Theoretical mechanics

Course description sheet

Basic information

Field of study Technical Physics **Major** - **Organisational unit** Faculty of Physics and Applied Computer Science **Study level** First-cycle (engineer) programme **Form of study** Full-time studies **Profile** General academic	**Didactic cycle** 2024/2025 **Course code** JFTCS.Ii8.01339.24 **Lecture languages** Polish **Mandatoriness** Elective **Block** Core Modules **Course related to scientific research** Yes

Course coordinator	Radosław Strzałka
Lecturer	Radosław Strzałka

Period Semester 4	**Method of verification of the learning outcomes** Completing the classes **Activities and hours** Discussion seminars: 45	**Number of ECTS credits** 3

Goals

C1	The aim of the lecture is to bridge the gap between the basic mechanics course (semester 1 or 2) and the quantum mechanics course and to present the advanced tools of theoretical mechanics developed in the 18th, 19th, and 20th centuries. The course in relativistic mechanics, theoretical astronomy, nonlinear dynamics, chaos theory, and classical electrodynamics can be a natural continuation of the lecture topics.

Course's learning outcomes

Code	Outcomes in terms of	Learning outcomes prescribed to a field of study	Methods of verification
Knowledge – Student knows and understands:			
W1	The student knows the advanced formalism of mechanics theoretical, in particular Lagrange's approach, Hamilton and Jacobi.	FTC1A_W01, FTC1A_W02, FTC1A_W03	Activity during classes, Participation in a discussion, Execution of exercises, Scientific paper, Essay, Presentation
W2	The student knows the application of theoretical mechanics methods to describe contemporary issues of theoretical physics (vibration theory, astrophysics, chaos theory, and nonlinear dynamics).	FTC1A_W01, FTC1A_W03, FTC1A_W04, FTC1A_W06	Activity during classes, Participation in a discussion, Execution of exercises, Scientific paper, Essay, Presentation
Skills – Student can:			
U1	The student is able to apply the Lagrange and Hamilton formalism to describe the problems of mechanics, including small vibrations, motion in the central field, description in phase space, as well as nonlinear and chaotic systems.	FTC1A_U01, FTC1A_U02, FTC1A_U04	Activity during classes, Participation in a discussion, Execution of exercises, Scientific paper, Essay, Presentation
Social competences – Student is ready to:			
K1	The student is able to speak in a substantive discussion and prove his position based on the literature data and his own study of the issue.	FTC1A_K02, FTC1A_K03	Participation in a discussion, Scientific paper, Essay, Presentation

Program content ensuring the achievement of the learning outcomes prescribed to the module

Newton's laws, Non-inertial frames of reference, General solution of equations of motion, Periodic motion, Mechanical similarity, Problems of Newton's formalism, Lagrange function, Generalized coordinates, Constraints, Simple applications of Lagrange's equations, Calculus of variations and Hamilton's principle, Conservation laws, Nonholonomic systems, Lagrange multipliers, Small vibrations, Two-body problem, Equation of motion in the field of central forces, Periodic and quasiperiodic motion in the central field, Hamilton equations, Poisson brackets, Principle of least action, Canonical transformation, Phase space, Hamilton-Jacobi method, Motion integrable and disturbed systems, Correspondence principle: transition to quantum mechanics.

Student workload

Activity form	Average amount of hours* needed to complete each activity form
Discussion seminars	45
Realization of independently performed tasks	30
Preparation of project, presentation, essay, report	5

Contact hours	5
Student workload	**Hours** 85
Workload involving teacher	**Hours** 45

* hour means 45 minutes

Program content

No.	Program content	Course's learning outcomes	Activities
1.	Newton's mechanics 1. Newton's laws (laws of dynamics): Newton's law of inertia, II Newton's law, Conservative forces, Galileo transformation; Non-inertial reference frames: Acceleration transformation, Rotation + translation.	W1, W2, U1, K1	Discussion seminars
2.	Newton's mechanics 2. A general solution of equations of motion (Integration of equations of motion); Periodic motion: Mathematical pendulum, General about the period in an oscillating motion, Determination of potential energy based on the period of vibration, Correction to potential; Mechanical similarity: Virial theorem.	W1, W2, U1, K1	Discussion seminars
3.	Lagrange's formalism 1. Newton's formalism problems: The problem of constraints, The problem of invariance with respect to transformation of the coordinate system; New approach - Lagrange function: Derivation of Lagrangian from the Galilean transformation and from the d'Alembert hypothesis.	W1, W2, U1, K1	Discussion seminars
4.	Lagrange's formalism 2. Generalized coordinates; Bonds; Simple applications of Lagrange's equations: Mathematical pendulum, Bead on a wire, Cyclic coordinates - the behavior of generalized momentum, Pendulum on a spring.	W1, W2, U1, K1	Discussion seminars
5.	Lagrange's formalism 3. Approaching Lagrangian and Lagrange equations, Exercises; Variational calculus and the Hamilton principle, Lagrangian ambiguity.	W1, W2, U1, K1	Discussion seminars
6.	Lagrange's formalism 4. Conservation laws: Generalized momentum, Total energy, Noether theorem; Nonholonomic systems: Forces of constraints reaction, Lagrange multipliers.	W1, W2, U1, K1	Discussion seminars
7.	Small vibrations. Newtonian approach: Matrix notation, Normal modes; Lagrangian approach: Double pendulum, Coupled pendulums; General case of many degrees of freedom, Normal coordinates.	W1, W2, U1, K1	Discussion seminars
8.	Movement in the central field. The two-body problem: Lagrangian, Center of mass and reduced mass; Equation of motion in the field of central forces: General solution for $U(r)$, II Kepler's law, Kepler's problem, Hidden symmetry in the Kepler problem, Elliptical orbit; Periodic and quasiperiodic motion in the central field: Periodicity of motion, Bertrand's Theorem, Small vibrations in the central field.	W1, W2, U1, K1	Discussion seminars

