self-knowledge;

D.17. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- Introduction to the high-energy sky: Historical perspective
- Stellar evolution relevant to high-energy astrophysics: final stages of stellar evolution;
- Particle acceleration: Galactic and extragalactic;
- Processes involving high energies: Interaction of high-energy particles with matter (Bremsstrahlung and spallation products), Interaction of electrons with magnetic fields (synchrotron and curvature radiation), Interaction of electrons with photons (Compton scattering -Thomson & Klein-Nishina limits), Interstellar gas, magnetic field and associated galactic non-thermal radiation;
- Basic properties of pulsars and neutron star astrophysics;
- Origin of electrons in our galaxy: Supernova, supernova remnants;
- Accretion and X-ray binaries;
- Gamma-ray bursts.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information.

The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will provide the means to give a concise, focused presentation of the subject matter of the module. The lecture material will be explicitly linked to the contents of recommended textbooks for the module, thus making clear where students can begin independent study. When appropriate, the lectures will also be supported by the distribution of written material, or by information and relevant links. During lectures, the efforts will be made to link the new knowledge to prior knowledge of the students. Efforts will be made to address the misconceptions of the students. Analogy and examples related to the module will be used. The concepts/principles related to the module will be presented in a well-organized way and conceptual links will be provided. The organization of presented knowledge will be made as clear as possible by frequent summaries, as well as by concept-map diagrams.

Exercises: problems for the exercises will be handed out on a weekly basis in order to give students the chance to develop their theoretical understanding and problem solving skills and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the black board. Efforts will be made for active participation of students, by inviting questions, reactions and suggestions from the students, asking questions to them, etc Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and black board for solving problem.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement. Summative assessment of students' performance will be made through in course Assessment Tests and final examination. The frequent formative assessment will be used in various forms to monitor learning progress during instruction. The conceptual questions will be an integral part of the lectures/tutorials. The diagnostic test/home assignment can help to diagnose learning difficulties and misconceptions of students.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered

In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A8, B1-B8, C1-C5**
CA II: Mid-Semester Examination	30	**A1-A8, B1-B8, C1-C5, D1-D17**
End Semester Examination	40	**A1-A8, B1-B8, C1-C5, D1-D17**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

Core Text:

- Blandford R.D., Hewish A., Lyne A.G., L. Mestel, Pulsars as Physics Laboratories, The Royal Society, Oxford University Press, 1992.
- Longair M. S., High Energy Astrophysics: Particles, photons and their detection,Vol. 1, Cambridge University Press, 1992.
- Longair M. S., High Energy Astrophysics: Stars, the Galaxy and the interstellar medium, Vol. 2, 1994, Cambridge University Press, 1994.
- Mészáros P. High-Energy Radiation from Magnetized Neutron Stars, The University of Chicago Press, Chicago & London, 1992.

Background Texts:

- Bradley W. Carroll and Dale A. Ostlie, An Introduction to Modern Astrophysics, Benjamin Cummings, 1995.

Journals:

- *The NASA Astrophysics Data System:* http://adswww.harvard.edu/

  The SAO/NASA Astrophysics Data System (ADS) is a Digital Library portal for researchers in Astronomy and Physics, operated by the Smithsonian Astrophysical Observatory (SAO) under a NASA grant. The ADS maintains three bibliographic databases containing more than 8.3 million records: Astronomy and Astrophysics, Physics, and arXiv e-prints. The main body of data in the ADS consists of bibliographic records, which are searchable through highly customizable query forms, and full-text scans of much of the astronomical literature which can be browsed or searched via our full-text search interface. Integrated in its databases, ADS provides access and pointers to a wealth of external resources, including electronic articles, data catalogs and archives.

- *Astrophysical Journal*

  The Astrophysical Journal (APJ) is a peer-reviewed scientific journal covering astronomy and astrophysics. It was founded in 1895 by the American astronomers George Ellery Hale and James Edward Keeler. It publishes three 500-page issues per month. The journal is published by the Institute of Physics Publishing.

- *Astronomy and Astrophysics*

  The Astronomy and Astrophysics(abbreviated as A&A in the astronomical literature, or else Astron. Astrophys.) is a European Journal, publishing papers on theoretical, observational and instrumental astronomy and astrophysics. It is published by EDP Sciences. The journal copyright is owned by the European Southern Observatory.

- *Monthly Notices of the Royal Astronomical Society*

  The Monthly Notices of the Royal Astronomical Society (MNRAS) is one of the world's leading scientific journals in astronomy and astrophysics. It has been in continuous existence since 1827 and publishes peer-reviewed letters and papers reporting original research in relevant fields. MNRAS is published by Blackwell Scientific Publications (later Wiley-Blackwell) on behalf of the Royal Astronomical Society(RAS).

- *Publications of the Astronomical Society of the Pacific*

  “Publications of the Astronomical Society of the Pacific” is a monthly scientific journal which publishes astronomy research and review papers, instrumentation papers and dissertation summaries. It is managed by the Astronomical Society of the Pacific, and published by the University of Chicago Press. It has been published monthly since 1899, and along with the Astrophysical Journal, Astronomical Journal, Astronomy and Astrophysics and MNRAS is one of the primary journals for the publication of astronomical research.

Key websites and on-line resources:

- *Imagine the Universe!*

  http://imagine.gsfc.nasa.gov/

  This is an educational resource for students, teachers, and the general public. “Imagine the Universe!” provides information on topics in astrophysics about the Structure and Evolution of the Universe. If you don't find your questions answered, you can "Ask an Astrophysicist". Material is written at a variety of reading levels from middle school to college. Teacher resources includes information on resources at the Laboratory for High-Energy Astrophysics, "Adopt an Astronomer", summer intern programs, and lesson plans. We also maintain a list of other astronomy education resources on the WWW, as well as search facilities with our site to find specific topics.

- *StarChild*

  http://starchild.gsfc.nasa.gov/docs/StarChild/StarChild.html

  This is a learning center for young astronomers. It is an educational resource for younger readers (from kindergarten to junior high school). StarChild has information at multiple reading levels on astronomy and space exploration.

- *WebStars: Astrophysics in Cyberspace*

  http://heasarc.gsfc.nasa.gov/docs/outreach/webstars.html

  The website lists astronomical resource sites for users who have a general interest in astronomical topics.

- *The AstroWeb Consortium (NRAO site)*

  http://www.cv.nrao.edu/fits/www/astroweb.html

  Several institutions around the world maintain closely related links to Astronomy resources called the AstroWeb Consortium. The following links are excellent starting points for browsing for astronomy resources.

- *The Galaxy Page*

http://www.dmoz.org/Science/Astronomy/

The University of Arizona Students for the Exploration and Development of Space (SEDS) has a truly impressive list of resources through the WWW. These include resources lists on the solar system, astronomy and astrophysics (including amateur astronomy, date sources, news, periodical, software, celestial events, observatories, and more!), aerospace and astronautics (including launch vehicles, current and future satellites, shuttle schedules, etc), and future exploration (including forthcoming launch systems, the new International Space Station, and the human exploration of space).

Here you'll find links to NASA Education News, with information on upcoming events and recent projects. Also, links are provided to NASA's educational programs, services, and curriculum support products. This site is mainly intended for educators.

- *NASA Education resource:*

  http://www.nasa.gov/offices/education/about/index.html

- *StarDate Online:*

  http://stardate.org/

  General information on the night sky is provided and updated daily.

- *A Guide to Astronomy Careers and Resources:*

  (http://www.guidetocareereducation.com/tips-and-tools/astronomy-careers

  The following are links to the best resources on the web for pursuing an education and career in astronomy. All of the links will direct you to resources from universities, government agencies, and respectable independent organizations.

- *MIT courses:*

  http://ocw.mit.edu/courses/physics/

- *Free astrophysics/astronomy e-books:*

  http://www.e-booksdirectory.com/listing.php?category=167

  http://www.e-booksdirectory.com/listing.php?category=165

Software:

Astrophysics/Astronomy software (online and downloadable):

http://www.midnightkite.com/software.html

Students will be indicated useful software to download during exercises and practices, some important are with (*) for very needed:

On Windows PC:

- ASTRONOM: planetary information software
- Astronomer's Digital Clock: displays time, date, and Julian day
- CLEA (*): Windows Software Modern Laboratory Exercises in Astronomy
- Cartes du ciel: Free sky atlas for windows that provides access to catalogs and photographs (Sky charts in English
- Celestia (*): A free real-time space simulation that lets you experience our universe in three dimensions
- CyberSky: Colorful, easy-to-use planetarium program
- Maxclock 3.1: High-precision clock, displays sidereal and solar times, equation of time, Julian dates, Delta-T, equatorial and ecliptic coordinates of sun and moon
- Stellarium (*): Freeware that renders 3D photo-realistic skies in real time (or here http://www.stellarium.org/)
- Celestia (*): A scientifically accurate 3D space simulation (uses OpenGL), contains 3D positions of everything from stars to asteroids and artificial satellites (also a large amount of expansion ad dons are available).

On LUNIX PC:

- Fchart: Draws practical, well-readable deepsky finder charts in Postscript (EPS) and Adobe PDF format.
- IRAF (*): Image Reduction and Analysis Facility

Java, JavaScript, and Active Server Pages:

- Aladin: Sky atlas allowing the user to visualize digitized images of any part of the sky, to superimpose entries from astronomical catalogs or personal user data files, and to access related data and information from the SIMBAD, NED, VizieR, etc.
- DeepSkyLive: A free web-based star charting java-applet: draws stars to mag 11.5, can display all NGC objects
- Picosky: Sideral time calculator

Teaching/Technical Assistance

One Assistant Lecturer is needed to help in tutorial sessions, some being run in computer labs.

