Mechanics and relativity

Academic Year: (2022 / 2023) **Review date: 19-05-2022**

Department assigned to the subject: Physics Department

Coordinating teacher: MARTIN SOLIS, JOSE RAMON

Type: Compulsory ECTS Credits : 6.0

Year : 2 Semester : 1

REQUIREMENTS (SUBJECTS THAT ARE ASSUMED TO BE KNOWN)

Physics I, Linear Algebra, Calculus I and II of the first year

OBJECTIVES

The course on Mechanics and Relativity constitutes an extension of the Mechanics learned during the first year in the Physics I course. In the first place, new ways of formulating and solving problems in Classical Mechanics, alternative to the Newton¿s laws studied during the first year, will be presented: the Analytical Mechanics. Its fundamentals, advantages and disadvantages will be presented. Particular attention will be paid to the method based on the Lagrange¿s equations. Applications will be also presented to the study of the motion of the rigid body in space for which an essential tool, the Inertia Tensor, will be introduced. A generalized analysis of the small oscillations about the equilibrium position of systems with several degrees of freedom will be also addressed. The last part of the course will be devoted to one of the main areas of Modern Physics, developed during the first half of the twentieth century: the Relativistic Mechanics. The two postulates on which it is based will be presented, together with some of their main consequences such as a new approach to the concepts of space and time, or the well-known mass-energy equivalence.

The following competences and skills should be acquired:

- Ability to know and understand what does it mean the Analytical Mechanics and some of the main tools developed within it to solve mechanical problems, particularly, among them, the Lagrange¿s equations.
- Ability to understand the general motion of a rigid body in space, based on the tool of the inertia tensor
- Ability to understand the application of the Lagrange¿s method to the generalized analysis of small oscillations in systems with several degrees of freedom, as well as the meaning of the normal modes and frequencies
- Ability to understand the meaning of the postulates of the special theory of relativity, and some of their main consequences: revision of the concepts of space and time, the mass-energy equivalence, etc
- Ability to understand and use the mathematics involved in the physical models
- Ability to develop skills to solve problems
- Ability to use scientific instruments and analyze experimental data
- Ability to verify in the laboratory some of the results obtained in the theoretical classes
- Ability to retrieve and analyse information from different sources
- Ability to work in a team.

DESCRIPTION OF CONTENTS: PROGRAMME

PART I ANALYTICAL MECHANICS

1. Introduction to Analytical Mechanics
   - 1.1 Introduction
   - 1.2 Generalizad Coordinates
   - 1.3 Systems with Constraints
   - 1.4 Kinetic Energy and Generalized Momenta
     - 1.4.1 Generalized Velocity
     - 1.4.2 Kinetic Energy
     - 1.4.3 Generalized Momenta
   - 1.5 Virtual and Real Displacements
   - 1.6 Virtual Work. Generalized Forces
     - 1.6.1 Virtual Work
     - 1.6.2 Generalized Forces

1.6.3 Virtual Work and Forces of Constraint
2. The Lagrange¿s Equations
   2.1 Introduction
   2.2 Derivation of the Lagrange¿s Equations
   2.3 Lagrange¿s Equations for Conservative Forces. The Lagrangian of a Mechanical System
   2.4 Lagrange¿s Equations for Conservative and Non-Conservative Forces
   2.6 Lagrangian Mechanics and Newtonian Mechanics
   2.7 Cyclic Coordinates and Conservation Theorems
      2.7.1 Constants of Motion
      2.7.2 Definition of Cyclic (or Ignorable) Coordinates. Conservation Theorem for Cyclic Coordinates
3. The Hamilton¿s Equations. The Hamilton¿s Principle
   3.1 Introduction
   3.2 Derivation of the Hamilton¿s Equations. The Hamiltonian of a Mechanical System
   3.3 General Procedure to determine the Hamiltonian and obtain the Hamilton¿s Equations
   3.4 Other Expressions for the Hamiltonian. Physical Meaning
   3.5 Cyclic Coordinates and Conservation Theorems in the Hamiltonian Mechanics
   3.6 Comparison between the Hamiltonian and the Lagrangian formulation of Mechanics
   3.7 Fields of Application of the Hamiltonian Mechanics
   3.8 The Hamilton¿s Principle. Principle of Least Action
4. Analytical Statics
   4.1 The Principle of Virtual Work
   4.2 D'Alembert¿s Principle
PART II. THE RIGID BODY
5. Introduction to the Rigid Body
   5.1 Definition of the Rigid Body. Degrees of Freedom
   5.2 General Motion of a Rigid Body in Space. Chasles Theorem
   5.3 Angular Velocity of Rotation of a Rigid Body
   5.4 Kinetic Energy. Köning¿s Theorem
6. The Inertia Tensor
   6.1 Rotational Kinetic Energy. Definition of the Inertia Tensor
   6.2 Angular Momentum with respect to a Point
      6.2.1 Angular Momentum
      6.2.2 Relation between the Angular Momentum and the Rotational Kinetic Energy
   6.3 Planar Motion
   6.4 Properties of the Inertia Tensor
   6.5 Principal Axes of Inertia
      6.5.1 Principal Axes and Principal Moments of Inertia
      6.5.2 Procedure to Determine the Principal Axes an Moments
      6.5.3 Ejes Principales y Propiedades de Simetría
   6.6 The Ellipsoid of Inertia
7. Equations of Motion of a Rigid Body. Applications
   7.1 Eulerian Angles
      7.1.1 Translational and Rotational Coordinates. Eulerian Angles
      7.1.2 Angular Velocity of Rotation as a function of the Eulerian Angles
   7.2 Equations of Motion
   7.3 Euler¿s Equations
   7.4 Gyroscopic Motion
PARTE III. OSCILLATIONS
8. Oscillations
   8.1 Introduction
   8.2 Formulation of the Problem
   8.3 The Eigenvalue Equation. Normal modes and Frequencies
   8.4 Normal Coordinates
   8.5 Summary of the Method
PARTE IV. INTRODUCTION TO THE SPECIAL THEORY OF RELATIVITY
9. Postulates of the Special Theory of Relativity
   9.1 Introduction
   9.2 The Classical Relativity
      9.2.1 The Galilean Principle of Relativity
      9.2.2 The Galilean Transformation and Classical Mechanics
   9.3 The Principle of Relativity and the Electromagnetic Theory
   9.4 Einstein¿s Potulates
10. Relativistic Kinematics
   10.1 Lorentz Transformation