No.	Program content	Course's learning outcomes	Activities
9.	Hamilton's formalism 1. Hamilton's equations: Derivation by "guessing" and by the method of total differential Lagrangian, Simple examples; Poisson brackets: Definition and properties, Integrals of motion, Conservation of energy.	W1, W2, U1, K1	Discussion seminars
10.	Hamilton's formalism. 2. The principle of least action. Canonical transformation: Integral of action in Hamilton's formalism, Hamilton's equations from the principle of least action, Canonical variables, Canonical transformation, Symplectic approach.	W1, W2, U1, K1	Discussion seminars
11.	Hamilton's formalism. 3. Phase space: Trajectories in phase space, Poincare sections, Liouville's theorem, and Poincare recurrence theorem.	W1, W2, U1, K1	Discussion seminars
12.	Hamilton-Jacobi formalism 1. Hamilton-Jacobi equations, Complete Integral, Special cases, Method of separation of variables.	W1, W2, U1, K1	Discussion seminars
13.	Hamilton-Jacobi formalism. 2. Movement of integrable and disturbed systems: integrable system, Action-angle coordinates.	W1, W2, U1, K1	Discussion seminars
14.	Hamilton-Jacobi formalism. 3. KAM theorem, Adiabatic invariants. The principle of correspondence: the transition to quantum mechanics.	W1, W2, U1, K1	Discussion seminars
15.	Student presentations: Presentations of issues developed by students from the list of the lecturer or their own, other than the basic topics of the lecture.	W1, W2, U1, K1	Discussion seminars

Extended information/Additional elements

Teaching methods and techniques :

Practice method (doing tasks at the blackboard), Project Based Learning, Lectures, Discussion

Activities	Methods of verification	Credit conditions
Discussion seminars	Activity during classes, Participation in a discussion, Execution of exercises, Scientific paper, Essay, Presentation	Credit is awarded to a student who regularly participated in the classes and was active during the classes. In practice, this means that he participated in at least 50% of the classes and showed at least 1 positive activity during the classes. The teacher does not plan a final test or final exam.

Additional info

- According to the teacher, the classes are to take the form of a seminar ("lecture-exercises"), which means that they will be a combination of a lecture and exercises. In practice, this is to be realized through the active participation of students in the lecture (carrying out calculations, transformations, deductions; of course with the help of the teacher) and solving examples and tasks on the blackboard. The lecture will take the form of a blackboard (written) lecture.
- Regular exercises for the course are not planned. Tasks to be solved by students on their own will be proposed during the seminar. Additional tasks can be found in the literature and collections of tasks proposed by the teacher.
- The lecture was based on the textbooks by Landau, Taylor, Greiner, Goldstein, and Rubinowicz, as well as the lecture by prof. P. Bizoń for students of theoretical physics at Jagiellonian University.

Conditions and the manner of completing each form of classes, including the rules of making retakes, as well as the conditions for admission to the exam

Credit is awarded to a student who regularly participated in the classes and was active during the classes. In practice, this means that he participated in at least 50% of the classes and showed at least 1 positive activity during the classes. The teacher does not plan a final test or final exam.

Method of determining the final grade

Final grade:

- A grade of 3.0-3.5 (dst or dst +) is obtained by a student who has participated in at least 50% of the classes and has demonstrated positive activity at least once during the classes. It is also a condition for passing the course for all students (with a grade of 3.0). A student with more than one activity will receive a grade of 3.5.
- A grade of 4.0-4.5 (db or db +) is obtained by a student who, above all, will present independently made and correct solutions to tasks and examples left at the lecture for self-solution (4.5 - all, 4.0 - what at least half).
- A 5.0 (very good) grade is awarded to a student who, above all, develops an issue of his choice regarding theoretical mechanics (e.g. selected from the list of issues proposed by the teacher or by himself) and presents it in the form of a presentation (a lecture, a multimedia presentation, or mini-blackboard lecture, etc.), or an essay (if time is limited).

Manner and mode of making up for the backlog caused by a student justified absence from classes

A 50% attendance is required from the student during the classes. The student's absence of <50% does not require additional compensation, apart from supplementing notes and solving tasks left for independent solutions (in the case when the student aspires to receive a grade higher than 3.5). Absence of more than 50% of the classes will result in failure to complete the course.