Laboratory space and equipment

The 4 inch small telescope is in good health and will be used to demonstrate basic principles of observing objects in the sky. However, in the future with more students in postgraduate levels, there will be a need of a research optical telescope for students who will choose to do further research in Astrophysics.

Computer requirements

There will be computer simulations, data reduction using specific astrophysical software which will be installed on computers in the departmental postgraduate computer lab. A computer lab is required. These computers will run both in Windows and Linux and will be connected to a local or a university computer server (which will be in charge of keeping useful software of science in general).

Please add anything else you think is important

Video films or computer simulations related to the content will be shown to the students.

15. Module Team

Module Leader: Dr. Ravi Sheth

Team members: Prof. Manasse Mbonye, Dr. Pheneas Nkundabakura

Senior Lecturer to be recruited

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1. **Module Code:** CMP6361
2. **Module Title:** ELECTRONS AND PHONONS IN SOLIDS
3. **Level:** 6 **Semester:** 3 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** Statistical Physics (MPH6261), Quantum Mechanics II (MPH6262), Solid State Physics (MPH6263)
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24

Structured exercises	2	24	48
Self study	2	24	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

This module aims to give an introduction to the physics of electrons and phonons in solids together with theoretical concepts and techniques as applied to these systems. Theoretical approaches are developed which can deal with a macroscopic number of interacting quantum objects, with the focus on electrons and quantized lattice vibrations (phonons). Various applications are discussed with emphasis on experimental and theoretical research directions of the Condensed Matter and Statistical Physics area of the ICTP.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Describe different types of crystal structures in terms of the crystal lattice and the basis of constituent atoms;

A.2.Formulate the theory of X-ray diffraction in the reciprocal lattice (k-space) formalism and apply this knowledge to generalize the formulation for matter waves;

A.3. Recognize that the developed k-space formalism to describe phonons, electrons, is more general and can be used to describe waves in a periodic media and identify such ‘out-of-the-course’ physical situations/problems;

A.4. Develop the concept of energy bands in the tight-binding approximation and compare the outcome of this methodology with the Quasi Free-Electron Model;

A.5. Demonstrate the Born-Oppenheimer Approximation

A.6. Describe the different physical mechanisms involved in crystal binding identifying the repulsive and attractive interactions and correlate these with the atomic properties;

A.7. Formulate the theory of lattice vibrations (phonons) and use that to determine thermal properties of solids.

B. Cognitive/Intellectual skills/Application of Knowledge/

B.1. Apply the knowledge obtained to make a judicious choice of a solid in terms of its desired property;

B.2. Formulate the problem of electrons in a periodic potential, examine its consequence on the band-structure of the solid and develop a framework that explains the physical properties of solids in terms of its band-structure;

B.3. Demonstrate the ability to critically and systematically integrate knowledge and analyse, assess and deal with complex phenomena, issues and situations even with limited information;

B.4. Work effectively, independently and under direction.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Perform calculations based on Electron and Phonon Physics;

C.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods;

C.3. Undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work.

C.4. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences.

D. Transferrable skills

Having successfully completed the module, students should (be able to):

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of electrons and photons in solids and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of electrons and photons in solids concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- *Introduction*
- *Crystal Structures:* Bravais Lattices. Wigner-Seitz Unit Cell. Lattices with a Basis. Close Packed Lattices.
- *Reciprocal Lattice:* Plane Waves with Lattice Periodicity. Definition of Reciprocal Lattice. Brillouin Zone.
- *Electronic States in a Crystal:* Bloch Theorem. K-dependent Hamiltonian. Band Structure. Fermi Level and Fermi Surface. Density of States. Fermi-Dirac Distribution. Heat Capacity of Free Electrons.
- *Quasi-Free-Electron Model:* Free-Electron Bands in a Ghost Lattice. Splitting Degeneracies. Estimate of Splitting with Bare Ionic Potential. Thomas-Fermi screening.
- *Tight-Binding Approximation:* Derivation of Secular Equation. Matrix Elements between s and

p States. Examples including Graphene, fcc and bcc Lattices with s, p Orbitals.

- *Application of Band Theory:* Optical Properties of Crystals. Vertical Transitions. Direct and Indirect Gap. Velocity of a Bloch State. Semiclassical Transport. Bloch Oscillations.
- *Born-Oppenheimer Approximation:* Full Hamiltonian (Electrons + Ions). Electronic Hamiltonian. Newton's Equation as Classical Limit & Ion Dynamics.
- *Phonons:* Expansion of Total Energy. Force Constants and Dynamical Matrix. Normal Modes. Linear Monoatomic Chain. Linear Chain with Two Springs.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and

assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A7, B1-B4, C1-C4**
CA II: Mid-Semester Examination	30	**A1-A7, B1-B4, C1-C4, D1-D16**
End Semester Examination	40	**A1-A7, B1-B4, C1-C4, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Ashcroft N.W. and N. D. Mermin,Solid State Physics, Harcourt, 1976.
- Kittel C., Introduction to Solid State Physics, 7th ed., John Wiley & Sons, 1996.

15. Module Team

Module Leader: Prof. Scandolo Sandro

Team members: Prof. Karamera Marembo P.C., Dr. Emmanuel Nshingabigwi

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1. **Module Code :** CMP6362
2. **Module Title:** NUMERICAL METHODS II
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules:** Numerical Methods I (MPH6264), Statistical Physics (MPH6261)
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-

Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim:

This module aims to teach students in second year Condensed Matte Physics. It will build from the NUM1 course that was taught in the first year and is especially designed for students in the Condensed Matter Physics section aiming at specializing in the areas of computational physics and chemistry.

Content:

Students will be taught about more advanced simulation techniques such as Molecular Dynamics and Monte Carlo both from a classical and quantum perspective with particular emphasis on applications in solid-state physics, organic and inorganic molecular systems and the modeling of biological systems. Besides sharpening their programming skills with more challenging numerical problems, students will also be exposed to state-of-the-art open source packages that allow for the simulation/modeling of complex systems with a particular emphasis on biomolecular simulations.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Understand the principles of molecular dynamics and Monte-Carlo and the underlying theory behind these techniques.

A.2. Develop an appreciation for the limitations and challenges in simulation techniques – the sampling problem and how to deal with these issues.

A.3. Be exposed to more sophistical MD codes which will be useful for them in their future research.

B. Cognitive/Intellectual skills/Application of Knowledge

On successful completion of the module students should be able to:
B.1. Apply their knowledge of numerical computer simulation techniques to solve real physical problems that they will encounter during their research.
B.2. More importantly identify and synthesize the information that they learnt in this class to attack problems that they may encounter during their research.

C. Communication/ICT/Numeracy/Analytic Techniques/Practical Skills

On completion of this module, students will be able to demonstrate the following skills:
C.1. Skills of how to setup molecular dynamics simulations and how to debug problems in them.
C.2. Skills of using open-source packages available as well post-processing tools to analyze simulation results.

D. Key Transferable Skills

D.1: Technical and theoretical background useful for pursuing a PhD degree in the area of material science, condensed matter, biophysics or physical chemistry.

9. Indicative Content

PART I

LECTURES: MOLECULAR DYNAMICS

- Review of Statistical Mechanics and Thermodynamics: Ergodicity, Partition functions, ensembles, relationships of thermodynamic properties and derivatives of partition functions.
- Interaction potentials in physical and chemical systems: short range and long-range interactions. Typical approximations used to model interactions between particles in a system – electrostatics, van-der-Waals potentials.
- Periodic boundary conditions, minimum-image convention, Ewald summation, smooth particle mesh Ewald.
- Hamilton’s equations, Lagrangians, Integrators for molecular dynamics: Verlet Algorithm

(velocity, leap-frog, symplectic integrators). Introduction to thermostats and barostats.

- Static and dynamics properties from molecular dynamics. Structural properties: radial distribution functions, thermodynamics from radial distribution functions, time correlation functions, diffusion constants (dynamical properties from simulations)
- Sampling problems/challenges in simulations. Determination of free energies. Introduction to enhanced sampling techniques: blue-moon ensemble, umbrella sampling, thermodynamic integration, metadynamics, parallel tempering.
- Introduction to sampling methods with Monte Carlo: Markov chains, Metropolis algorithm.
- Introduction to Biomolecular simulations
- Ab initio molecular dynamics, Car-Parrinello molecular dynamics and Path-integral molecular dynamics. Hellman-Feynman theorem. Born-Oppenheimer approximation.

PART II

LECTURES: METHODS OF STATISTICAL MECHANICS LECTURES

Mean field theories

Weiss Molecular Field of an Ising System, Bragg-Williams Approximation, Landau Theory of Continuous Phase Transitions, Critical Exponents in the Landau Theory, Short-Range Order and Fluctuations, Maxwell construction, correlation functions, Validity of The Mean-field Theory.

Monte Carlo Simulations

Stochastic Processes and Markov chains, Importance Sampling, Metropolis Algorithm, Practical Details and Data Analysis, The Renormalization Group Methods, a Trivial Example: The 1-D Ising Model, Renormalization Group transformations on the 2-D Ising Model, General Properties of Scaling and the Renormalization Group Transformations, Momentum-Space Renormalization Group, The Gaussian Model, The Landau-Wilson Model, Critical Exponents.