10.1.1 Lorentz Transformation of Coordinates
10.1.2 Lorentz Velocity Transformation
10.2 Consequences of the Lorentz Transformatiom
10.2.1 Time Dilation
10.2.2 Contraction of Length
10.2.3 Relativity of Simultaneity
11. Relativistic Dynamics
11.1 Introduction
11.2 Relativistic Linear Momentum
11.3 Relativistaic Expression of the Force
11.4 Relativistic Energy
11.4.1 Kinetic Energy
11.4.2 Definition of the Total Energy
11.4.3 Mass-Energy Equivalence
11.4.4 Energy-Momentum Relation

LEARNING ACTIVITIES AND METHODOLOGY

* Lectures where the theoretical concepts are explained

The lecturer will provide the following information (1 week in advance)
- Main topics to be discussed during the session
- Chapters/sections in each of the text books provided in the bibliography where the student can read about these topics

* Activities for the solution of problems

The main skills to be acquired in these activities are:
- To understand the statement of a problem (for instance drawing an scheme that summarizes the statement)
- To identify the physical phenomenon and the physical laws involved in the problem
- To develop an strategy to reach the objective (for instance breaking the problem in small subproblems)
- To be careful in the use of mathematics
- To be able to make a critical analysis of the results (is the final number sensible?, are the dimensions consistent?)

* Small tasks focused to search for scientific information from different sources (mainly internet)

* Laboratoy sessions (20 - 30 students divided in 2 people groups)

The main skills to be developed in this activity are:
- To understand that physics is an experimental science and that they can verify the laws that have been theoretically explained in the lectures
- To use scientific instruments and to be careful in its operation
- To be careful in the acquisiton of experimental data.
- To learn the basis for the management of a scientific data set
- To be able to write a report with the main results of the experiment
- To be able to discuss in a critical way the experimental results: have we achieved the goals of the experiment?

* Times for individualized tutorial sessions will be fixed via Aula Global. It will be possible to fix other sessions by appointment with the lecturer

ASSESSMENT SYSTEM

* Laboratory sessions (15% of final mark)

Attendance to the laboratory sessions is compulsory. The students must also write a report on each of the experiments carried
out in every session. The mark will be common for all the members of each group.

* Activities in groups (25% of final mark)

The evaluation will take into account attendance and student attitude, short exams periodically proposed, as well as the
student performance in the proposed activities.

* Written exam (60% of final mark)

The exam will take place at the end of the semester and it will be common for all the students.
Contents:

- Problems to be solved covering the main topics of the program.
- Short theoretical questions.

A minimum mark of 3 out of 10 will be required in the written exam in order to pass the course.

% end-of-term-examination:	60
% of continuous assessment (assigments, laboratory, practicals…):	40

BASIC BIBLIOGRAPHY

- GOLDSTEIN, H., POOLE, C., SAFKO, J. CLASSICAL MECHANICS, Pearson, 2013
- THORNTON, S.T., MARION, J.B. CLASSICAL DYNAMICS OF PARTICLES AND SYSTEMS, Brooks/Cole, 2003
- TIPLER, P.A., MOSCA, G PHYSICS for Scientists and Engineers, W.H. Freeman, 2007

ADDITIONAL BIBLIOGRAPHY

- FRENCH, P.A. SPECIAL RELATIVITY, The M.I.T. Introductory Physics Series, CRC Press, 2017
- SERWAY, R.A., JEWETT, J.W PHYSICS for Scientists and Engineers, Brooks/Cole, 2012
- SYMON, K.R. MECHANICS, Addison Wesley, 1971