Prerequisites and additional requirements

Basic course in mechanics and mathematical analysis (within the first year of first-cycle studies).

Rules of participation in given classes, indicating whether student presence at the lecture is obligatory

Seminar: Attendance is obligatory. A 50% attendance is required from the student during the classes.

Literature

Obligatory

1. L.D. Landau, J.M. Lifszyc, "Mechanika", Wydawnictwo Naukowe PWN, Warszawa 2007
2. J.R. Taylor, "Mechanika klasyczna, tom 1 i 2", Wydawnictwo Naukowe PWN, Warszawa 2012.
3. W. Greiner, "Classical Mechanics", Springer-Verlag New York 2003.
4. H. Goldstein, C. Poole, J. Safko, "Classical Mechanics", Addison Wesley 2001 (dostępny online: http://www.cmi.ac.in/~souvik/books/mech/Goldstein.pdf).
5. W. Rubinowicz, W. Królikowski, "Mechanika teoretyczna", Wydawnictwo Naukowe PWN, Warszawa 1998.

Optional

1. G.L. Kotkin, W.G. Serbo, "Zbiór zadań z mechaniki klasycznej", WNT, Warszawa 1972.
2. L.G. Grieczko, W.I. Sugakow, O.F. Tomasiewicz, "Zadania z fizyki teoretycznej", PWN, Warszawa 1975.

Scientific research and publications

Publications

1. Relativistic equation of motion in the presence of a moving force field / Janusz WOLNY, Radosław STRZAŁKA // Novel Research in Sciences [Dokument elektroniczny]. - Czasopismo elektroniczne ; ISSN 2688-836X. — 2021 vol. 6 iss. 1, s. 1–5. — Wymagania systemowe: Adobe Reader. — Bibliogr. s. 5, Abstr.. — Publikacja dostępna online od: 2021-03-03. — tekst: https://crimsonpublishers.com/nrs/pdf/NRS.000630.pdf

2. Description of the motion of objects with sub- and superluminal speeds / Janusz WOLNY, Radosław STRZAŁKA // American Journal of Physics and Applications ; ISSN 2330-4286. — 2020 vol. 8 iss. 2, s. 25–28. — Bibliogr. s. 28, Abstr.. — Publikacja dostępna online od: 2020-06-04. — tekst: http://article.sciencepublishinggroup.com/pdf/10.11648.j.ajpa.20200802.12.pdf
3. Momentum in the dynamics of variable-mass systems: classical and relativistic case / J. WOLNY, R. STRZAŁKA // Acta Physica Polonica. A ; ISSN 0587-4246. — 2019 vol. 135 no. 3, s. 475–479. — Bibliogr. s. 478–479. — tekst: http://przyrbwn.icm.edu.pl/APP/PDF/135/app135z3p25.pdf

Learning outcomes prescribed to a field of study

Code	Content
FTC1A_K02	respektuje etyczne zasady wykonywanego zawodu, publikuje efekty swoich prac w sposób rzetelny i uczciwy, ma świadomość odpowiedzialności za swoje wypowiedzi oraz rozumie potrzebę stałego samokształcenia i samorozwoju zawodowego
FTC1A_K03	rozumie skutki działalności techniczno-inżynierskiej w środowisku naturalnym i społecznym, wykazuje postawę proekologiczną, potrafi przekazać społeczeństwu w sposób zrozumiały informację o osiągnięciach i ich wpływie na rozwój technologi oraz dostrzega możliwość komercjalizacji rozwiązań fizyki technicznej
FTC1A_U01	ma umiejętność samodzielnego uczenia się oraz zdobywania i integrowania wiedzy z różnych baz danych w języku polskim i angielskim
FTC1A_U02	potrafi posługiwać się językiem specjalistycznym z zakresu nauk fizycznych i technicznych zarówno w dyskusji, jak i w piśmie, także w języku obcym na poziomie B2
FTC1A_U04	potrafi zaplanować, przeprowadzić oraz przeanalizować proste zadania inżynierskie odpowiednio dobierając metody i narzędzia stosowane w fizyce i statystyce
FTC1A_W01	zna i rozumie podstawowe zagadnienia z zakresu fizyki oraz podstawowe mechanizmy fizyczne procesów zachodzących w przyrodzie
FTC1A_W02	zna i rozumie podstawowe zagadnienia z zakresu matematyki, chemii, informatyki, elektroniki potrzebne do zrozumienia podstawowych procesów technologicznych
FTC1A_W03	ma podstawową wiedzę o trendach rozwojowych i współczesnych zastosowaniach fizyki w technice oraz o cyklu życia urządzeń, obiektów i systemach technicznych
FTC1A_W04	zna i rozumie metodologię rozwiązywania prostych problemów inżynierskich oraz metody fizyczne i matematyczne analizy otrzymywanych wyników
FTC1A_W06	zna i rozumie ogólne zasady tworzenia i rozwoju form indywidualnej przedsiębiorczości