LAB LECTURES

Numerical Analysis II will involve more theoretical lectures than practical lab sessions. However, students will have the opportunity to do several hands-on-exercises:

- Write simple FORTRAN programs that will test their understanding of some of the basics that they will learn in the theory part. For example, this may include (but is not limited to) simple programs to do molecular dynamics in model potential systems, and in different ensembles.

- The students will also be exposed to more advanced MD packages like DLPOLY, GROMACS, NAMD and CP2K which will allow them to do more realistic applications on topics/systems that will be decided later on. In these exercises, students will be taught how to choose a correct timestep, energy conservation etc.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning

outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A3, B1-B2, C1-C2**
CA II: Mid-Semester Examination	30	**A1-A3, B1-B2, C1-C2, D1**
End Semester Examination	40	**A1-A3, B1-B2, C1-C2, D1**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Binder K. and D.W. Heermann, Monte Carlo simulations in Statistical Physics: An Introduction, Springer-Verlag Berlin and Heidelberg GmbH & Co. K, 2010.
- Frenkel D. and B. Smit, Understanding Molecular Simulation, Second Edition: From Algorithms to Applications, Academic Press, 2001.
- Leach A., Molecular Modeling: Principles and Applications, Prentice Hall, 2001
- Rapaport D.C., The Art of Molecular Dynamics Simulation, Cambridge University Press, 2004.

Background Texts:

- Allen M.P. and D. J. Tildesley, Computer Simulation of Liquids, Clarendon Press , 1989.
- Atkins P. and J. de Paula, Physical Chemistry, 9th ed., W. H. Freeman, 2009.
- Jensen F., Introduction to Computational Chemistry, 2nd ed., Wiley, 2017.
- Schlik T., Molecular Modeling and Simulation: An Interdisciplinary Guide, Springer Science & Business Media, 2010.

Computer Requirements

FORTRAN compilers, python, Mathematica/Matlab, Xmgrace, gnuplot, DLPOLY, GROMACS, NAMD, CP2K, CPMD codes to be compiled on the machines.

15. Module Team

Module Leader: Dr. Hassan Ali

Team members: Senior Lecturer to be recruited

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1. **Module Code :** CMP6363
2. **Module Title:** MANY-BODY PHYSICS
3. **Level:** 6 **Semester:** 3 **Credits:** 15
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules:** Statistical Physics (MPH6261), Quantum Mechanics II (MPH6262), Solid State Physics (MPH6263)
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	3	36	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	2	24	48
Self study	3	36	-
Assignments – preparation and writing	1.5	18	36
Revision	1.5	18	-
Examination – Preparation and attendance		6	9
Other:			
Invigilation	-	-	4
Marking			(*)
Total		150	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

Content

8. **Learning Outcomes**

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Demonstrate knowledge and understanding of the formulation of Many-Body Physics in the language of coherent state path integrals and will be able to apply this to physical models for systems with broken symmetry, e.g. ferromagnetic transitions;

A.2. Demonstrate knowledge and understanding of types of phase transitions, and how these can be described theoretically in different ways, e.g., using renormalization group theory.

A.3. Demonstrate knowledge and understanding of the microscopic origin of superconductivity and the description of coupled electron-phonon systems will also be known.

A.4. Demonstrate knowledge and understanding in the main field of study, including both broad knowledge of the field and a considerable degree of specialised knowledge in certain areas of the field as well as insight into current research and development work;

A.4. Demonstrate specialised methodological knowledge in the main field of study.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Demonstrate the ability to critically and systematically integrate knowledge and analyse, assess and deal with complex phenomena, issues and situations even with limited information.

B.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods, undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work.

B.3. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences, and

B.4. Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

B.5. Demonstrate the ability to pursue further studies within this research field, i.e. a M.Sc. project in theoretical condensed matter physics.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Perform calculations based on Many Body Physics;

C.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods;

C.3. Undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

C.4. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of Many Body Physics and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of Many Body Physics concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Be able to construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

PART 1: MANY BODY FUNDAMENTAL

PHONONS

- *Lattice dynamics in one dimension:* Classical harmonic chain. Continuum limit and sound waves in elastic string. Quantum approach: acoustic phonons. Lattice with a basis: optical phonons
- *Lattice dynamics in three dimensions. Debye model.*
- *Lattice stability. Role of dimensionality.*

MAGNONS

- *Spin waves in ferromagnets:* Holstein-Primakoff transformation. Equations of motion
- *Spin waves in antiferromagnets.*

ELECTRONS AND PHONONS

- *Electrons on a lattice:* Tight-binding model. Band spectrum. Electrons on a diatomic chain: ground state energy and charge density wave.
- *Electron-phonon interaction:* Electron-phonon interaction. Peierls insulators. Soliton excitations.

INTRODUCTION TO PHASE TRANSITIONS AND CRITICAL PHENOMENA

- *Overview:* First order and second order transitions. Spontaneous symmetry breaking and long-range order. Examples and basic models. Goldstone theorem.
- *Mean-field theory:* Mean-field theory of magnetic phase transitions. Pair correlations and Ornstein-Zernike formula. Validity of mean-field theory. Ginzburg criterion. Mermin-Wagner theorem.
- *Critical fluctuations. Ideas of scaling. Universality*
- *Exactly solvable models:* One-dimensional Ising model. Two-dimensional degenerate systems: topological phase transition in 2D XY model.

PART 2: MANY BODY PHENOMENOLOGY

- *Fermions:* Symmetry and statistics. Ideal Fermi gas. Thermodynamics. Pauli paramagnetism.

Landau diamagnetism. Fermi liquid. Quasiparticles: electrons and holes. Life time of quasiparticles. Random Phase Approximation for interacting fermions.

- *Bosons:* Ideal Bose gas. Thermodynamics. Bose-Einstein Condensation. Weakly interacting Bose-gas. Gross-Pitaevskii equation. Quasiparticles: phonons. Goldstone theorem. Lifetime of quasiparticles. Superfluidity. Vortices. Ultra-cold atomic gases in traps and optical lattices.
- *Superconductivity*: London equations. Electron-phonon interaction. Cooper instability. Bardeen-Cooper-Schrieffer theory. Ginzburg-Landau theory. Thermodynamics and electrodynamics of superconductors. Type 1 and type 2 superconductors. High-temperature superconductivity.
- *Local magnetism:* Phenomenological theory of local magnetism. Weiss molecular field. Langevin and Brillouin functions. Ground state. Spin susceptibility. Random Phase Approximation for magnetic systems. Correlation length. Long-range order. Spin dynamics. Bloch equation. Transverse and longitudinal relaxation times. Kondo effect. Magnetism of strongly correlated systems.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered

In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B5, C1-C4**
CA II: Mid-Semester Examination	30	**A1-A4, B1-B5, C1-C4, D1-D16**
End Semester Examination	40	**A1-A4, B1-B5, C1-C4, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Kittel C., Quantum Theory of Solids, John Wiley and Sons, New York, 1987.
- Ziman J.M., Principles of the Theory of Solids, Cambridge University Press, Cambridge, 1979.

Background Texts:

- Abrikosov A.A.. Fundamentals of the Theory of Metals, North-Holland, Amsterdam, 1988.
- Ashkroft N.W. and N.D. Mermin. Solid State Physics, Holt, Rinehart and Winston, New York, 1976.
- Auerbach A., Interacting Electrons and Quantum Magnetism, Springer-Verlag, 1994.
- Mahan G., Many-Particle Physics, Plenum press, NY, 1993.

- Schrieffer R., Theory of Superconductivity, Westview Press, 1971.
- Taylot P.L. and O. Heinonen, A quantum approach to condensed matter, Cambridge University Press, 2002.
- Tinkham M., Introduction to superconductivity, Mc- Graw Hill, New York, 1996.
- White R., Quantum Theory of Magnetism, Springer-Verlag, 1983.

15. Module Team

Module Leader: Prof. Scandolo Sandro

Team members: Dr. Hassan Ali

Senior Lecturer: to be recruited

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1. **Module Code :** CMP6364
2. **Module Title:** ADVANCED STATISTICAL MECHANICS
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules:** Statistical Physics (MPH6261), Quantum Mechanics II (MPH6262), Solid State Physics (MPH6263)
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aim

The aim of this module is to provide to students a deep knowledge of the formulation of statistical mechanics and probability theory to derive relations between thermodynamical quantities and to introduce them to the transition from the classical statistical mechanics to quantum many-body systems.

Content

This module starts by reviewing basic topics in equilibrium statistical mechanics. This includes thermodynamical quantities (entropy, energy, temperature, pressure, volume), Van der Waals gases and Maxwell construction, ensembles (microcanonical, canonical, grand canonical) and their equivalence, Gibbs distribution and the idea of Monte Carlo simulations, partition functions, classical ideal gases, equations of state, kinetic theory. The second part comes with the Principles of quantum statistical mechanics where the following topics are discussed: quantum ideal gases (bosonic and fermionic), blackbody radiation, phonons, Bose-Einstein condensates, and degenerate Fermi gases (white dwarves), phonons in solids; radiation, Planck’s law, magnetic systems: Ising model, Heisenberg model, mean field theory; fluctuations and stability of order (Mermin Wagner theorem); critical phenomena (second order phase transitions), Goldstone modes.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Demonstrate knowledge and understanding of the formulation of statistical mechanics and probability theory to derive relations between thermodynamical quantities;

A.2. Develop useful approximations that describe the statistical behaviour of classical and quantum many-body systems;

A.3. Discuss the microscopic meaning of phase transitions in statistical many-body systems.

A.4. Demonstrate knowledge and understanding in the main field of study, including both broad knowledge of the field and a considerable degree of specialised knowledge in certain areas of the field as well as insight into current research and development work;

A.4. Demonstrate specialised methodological knowledge in the main field of study.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Demonstrate the ability to critically and systematically integrate knowledge and analyse, assess and deal with complex phenomena, issues and situations even with limited information.

B.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods, undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work.

B.3. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences, and

B.4. Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

B.5. Demonstrate the ability to pursue further studies within this research field, i.e. a M.Sc. project in Statistical Physics.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Perform calculations based on Statistical Physics

C.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods;

C.3. Undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

C.4. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of Statistical Physics and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of Statistical Physics concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- Fundaments of statistical physics: Phase space, Liouville theorem, statistical.
- Distribution function; elements of probability theory.
- Brief review of thermodynamics: work, heat, first law, second law, entropy.
- Entropy from the statistical mechanics point of view, Nernst theorem.
- Information theoretic entropy (Shannon).
- Thermodynamic potentials and thermodynamic stability.
- Phase equilibrium, phase diagrams, phase transitions (1st/2nd order).
- Van der Waals gas, Maxwell construction.
- Ensembles and their equivalence.
- Gibbs distribution and the idea of Monte Carlo simulations.
- Principles of quantum statistical mechanics.
- Classical and quantum gases (Maxwell/Boltzmann - Bose and Fermi distributions)

- Fermions: the Fermi sea.
- Bose systems: Bose-Einstein condensation.
- Solids, phonons; radiation, Planck's law.
- Magnetic systems: Ising model, Heisenberg model.
- Mean field theory.
- Fluctuations and stability of order (Mermin Wagner theorem).
- Critical phenomena (second order phase transitions), Goldstone modes.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and

assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A7, B1-B5, C1-C4**
CA II: Mid-Semester Examination	30	**A1-A7, B1-B5, C1-C4, D1-D16**
End Semester Examination	40	**A1-A7, B1-B5, C1-C4, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Recommended textbooks

- Huang K., Statistical Mechanics, John Wiley & Sons, New York, 1987. - General, good, especially for kinetics, hydrodynamics, Ising model.
- Landau L. & I. Lifshitz, Statistical Physics (Vol. 5), Pergamon Press, 1969. - General, logical structure.
- Reif F., Fundamentals of statistical and thermal physics, McGraw-Hill Book Company New York, 1965. - General, thorough.
- Sommerfeld A., Thermodynamics and Statistical Mechanics, Academic press, New York, 1956. - Good for traditional thermodynamics.

Advanced texts:

- Chaikin P. and T. Lubensky, Principles of Condensed Matter Physics, Cambridge University Press, 1995. - Phase transitions, rich on applications to condensed matter
- Feynman R.P., Statistical Mechanics – A set of lectures, Frontiers in Physics, Benjamin/Cummings, Reading Massachusetts, 1982. - Path integrals, chosen subjects in statistical mechanics.
- Goldenfeld N., Lectures on Phase transitions and the Renormalization Group, Frontiersin Physics, Addison Wesley, Reading Massachusetts, 1994. - Phase transitions, RG.

- Landau L. and I. Lifshitz: Statistical Physics II (Vol. 9), Pergamon Press Modern Theory of quantum gases and liquids, magnetic systems.

15. Module Team

Module Leader: Prof. Scandolo Sandro

Team members: Dr. Hassan Ali

Senior Lecturer: to be recruited

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1. **Module Code :** MPH6265
2. **Module Title:** CONTINUUM MECHANICS
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** Classical Mechanics (MPH6161)
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Aims:

The modeling and simulation of fluids and solids with significant coupling and thermal effects is an important area of study in Geophysics.

Content:

In this module, we consider the case when the number of particlestends to infinity, with relative motion between the particles.This course will develop the idea of a continuum and study the deformation, strain and stress of both elastic and fluid continua. A preliminary survey of the physical properties of common elastic solids and fluids will be followed by adevelopment of the appropriate strain and stress tensors and general conservation laws. Examples of deformation such as 1-D, 2-D and 3-D tension and torsion in elastic solids will be given. We will then proceed to derive some commonly used models governing isothermal fluids and solids, consisting of systems of partial differential equations (PDEs). We will end with the exploration of thermal case.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be (able to):

A.1. Demonstrate a broad knowledge and understanding of conservation laws in fluids and solids;

A.2. Demonstrate a broad knowledge and understanding of deformations in fluids and solids;

A.2. Realize which effects play a role in the motion of a fluid;

A.3. Describe the flow (velocities and pressures) in certain configurations, for example, the flow around a cylinder, sphere and aerofoil.

A.4. Describe alternative theories to describe thermal motion as a wave and their interaction with elasticity and fluid mechanics.

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Demonstrate the ability to critically and systematically integrate knowledge and analyse, assess and deal with complex phenomena, issues and situations even with limited information;

B.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods, undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

B.3. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences;

B.4. Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

B.5. Demonstrate the ability to pursue further studies within this research field.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Perform calculations based on Continuum Mechanics;

C.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods;

C.3. Undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

C.4. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of Continuum Mechanics and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of Continuum Mechanics concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- Introduction to Continuum Mechanics: kinematic properties, conservative principles and related local balance equations in both formalisms eulerian and lagrangian; classical and non classical constitutive theories for fluids and solids: barotropic perfect fluids, Newtonian fluids, viscoelastic fluids and linear elastic solids. Uniqueness, stability and wave propagation properties.

- Thermodynamic considerations: the entropy principle, energy and entropy influxes, the free energy and the Clausius-Duhem inequality. Thermodynamic compatibility. The Navier-Stokes-Fourier model. Rigid heat conduction. Thermo-elastic models. Alternative theories to describe thermal motion as a wave and their interaction with elasticity and fluid mechanics. Analogies with the viscoelastic behavior: the polymeric liquid. Convective instabilities: the Boussinesq approximation and the classical Bénard problem.

- Nonlinear hyperbolic models in conservative form: weak solutions and shock waves. The Euler model and the fluidodynamic traffic model.

- Nonlinear diffusive parabolic models: the nonlinear porous medium equation, its properties and its applications in the description of the flow of an isentropic gas through a porous medium, in non local heat conduction and in mathematical biology. Analogies between the chemotactic collapse and the gravitational collapse in an astrophysical setting.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B5, C1-C4**
CA II: Mid-Semester Examination	30	**A1-A4, B1-B5, C1-C4, D1-D16**
End Semester Examination	40	**A1-A4, B1-B5, C1-C4, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Gonzalez O., A. Stuart, A first course in continuum mechanics, Cambridge University Press, 2008.
- Liu S., Continuum mechanics, Springer, 2002

Background Texts

- Ruggeri T., Introduzione alla termomeccanica dei continui , Monduzzi, 2007
- Straughan B., The energy method, stability and nonlinear convection, Springer New York, 2004
- Straughan B., Heat Waves, 2011th ed., Springer, New York.
- Vazquez J.L., An introduction to the mathematical theory of the porous medium equation Oxford University Press, 2007.

15. Module Team

Module Leader: Prof. Abdelakrim Aoudia

Team members: Prof. Bonfils Safari

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1. **Module Code :** GEP6361
2. **Module Title:** FUNDAMENTAL OF SOLID EARTH SCIENCE
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24

Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

This is a core course for all beginning graduate students in the Solid Earth Sciences. A quantitative introduction to Solid Earth Science, focusing on the underlying physical processes and their geological and geophysical expression as well as the different techniques and methods used in the study of the solid Earth.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be (able to):

A.1. Demonstrate a broad knowledge and understanding of how geophysics is used to build up a picture of the interior of the Earth and the processes which generate its surface and surface features;

A.2. Explain the theoretical background of gravity methods

A.3. Describe the working principles of zero-length gravimeter

A.3. Explain the gravity field procedure, data processing and interpretations.

A.4. Describe density determination and variations within the solid earth

A.5. Explain the origin and properties of geomagnetism

A.6. Discuss the working principle of proton magnetometer

A.7. Explain the magnetic field procedure, data processing and interpretations

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Demonstrate the ability to critically and systematically integrate knowledge and analyse, assess and deal with complex phenomena, issues and situations even with limited information;

B.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods, undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

B.3. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences;

B.4. Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

B.5. Demonstrate the ability to pursue further studies within this research field.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Perform calculations based on Solid Earth Physics

C.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods;

C.3. Undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

C.4. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of Solid Earth Physics and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of Solid Earth Physics concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights.

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- Introduction
- Electric, Magnetic, gravity Earth fields in comparison. Gravity-Solid Earth coupling. Gravitative effects in Earth evolution.
- Measurement of the Earth gravity field. Gravimeter; absolute and relative measurements; setup of field campaign.
- Measurement of Earth magnetic field. Magnetometer. Total field observation, three component instruments, setup of field campaign. Examples of magnetic map. Differences and common features to gravity map.
- Satellite observations. Altimeter; gravity-magnetic missions, latest gravity field mission GOCE, next mission.
- Spherical harmonic expansion of gravity field. International ellipsoid. Anomalous field. Analogy to magnetic field.
- Physical properties of rocks, density, seismic velocity, susceptibility. Correlation of different parameters. Temperature and pressure dependence. Curie Temperature.

- Lithospheric flexure model, effective elastic thickness, flexural rigidity, local isostatic compensation, mantle visosity.
- Examples of lithospheric flexure. Crustal thickening at orogens. Crustal thinning. Postglacial uplift and subsidence.
- Setup of a lithospheric density and susceptibility model. Physical constraints. Conditioning of solution.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning

outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A5, B1-B6, C1-C5**
CA II: Mid-Semester Examination	30	**A1-A5, B1-B6, C1-C5, D1-D8**
End Semester Examination	40	**A1-A7, B1-B5, C1-C4, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Blakely R.J., Potential theory in Gravity and Magnetic Applications, Cambridge University Press, 1996.
- Fowler A.C., The Solid Earth, Cambridge University Press, 2005.

Background Texts:

- Watts A.B., Isostasy and Flexure of the Lithosphere, Cambridge University Press, 2001.
- William Lowrie, Fundamentals of Geophysics, Cambridge University Press, 2007.

15. Module Team

Module Leader: Prof. Abdelakrim Aoudia

Team members: Senior Lecturer to be recruited.

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1. **Module Code :** GEP6362
2. **Module Title:** THEORETICAL AND OBSERVATIONAL SEISMOLOGY
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

This module aims to provide an in-depth understanding of the physics that governs earthquakes, earthquake induced tsunamis and the seismic waves. The module provides an introduction into the concepts and methods in seismology and how they are applied to investigate the Earth's interior.

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to demonstrate good knowledge and understanding of:

A.1. Faults and body forces and their representation, the elastodynamic Green function, Focal mechanisms

A.2. The Physics behind an Earthquakes and a Tsunami

A.3. The origin of surface waves and their types

A.4. Parameters which characterize size and strength of seismic sources (intensity, magnitude seismic moment) and their determination in seismometry

A.5. How to interpret a Seismogram

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Explain how to identify an Earthquake location using different methodologies

B.2. Explain how to determine the Earth's structure and seismic phases at different distance ranges

B.3. Explain different Global Earth models

C. *Communication /ICT/ Numeracy / Analytic Techniques/Practical skills*

Having successfully completed the module, students should be able to:

C.1. Use the inversion of seismic data for determination of Earth structure

C.2. Use Seismic tomography and other methodologies for the study of Earth structure

C.3. Demonstrate ability in Seismic data analysis and seismogram interpretation

C.4. Use the Geophysical inverse theory for the determination of geophysical information

C.5. Use statistical techniques for the estimation of parameters of seismic hazards

D. Transferable skills

Having successfully completed the module, students should demonstrate good skills in:

D.1. Processing, interpreting and presenting seismological data using appropriate software

D.2. Solving geophysical problems using computational and analytical techniques

D.3. Using the Internet as a source of geophysical information

D.4. Application of statistics to hazard

D.5. Working independently, taking initiative himself, and being able to organize to achieve results and to plan and execute a project

D.6. Developing independent learning strategies

D.7. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights

D.8. Generating innovative and competitive proposals for research and professional activities

9. Indicative Content

Introduction

Faulting

- Rupture process. Faults and their geometry. Strike, dip, rake and slip.
- Brittle deformation and stresses. Tensile cracking. Shear fracture and Coulomb criterion. Frictional sliding. Byerlee's law.
- Stresses and faulting. Stress cycle & Stick slip

Faults and their representation

- Elastodynamic basic theorems
- Elastodynamic Green function
- Representation theorem

Faults and body forces

- Equivalent body forces.
- Moment density tensor.
- Shear Dislocation Far source condition. Moment tensor. Seismic moment.
- Double couple. Faults and moment tensor components.
- Application to a specific case.

The elastodynamic Green function

- Impulse response & Transfer function. Transformed domain. Convolution theorem.
- Spherically symmetric problem. Lamè theorem.
- GF in a isotropic and homogeneous medium. Near and far field.
- Response to a double-couple. Near, intermediate and far field.

Focal mechanisms

- Faulting and radiation pattern.
- Basic fault plane solutions.
- Faults and plates.

Earthquakes and seismometry

- Extended faults. Haskell model. Rupture time.
- Directivity.
- Source spectra. Omega square model.
- Seismometry. Inertial instruments. Mechanical and electromagnetic instruments Response curves.

Earthquakes size and seismometry

- Astatic instruments.
- Digital signals; sampling & dynamic range.
- Broad band instruments; Feedback & Force balance.
- Strong motion; noise.

Intensity and magnitude measurements

- Intensity
- Magnitude. M_L, m_b, M_S. Saturation.
- Similarity conditions: geometric and dynamic.
- Moment Magnitude.

Tsunami Physics

- Long Gravity waves. Excitation by seismic sources.
- Tsunami modeling.
- Tsunami measurements.

Tsunami and seismic hazard

- Hazard and risk.
- Tsunami hazard. Seismic Hazard.
- Recap of the course.

Earth structure and seismic phases - *Seismogram interpretation*

- Origin time, arrival time and travel time.
- Seismic rays, travel times amplitudes and phases.
- Hypocentre and epicenter. Local, regional and teleseismic earthquakes.
- Refraction, reflection and conversion of waves at boundaries.
- Seismic phases at different distance ranges.
- Seismogram analysis and travel time curves.
- Phase picking and first arrival polarities.
- Determination of structure (introduction).
- Global Earth models.

Earthquake location

- Manual location.
- Single station location.
- Multiple station location.
- Wadati diagram.
- Manual location and computer location.
- Earthquake location: general problem and generalize inverse.

- Location by iterative methods.
- Relative location methods.
- Joint hypocenter location.
- Double difference earthquake location.

Intensity and magnitude measurements

- Parameters which characterize size and strength of seismic sources: intensity, magnitude seismic moment.
- Magnitude determination: magnitude scales for local events; common teleseismic magnitude scales.
- Complementary magnitude scales.

Surface waves

- Origin of surface waves.
- Dispersion and polarization.
- Crustal surface waves and guided waves.
- Normal modes.
- Surface wave dispersion measurement: theoretical aspects and practical measurement with computer programs.
- Frequency-time analysis (FTAN).

Earth structure

- Inversion of seismic data for determination of Earth structure.
- Refraction and Reflection seismology.
- Body waves travel time studies.
- Inversion of surface wave dispersion.

Seismic tomography

- Seismic tomography: body wave tomography; surface wave tomography.
- Ambient noise analysis and tomography.
- Other methodologies for the study of Earth structure.

Seismic data analysis

- Seismic data formats and digital waveform data.
- Software for seismic data analysis.

- Data analysis and seismogram interpretation: problems and caveats.
- Criteria and parameters for routine seismogram analysis.
- Software for routine seismological analysis (Seisan, SAC) with computer based lectures.
- Software installation and usage.

Geophysical inverse theory

- Geophysical inverse theory.
- Parameter estimation and inverse problems.
- Forward problems and inverse problems.
- Linear inverse problems: discrete problems, continuous problems.
- Equi-determined, over-determined and under-determined problems.
- Least square inverse.

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

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Grading:

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Academic honesty:

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12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
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CA II: Mid-Semester	30	**A1-A5, B1-B6, C1-C5, D1-D8**

Examination		
End Semester Examination	40	**A1-A5, B1-B6, C1-C5, D1-D8**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Aki K. and P., Richards, Quantitative Seismology: Theory and Methods, Society of Exploration Geophysicists, 2007.
- Lay T. and Wallace T., Modern Global Seismology, Academic Press, 1995.
- Wysession M., An introduction to seismology, Earthquakes and Earth Structure, Blackwell Publishing, 2003.

15. Module Team

Module Leader: Prof. Abdelakrim Aoudia

Team members: Senior Lecturer to be recruited.

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1. **Module Code :** GEP6363
2. **Module Title:** GEOPHYSICAL IMAGING OF THE SUB SURFACE

3. **Level:** 6 **Semester:** 3 **Credits:** 10

4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH

5. **Pre-requisite modules, excluded combinations:** N/A

6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

Geophysical imaging is central to many aspects of subsurface science. The aim of the course is to teach the basic principles and methods of subsurface sensing and imaging for sustainable energy and natural hazards. It starts with fundamental seismic methods and leads to the high-end imaging technologies to address industry exploration problems.

8. **Learning Outcomes**

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.2. Understand the basic principles and methods of subsurface sensing and imaging based on physical principles

A.2. Understand the use of different types of geophysical imaging and their applications A.3. Understand the mechanisms of wave focusing in random environments

B. Cognitive/Intellectual skills/Application of Knowledge/ Communication /ICT/ Numeracy /

Analytic Techniques/Practical skills

Having successfully completed the module, students should be able to:

B.1. Producing images of sub-surface structures from electrical resistivity measurements made at the surface

B.2. Interpret images to estimate the location and quantity of different materials in the subsurface

B.3. Use inversion method from waves that reflect several times before being recorded

B.4. Map the low-frequency components of the background physical parameters

B.5. Create images in increasingly complicated geological environments.

B.6. Extract more information from limited data sets and using that information to its fullest extent

D. Transferable skills

Having successfully completed the module, students should be able to:

D.1. Processing, interpreting and presenting geophysical data using appropriate software

D.3. Use the Internet as a source of geophysical information

D.4. Application of statistics to imaging

D.5. Working independently, taking initiative himself, and being able to organize to achieve results and to plan and execute a project

D.6. Developing independent learning strategies

D.7. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights

D.8. Generating innovative and competitive proposals for research and professional activities

9. Indicative Content

There are many different kinds of imaging techniques, all which are based on applied physics.

Types of geophysical imaging:

- Electrical resistivity tomography
- Ground-penetrating radar
- Induced polarization
- Seismic tomography and Reflection seismology

- Magnetotellurics

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A2, B1-B6**
CA II: Mid-Semester Examination	30	**A1-A2, B1-B6, D1-D8**
End Semester Examination	40	**A1-A2, B1-B6, D1-D8** .
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Text:

- W. M. Telford, L. P. Geldart, R. E. Sheriff, Applied Geophysics, Cambridge University Press, 1990.

Background text:

- Everett Mark, Near-Surface Applied Geophysics, Cambridge University Press, 2013.

15. Module Team

Module Leader: Prof. Abdelakrim Aoudia

Team members: Senior Lecturer to be recruited.

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1. **Module Code :** GEP6364
2. **Module Title:** GPS GEODESY AND INSAR
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-

Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

The aim of this module is to introduce physical geodesy and satellite based techniques to study the Earth deformation. The module will focus mainly on GPS Geodesy and INSAR.

8. Learning Outcomes

A. Knowledge and Understanding

After completing the module, students shall have an in-depth understanding and knowledge on the following:

A.1. Earth gravity field and the reference surfaces (geoid and ellipsoid)

A.2. Space Geodesy and global and local coordinate systems

A.3. Satellites positions objects on and above surface of the Earth, as well as in space and forces exerted on them

A.4. Methods and techniques for determination of Earth’s size and shape and its deformation and change in time using positioning satellites

A.4. Methods of processing GPS data

B. Cognitive/Intellectual skills/Application of Knowledge/ Communication /ICT/ Numeracy / Analytic Techniques/Practical skills

Having successfully completed the module, students should be able to:

B.1. Carry out coordinate computations using commercial and scientific software including correction terms

B.2. Calculate other parameters from GPS time series like Earth’s deformation and change parameters, including analysis and interpretation of the results

B.3. Analyze and process data collected using different techniques such as Differential Global Positioning System (DGPS) and Network-Based Real Time Kinematic (NRTK), Differential Synthetic Aperture Radar (DinSAR) and Interferometry.

D. Transferable skills

Having successfully completed the module, students should be able to:

D.1. Understand the global positioning satellite data interface and relation with other related disciplines

D.2. Identify the international perspective of satellite positioning and navigation and be able to cooperate internationally

D.3. Work independently and in a team towards relevant research front in Global positioning and navigation systems, taking initiative himself and organize to achieve results and to plan and execute a project

D.4. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights

D.5. Process, interpret and present geophysical data using appropriate software

D.6. Use the Internet as a source of geophysical information

D.7. Developing independent learning strategies

D.8. Generating innovative and competitive proposals for research and professional activities

9. Indicative Content

Fundamentals of Geodesy

- Definition of the Earth gravity field
- Reference surfaces: geoid and ellipsoid

Fundamentals of Space Geodesy

- Definition of Space Geodesy
- Definition of global and local coordinate systems
- Description of the satellite motions
- Forces acting on the satellites

Global Positioning System (GPS) observables

- Pseudo ranges
- Carrier phases
- Receiver Independent Exchange (RINEX) format

Errors in the GPS observables

- Ionosphere
- Troposphere
- Multipath
- Phase Center Variation

Mathematical model of GPS observables

- Relative and Absolute Positioning
- Linear Combination of Observables

Methods of processing GPS data

- Commercial Software
- Scientific Software

GPS Time Series Analysis

- Deterministic model
- Stochastic model

Kinematic applications

- Differential Global Positioning System (DGPS)
- Network-Based Real Time Kinematic (NRTK)

Synthetic Aperture Radar (SAR)

- Definition of RAdio Detection And Ranging (RADAR)
- Definition of SAR

Interferometry

- Definition of Interferometric Synthetic Aperture Radar (INSAR)
- Phase Unwrapping
- Applications

Differential Synthetic Aperture Radar (DinSAR)Interferometry

- Definition of DinSAR
- Applications

GPS and InSAR geophysical applications case study

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

A student who misses to report to any assessment/exam should comply with the Examinations' Regulation.

Grading:

Grading will be made as transparent, consistent and fair as possible. For all written work, solutions and point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B3**
CA II: Mid-Semester Examination	30	**A1-A4, B1-B3, D1-D8**
End Semester Examination	40	**A1-A4, B1-B3, D1-D8**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Text:

- Hofmann-Wellenhof Bernhard, Moritz Helmut, Physical Geodesy, S Wien New York, Springer Wien New York, 2006.

Background Text:

- Gilbert Strang and Kai Borre, Linear Algebra, Geodesy, and GPS, Wellesley-Cambridge, 1997.

15. Module Team

Module Leader: Prof. Abdelakrim Aoudia

Team members: Senior Lecturer to be recruited.

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1. **Module Code :** GEP6365
2. **Module Title:** PHYSICS OF VOLCANOES
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. Brief Description of Aims and Content

Aim

The aim of the course is to provide an understanding of active volcanic processes.

Content

8. Learning Outcomes

A. Knowledge and Understanding

Having successfully completed the module, students should be able to:

A.1. Explain the various types of volcanism and their relations to tectonophysics

A.2. Demonstrate an understanding of magma generation and evolution; magma transport from the mantle to the crust

A.3. Demonstrate in-depth knowledge of magma storage, magma reservoir dynamics and thermodynamics, seismicity, deformation and gravity

A.4. Develop understanding of potential impacts of volcanic eruptions and their links to natural hazards and human activities

B. Cognitive/Intellectual skills/Application of Knowledge/ Communication /ICT/ Numeracy / Analytic Techniques/Practical skills

Having successfully completed the module, students should be able to:

B.1. Assimilate the causes of volcanism, the physical properties of magmas and the basis of physical modeling of volcanic eruptions

B.2. Make field observations and to record quantitative data including chemical, produce maps and cross-sections, and synthesize data into conceptual eruption models and volcano histories

C. Transferable skills

Having successfully completed the module, students should be able to:

C.1. Discuss the factors controlling the style of volcanic eruptions and their products, and explain the nature of volcanic hazards and assess methods of monitoring and prediction, with reference to recent examples

C.2. Interpret thin section observations of recent volcanic rocks

C.3. Develop IT and communication skills in preparing coursework using a variety of source material

C.4. Working in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights

C.5. Process, interpret and present geophysical data using appropriate software

C.6. Use the Internet as a source of geophysical information

C.7. Developing independent learning strategies

C.8. Generating innovative and competitive proposals for research and professional activities

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of Physics of Volcanoes and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of Physics of Volcanoes concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights;

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

- Types of volcanism and relations to tectonophysics
- Magma generation and evolution
- Magma transport from the mantle to the crust
- Magma storage, magma reservoir dynamics and thermodynamics, seismicity, deformation and gravity
- Dike propagation, induced seismicity and deformation
- Phase transitions in magma
- Laboratory experimentation on volcanic processes (Analogue experiments, rock mechanics)
- Conduit flow, degassing
- Explosive eruptions I (phreatomagmatic eruptions, Strombolian and Hawaiian activity)
- Explosive eruptions II
- Pyroclastic flows, lahars, lava flows, lava tubes
- Planetary volcanism

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

Different forms of teaching will be used in the class to reach the objective, such as power point presentations for head titles, definitions, figures, summary of conclusions, and white/black board for solving problem.

Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

- Coursework.
- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

Assessment dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to examination:

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Grading:

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Academic honesty:

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12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A4, B1-B2**
CA II: Mid-Semester Examination	30	**A1-A4, B1-B2, C1-C8, D1-D16**
End Semester Examination	40	**A1-A4, B1-B2, C1-C8, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Fagents S.A., K.P. T.K.P. Gregg, R.M. C. Lopes (Edtrs), Modeling Volcanic Processes, The Physics and Mathematics of Volcanism, Cambridge University Press, 2013.
- Gilbert J.S., R. S. J. Sparks (Edtrs): The Physics of Explosive Volcanic Eruptions, Geological Society Special Publication No 145, 1998.

15. Module Team

Module Leader: Prof. Abdelakrim Aoudia

Team members: Senior Lecturer to be recruited.

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1. **Module Code :** GEP6366
2. **Module Title:** MECHANICS OF EARTHQUAKES AND TECTONOPHYSICS
3. **Level:** 6 **Semester:** 3 **Credits:** 10
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Lectures	2	24	48
Seminars/workshops	-	-	-
Practical classes/laboratory	1	12	24
Structured exercises	1	12	24
Self study	2	24	-
Assignments – preparation and writing	1	12	24
Revision	1	12	-
Examination – Preparation and attendance		4	6
Other:			
Invigilation	-	-	4
Marking			(*)
Total		100	130 + (*)

(*): ½ H X Number of copies X 2 Exams

7. **Brief Description of Aims and Content**

This module provides fundamental mechanical principles of earthquakes and faulting from four related perspectives: rheology, seismology, geodesy and tectonics; Physical processes that control the rheology of faults, including friction and fracture, how these rheological processes are manifested in faulting and earthquakes; Earthquake cycle and rheology of the lithosphere, postseismic deformation and transients; mechanics of faulting vs. mechanics of earthquakes; Continental and oceanic examples of faulting and earthquakes.

8. **Learning Outcomes**

A. Knowledge and Understanding/Cognitive/Intellectual skills/Application of Knowledge/

Communication /ICT/ Numeracy / Analytic Techniques/Practical skills

Having successfully completed the module, students should have developed an in-depth knowledge and understanding of:

A.1. The physics of faulting and earthquakes vs seismic waves from four related perspectives: rheology, seismology, geodesy and tectonics;

A.2. The description of earthquake effects in terms of magnitude and intensity;

A.3. An appreciation of approaches to the mitigation of seismic hazard by means of case study;

A.4. Physical processes that control the rheology of faults, including friction and fracture and how these rheological processes are manifested in faulting and earthquakes;

A.5. Mechanics of faulting vs. mechanics of earthquakes.

B. Transferable skills

Having successfully completed the module, students should be able to:

B.1. Discuss the factors controlling Mechanics of faulting vs. mechanics of earthquakes and assess methods of monitoring and prediction, with reference to recent examples;

B.3. Develop IT and communication skills in preparing coursework using a variety of source material;

B.4. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights;

B.5. Use the Internet as a source of geophysical information;

B.6. Developing independent learning strategies;

B.7. Generating innovative and competitive proposals for research and professional activities.

C. Communication /ICT/ Numeracy / Analytic Techniques/

Having successfully completed the module, students should be able to:

C.1. Perform calculations based on Mechanics of Earthquakes and Tectonophysics;

C.2. Demonstrate the ability to identify and formulate issues critically, autonomously and creatively as well as to plan and, using appropriate methods;

C.3. Undertake advanced tasks within predetermined time frames and so contribute to the formation of knowledge as well as the ability to evaluate this work;

C.4. Demonstrate the ability in speech and writing both nationally and internationally to clearly report and discuss his or her conclusions and the knowledge and arguments on which they are based in dialogue with different audiences.

D. Transferrable skills

Having successfully completed the module, students should be able to:

D.1. Demonstrate the awareness of the nature of science, the structure and objectives of the physics module;

D.2. Become familiar with the language of Mechanics of Earthquakes and Tectonophysics and key theories and concepts, ultimately enabling students to read and understand research papers;

D.3.Demonstrate the skills required for participation in research and development work or autonomous employment in some other qualified capacity;

D.4. Communicate concepts and principles of Mechanics of Earthquakes and Tectonophysics concisely, accurately and informatively to specialist and non-specialist audiences;

D.5. Develop new skills and understanding of high level;

D.7. Work independently and take initiative itself;

D.8. Be organized to achieve results and to plan and execute a project;

D.9. Develop actively and reflectively independent learning strategies and to develop intuition;

D.10. Work in groups, assume shared responsibilities and interact professionally and constructively with others, showing absolute respect for their rights;

D.11. Tackle material which is given both unfamiliar and complex problem and to present written report;

D.12. Generate innovative and competitive proposals for research and professional activities;

D.13. Demonstrate a sense of self-organization, self-discipline and self-knowledge;

D.14. Construct clear, logical arguments;

D.15. Have a sense of self-organization, self-discipline and self-knowledge;

D.16. Have the ability to pursue further studies in this and related areas.

9. Indicative Content

Brittle deformation

- Stress tensor; Mohr circles; states of stress; Stress and strain
- Griffith theory and fracture mechanics: Theoretical Fracture Strength, Stress concentration;

Fracture Strength in Presence of Atomically Sharp Crack, Thermodynamic basis for fracture, Crack Extension Force, Crack Resistance, Stress Intensity Factor and Critical Stress Intensity Factor

- Crack models: elastic, Dugdale and small-scale yielding models
- Macroscopic failure criteria: faulting, fracture, friction
- Macroscopic strength
- Fracture energies
- Pore fluid effects on fracture
- Brittle-plastic transition

Friction and earthquakes

- Theoretical concepts: adhesion theory, elastic contact theory, other frictional interactions
- Experimental observations of friction
- Physics of faults: Stick-slip and stable sliding rate and state variable friction laws, frictional stability regimes, dynamics of stick-slip

Earthquake Mechanics

- The dynamic energy balance
- Dynamic shear crack propagation
- Earthquake ruptures (field, seismology, geodesy, laboratory)
- Scaling relations
- Aseismic slip
- Slow earthquakes, Creep events, Tsunamogenic earthquakes
- Slow precursors to “normal” earthquakes
- Earthquakes with a distinct nucleation phase
- Afterslip and transient postseismic deformation
- Normal (fast) earthquakes

Viscoelasticity

- Simple shear flow
- Newton’s law of viscosity
- Newtonian fluids
- Plasticity and yield stress

- Creep curve
- Stress relaxation and creep experiments
- Elastic (solid-like) response
- Viscous (liquid-like) response
- Network formulation of viscoleasticity: Maxwell, Voigt-Kelvin, Standard-linear solid
- Creep and relaxation functions
- Generalized Maxwell model
- Relaxation spectrum
- Generalized Voigt-Kelvin model
- Boltzman's principle
- Dynamic (Oscillatory) Testing
- Complex and Dynamic Viscosity

Active deformation

- Tools and techniques: GPS, DinSAR, Seismology, direct observations
- Tectonic geodesy and GPS seismology
- Velocity field
- Models of active deformation: distributed vs. localized
- Kinematics and dynamics of the deformation
- Strength and rheology of the lithosphere
- Mechanics of the earthquake cycle inclusive of transient deformation
- Case studies

10. Learning and Teaching Strategy

The major learning and teaching strategic goal of the module is to prepare students to become convinced and liable scientists. The approach to be used will be to become more a facilitator in the learning process rather than conducting the course in a one-way delivering of information. The material in this module is delivered through a combination of *formal lectures and exercises:*

Lectures: lectures will present the topics of the module in accordance with the curriculum presented above.

Exercises: problems for the exercises will be handed out on a weekly basis and the student is recommended to work out these tasks. At each exercise occasion solution methods will be presented by the teacher on the white board. Problems not considered at the exercises may be regarded as homework.

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Teaching material: students will be provided with textbook and or handout notes.

11. Assessment Strategy

The following methods of assessment will be used in various combinations:

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- Oral presentations and associated submissions.
- Mid-Semester and End Semester Examinations.

Assessment/exam:

The range of assessments and the type of questions and problems set within examinations and assignments are structured to balance theory and problem solving, to address individual learning outcomes and to discriminate between different levels of achievement.

Date of assessment/exam:

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Absence to examination:

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Grading:

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Students are encouraged to work into groups, but copying all, or part, of someone else's homework is not admitted. Looking at someone else's copy of exam during a test period, are all obvious forms of academic dishonesty. Sanctions will be taken against anyone found guilty of academic dishonesty. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
In-course assessment		
CA I: Performance of tasks (quizzes and homework)	30	**A1-A5, B1-B7**
CA II: Mid-Semester Examination	30	**A1-A5, B1-B7, C1-C4, D1-D16**
End Semester Examination	40	**A1-A5, B1-B7, C1-C4, D1-D16**
Total	100	

The details on the distribution of weight for CA I (performance of tasks) will be presented in the module handout.

13. Strategy for Feedback and Student Support during Module

The lecture / tutor sessions will be interactive with opportunity for students with difficulties to ask questions and to receive support. Each section of the module has structured problems and solutions to selected problems are given There will be peer marking of tutorial questions in order to bring constructive feedback. Group work feedback is provided by the tutors during the group work periods, as well as promoting discussion on the returned selected items. Particular feedback will be made through presentation of individual or group work reports. There will be opportunities for students to consult lecturer and/or assistant lecturers during office hours.

14. Indicative Resources

The course will be in principle self-contained. The evaluation will be based exclusively on the material taught in class and on the homework. However, students are strongly advised to consolidate and expand their knowledge on the subject by consulting textbooks. Some reference textbooks are:

Core Texts:

- Scholz C., Mechanics of Earthquakes and Faulting, Cambridge University Press, 2012.

- Segall P., Earthquake and Volcano Deformation, Princeton University, 2010.
- Karato S-I, Deformation of Earth Materials, Cambridge University Press, 2008.

15. Module Team

Module Leader: Prof. Abdelakrim Aoudia

Team members: Senior Lecturer to be recruited.

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1. **Module Code :**
   - HEP6369
   - CMP6366
   - GEP6367
2. **Module Title:**
   - SEMINARS ON NEW DEVELOPMENT IN HIGH ENERGY PHYSICS
   - SEMINARS ON NEW DEVELOPMENT IN CONDENSED MATTER PHYSICS
   - SEMINARS AND WORKSHOPS ON GEOPHYSICS FOR SUSTAINABLE ENERGY SOLUTIONS AND GEOTHERMAL DEVELOPMENT
3. **Level:** 6 **Semester:** 3 **Credits:** 0
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	Hours/Week	Student hours	Staff hours
Lectures			
Seminars/workshops	1	12	12H X #Students
Practical classes/laboratory			
Structured exercises			
Self study	7	84	-
Assignments – preparation and writing		4	-
Revision			
Examination – Preparation and attendance			
Other:			
Invigilation	-	-	-
Marking	-	-	-
Total		100	12H X #Students

7. Brief Description of Aims and Content

Aim

To help students understand and apply recent developments within some current researches.

Content

Selected topics on recent developments within some current researches.

8. Learning Outcomes

A. Knowledge and Understanding

At the end of the program students should be able to demonstrate knowledge and understanding of:

A.1. Selected recent developments within some current researches;

B. Cognitive/Intellectual skills/Application of Knowledge/

Having successfully completed the module, students should be able to:

B.1. Demonstrate a sophisticated use of a range of resources appropriate to the task at hand;

B.2. Demonstrate advanced capacity for deductive reasoning;

B.3. Engage directly with current research and developments in the subject;

B.4. Demonstrate the capacity to show independence of thought;

B.5. Demonstrate the qualitative methods of analysis;

B.6. Demonstrate a logical processing of information and to construct a coherent argument or debate.

C. Communication /ICT/ Numeracy / Analytic Techniques/Practical skills

Having successfully completed the module, students should be able to:

C.1. Show engagement with a variety of current research/development issues in the subject;

C.2. Communicate using a range of appropriate methods to a range of audiences with different levels of subject expertise;

C.3. Communicate with peers, more senior colleagues and specialists;

C.4. Use a wide range of appropriate software solutions;

C.5. Evaluate a wide range of numerical and graphical information;

C.6. Use a significant range of the principle skills, techniques, practices and/or materials including some at the forefront of developments, associated with their discipline;

C.7. Acquire proficiency in scientific computing, including the ability to obtain and manipulate datasets and to model these;

C.8. Master a range of appropriate research methodologies and data analysis tools;

C.9. Plan and carry out a significant project of research, investigation or development;

C.10.Prepare and deliver seminars on specific subjects;

C.11.Demonstrate originality in the application of knowledge;

C.12. Carry out a literature search for relevant material for the preparation of dissertations.

D. Transferable skills

Having successfully completed the module, students should be able to:

At the end of the program students should be able to:

D1. Effectively retrieve information from a variety of sources;

D2. Ability to use IT to collect, analyze and present technical information;

D3. Demonstrate self-direction and originality in tackling and solving problems;

D4. Interpret complex information of differing kinds;

D5. Act autonomously in planning and implementing decisions at a scientist level;

D6. Work creatively, flexibly and co-operatively with others and to delegate responsibility;

D7. Assess and evaluate own and other’s work constructively;

D8. Demonstrate the skills of life-long learning;

D9. Plan effectively and to organize work schedules and to manage resources and time;

D10. Complete work in accordance with deadlines;

D11. Communicate and collaborate effectively with other students;

D12. Solve advanced and complex problems;

D13. Recognize the value of numeracy in the precise statement of ideas;

D14. Present effectively technical information in both written and oral forms;

D15. Present rapports on time;

D16. Work effectively as a member of a team, plan and execute a small project;

D17. Exercise initiative and personal responsibility.

9. Indicative Content

Topics for seminars will be given by lecturers.

10. Learning and Teaching Strategy: N/A

Teaching material: N/A.

11. Assessment Strategy:

Assessment/exam: N/A

Date of seminars:

Seminars' dates are chosen to be balanced across the semester and advertised well in advance in the module handout and also on the timetable.

Absence to seminars:

Seminars will be audited. A student who misses to report or to attend to any seminar should comply with the Examinations' Regulations.

Grading: N/A

Academic honesty:

Sanctions will be taken against anyone found guilty of academic dishonesty or plagiarism. For additional information refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	**Weighting (%)**	**Learning objectives covered**
Written Report	N/A	**A1, B1-B6, C1-C12, D1-D17**
Written and Oral Presentation	N/A	

13. Strategy for Feedback and Student Support during Module

Supervision Sessions will be interactive with opportunity for students to ask questions and to receive support without difficulties. Particular feedback will be made through presentation of individual answers to questions raised by the supervisor or any other staff during seminars.

14. Indicative Resources

Reference Texts:

Students will strongly be advised to consolidate and expand their knowledge on the subject by reading and digesting published papers related to their topics of research.

15. Module Team

Module Leader: EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH

Team members: All EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH staff

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1. **Module Code :** MPH6461
2. **Module Title:** DISSERTATION
3. **Level:** 6 **Semester:** 4 **Credits:** 120
4. **First year of presentation:** 2016 **Administering School/Institute:** EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH
5. **Pre-requisite modules, excluded combinations:** N/A
6. **Allocation of study and teaching hours**

Mode of teaching/Learning	**Hours/Week**	**Student hours**	**Staff hours**
Supervision	2	60	90H X # Thesis
Seminars/workshops	-	-	-
Practical classes/laboratory	-	-	-
Structured exercises	-	-	-
Preparation and reading	-	1110	-
Self-directed study	-	-	-
Assignments – preparation and writing	-	-	-
Revision	-	-	-
Dissertation – Preparation and attendance		30	6H X # Thesis
Other:			
Invigilation	-	-	-
Reading and Marking Dissertation	-	-	(*)
Total		1200	(**)

(*): 6H X # Thesis X 2 Weeks

(**): 90H X # Thesis + 3 X # Thesis + (*)

7. **Brief Description of Aims and Content**

Aim

The module aims to assist students to develop creative and critical thinking, the ability to assemble material from several sources and to write an extended report and to produce a dissertation that gives a coherent account of the topic, presented in an original, well organized and appropriate manner.

Content

A list of topics which members of staff are willing to supervise will be circulated at the end of the Second Semester. Each member of staff should provide at least two choices; the list presents a wide choice. Students wishing to investigate a topic not on the list may be allowed to do so provided a member of staff is willing to supervise them.

8. Learning Outcomes

A. Knowledge and Understanding

At the end of the program students should be able to demonstrate knowledge and understanding of:

A1. Fundamental concepts, ideas and theories of Physics;

A2.Mathematical and computational techniques used to frame and solve physical problems;

A3. Techniques of practical work in Physics;

A5. Selected recent developments within some current research;

A.6. The chosen dissertation topic, including an appreciation of the development of that topic, its situation with respect to related topics and the directions in which that topic could lead.

B. Cognitive/Intellectual skills/Application of Knowledge/

B1. Apply knowledge of physics to the solution of theoretical and practical physical problems;

B2. Evaluate hypotheses, theories, methods and evidence within their proper contexts;

B3. Identify relevant techniques and concepts to solve problems;

B4. Demonstrate a sophisticated use of a range of resources appropriate to the task at hand;

B5. Solve complex problems by critical understanding, analysis and synthesis;

B6. Demonstrate advanced capacity for deductive reasoning;

B7. Engage directly with current research and developments in the subject;

B8. Demonstrate the capacity to show independence of thought;

B9. Demonstrate the qualitative methods of analysis;

B10. Demonstrate a logical processing of information and to construct a coherent argument or debate.

C. Communication /ICT/ Numeracy / Analytic Techniques/Practical skills

Having successfully completed the module, students should be able to:

C.1. Plan and carry out a significant project of research, investigation or development;

C.2. Master a range of appropriate research methodologies and data analysis tools;

C.3. Use a significant range of the principle skills, techniques, practices and/or materials including some at the forefront of developments, associated with their discipline;

C.4. Acquire proficiency in scientific computing, including the ability to obtain and manipulate datasets and to model these;

C.5. Use a wide range of appropriate software solutions;

C.6. Evaluate a wide range of numerical and graphical information;

C.7. Prepare and deliver seminars on specific subjects;

C.8. Demonstrate originality in the application of knowledge;

C.9. Carry out a literature search for relevant material for the preparation of dissertations;

C.10 Make presentation of a body of physics knowledge in an interesting, innovative and comprehensible manner;

C.11. Construct illustrative examples and produce original investigations.

D. Transferable skills

Having successfully completed the module, students should be able to:

D.1. Read and digest several sources;

D.2. Tackle material critically and communicate your thoughts on it effectively;

D.3.Plan effectively and to organize work schedules and to manage resources and time;

D.4. Make a report with appropriate chapters, sections, numbering and references with reference; lists, contents pages and acknowledgements of others' work in appropriate format.

D.5. Demonstrate the skills of life-long learning;

D.6. Complete work in accordance with deadlines;

D.7.Undertake appropriate further training of a scientist nature or a PhD program.

9. Indicative Content: N/A

10. Learning and Teaching Strategy

The student will research and write a dissertation on an advanced topic, under the guidance of his/her supervisor and the guidance notes provided.

Teaching material: students will be provided with books and published papers related to their topics of research

11. Assessment Strategy

There will formative assessments during regular sessions with supervisors to review students' progress. The student will produce work (for example, plans, lists of sources, drafts, reference lists, sample calculations, etc.) for the comments of the supervisor.

Assessment/exam:

A final assessment will be according to the Academic Regulations for Post Graduate Studies during the Oral Presentation of the Thesis Dissertation.

Date of assessment/exam:

The date of the Oral Presentation of the Dissertation will be announced according to the Academic Regulations for Post Graduate Studies

Absence to examination:

A student who misses to report to the Dissertation should comply with the Examinations' Regulation.

Grading:

Grading will be made according to the according to the Academic Regulations for Post Graduate Studies. Grading will be made as transparent, consistent and fair as possible. For all written work, point distributions will be distributed to make clear why any points have been deducted. All marks are provisional until confirmed by the examination board at the end of the semester.

Academic honesty:

For information about Academic Honesty and Plagiarism please refer to the Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis about that issue.

12. Assessment Pattern

Component	Weighting (%)	Learning objectives covered
Written Report	-	**A1-A6, B1-B10, C1-C11, D1-D7**
Written and Oral Presentation	-	

For details on Dissertation we will refer to Framework and Regulations for Higher Degrees by Coursework and Dissertations/Thesis.

13. Strategy for Feedback and Student Support during Module

Supervision Sessions will be interactive with opportunity for students to ask questions and to receive support without difficulties. Particular feedback will be made through presentation of individual answers to questions raised by the supervisor or any other staff during seminars.

14. Indicative Resources

Students will strongly be advised to consolidate and expand their knowledge on the subject by reading and digesting published papers related to their topics of research.

15. Module Team

Module Leader: EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH

Team members: All EAST AFRICA INSTITUTE FOR FUNDAMENTAL RESEARCH staff