

Physics I: Course Overview and Roadmap

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Physics I at a glance



Course profile

Programme	Space Technologies
Study level	Second-cycle (engineer)
Organisational unit	Faculty of Space Technologies
Language	English
Status	Obligatory
Course code	WTKSTES.IIi80000.03161.26

Workload and verification

- **4 ECTS**
- **30 h** lectures + **30 h** auditorium classes
- Didactic cycle: **2026/2027**
- Learning outcomes verified by an **exam** together with the auditorium-class component

Course perspective

Physics I consolidates the common language of measurement and classical mechanics, then extends it toward **rigid-body and orbital dynamics**, **analytical mechanics**, **thermodynamics and transport**, and the **solar and cosmological physics** required in the Space Technologies programme.

MSc-level course perspective: shared foundations, higher-level extension

A heterogeneous starting point

- Many students will already have completed a traditional first-cycle Physics I course.
- Others may come from engineering or science programmes where the coverage, notation, or depth was different.
- We therefore begin by establishing a **common quantitative foundation** without treating the course as elementary review.

What changes at second-cycle level?

- More emphasis on modelling assumptions and mathematical structure.
- Explicit treatment of two-body motion, variable-mass systems, rigid-body ideas, and transport.
- Extension to **Lagrangian mechanics, solar physics, and cosmology**.

Foundation & review → **analytical consolidation** → **advanced extension** → **Space Technologies**

Course goals, prerequisites, and learning approach

What the course is designed to develop

- A coherent understanding of measurement, Newtonian mechanics, conservation laws, rotations, gravitation, oscillations, waves, fluids, and thermal physics.
- Quantitative problem solving in Newtonian and **Lagrangian** mechanics, thermodynamics, solar physics, and cosmology.
- Critical analysis of engineering problems using physical models, mathematics, approximations, units, and consistency checks.

Expected background

The official prerequisite is **knowledge of mathematical analysis**. Prior exposure to elementary mechanics is useful, but the course does not assume that every student has followed the same first-cycle syllabus.

Learning approach

Physical question $\rightarrow$ model $\rightarrow$ mathematical relation $\rightarrow$ checks $\rightarrow$ interpretation $\rightarrow$ application.

Examination, auditorium classes, attendance, and final grade

Auditorium classes and exam admission

- Auditorium classes are **obligatory**; lectures are optional.
- Problems are solved individually at the blackboard or in written form and receive percentage grades.
- A **positive auditorium-class end-grade** is required for admission to the exam.
- If the end-grade is not positive, two retake dates are provided under the course rules.

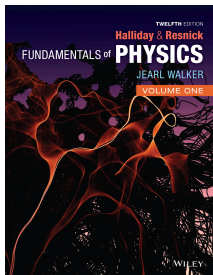
Attendance and final grade

- More than two **unjustified** auditorium absences prevent a positive end-grade.
- Two or more **justified** auditorium absences require additional test/problem-solving work on missed material.
- The **final grade** is the arithmetic average of the auditorium-class end-grade and the exam grade.

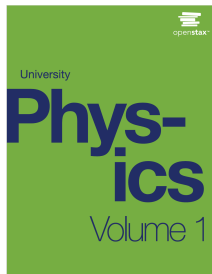
Practical note

Lecture materials are made available after the lecture through controlled access; auditorium problems are announced in advance.

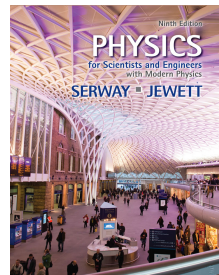
Main working references



D. Halliday, R. Resnick, J. Walker
Fundamentals of Physics, Volume 1
12th ed., John Wiley & Sons, 2022.



S. J. Ling, J. Sanny, W. Moebs
University Physics, Volume 1
OpenStax, original publication 2016; supplied revision 2018.

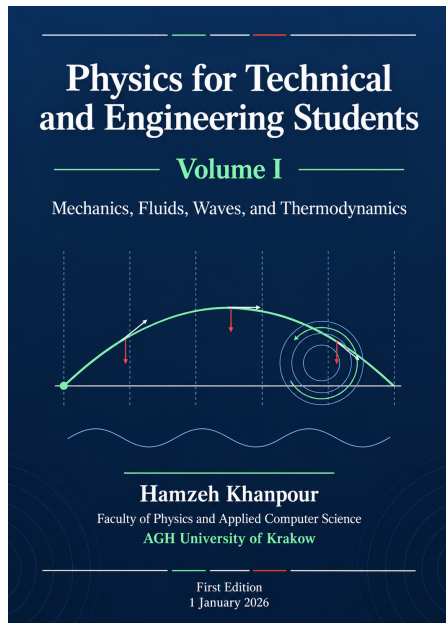


R. A. Serway, J. W. Jewett, Jr.
Physics for Scientists and Engineers with Modern Physics
9th ed., Brooks/Cole-Cengage, 2014.

How these references are used

These are the main working references used comparatively in the author-developed notes. The **official course literature** is defined separately by the formal course sheet and includes Halliday-Resnick-Walker *Principles of Physics* and Tipler-Llewellyn *Modern Physics*.

Our Physics I course book



Physics for Technical and Engineering Students - Volume I

Hamzeh Khanpour

Mechanics, Fluids, Waves, and Thermodynamics

Faculty of Physics and Applied Computer Science, AGH University of Krakow

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First edition: January 1, 2026

Role in this course

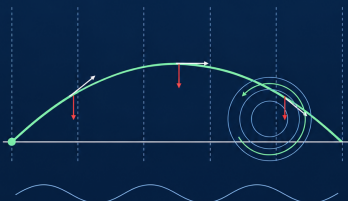
- Main structured support for measurement, mechanics, fluids, oscillations/waves, and thermal physics.
- Connects motivation to equations, assumptions, worked reasoning, and applications.
- Supports lectures, auditorium problem solving, and independent study.

What is distinctive about our Physics I book?

Physics for Technical and Engineering Students

Volume I

Mechanics, Fluids, Waves, and Thermodynamics



Hamzeh Khanpour

Faculty of Physics and Applied Computer Science
AGH University of Krakow

First Edition
1 January 2026

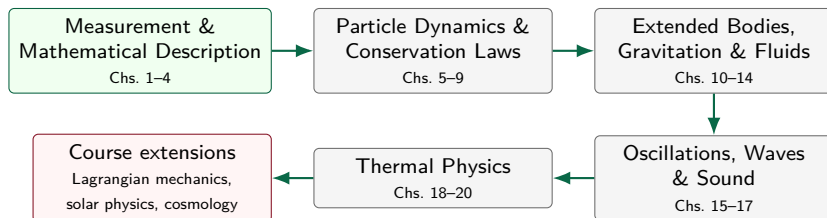
Core learning architecture

- Model-first explanations with explicit assumptions, sign conventions, units, and domain checks.
- Worked examples, practice material, chapter summaries, and solution support.
- Original figures with engineering, measurement, and computational connections.
- Every chapter contains **Advanced Topics for Technical and Engineering Students**.

Important scope distinction

The current 20-chapter Volume I does **not yet contain dedicated chapters** for **generalized/Lagrangian mechanics** or **solar physics and cosmology**. They remain formal Physics I course content and appear explicitly in this roadmap.

Physics I roadmap: the full journey



How to read this roadmap

The 20 chapters form the current **Volume I textbook architecture**. The official Space Technologies course is broader: it additionally requires **generalized equations/Lagrangian mechanics, diffusion and Fick's law**, and a dedicated block on **solar physics, stellar evolution, cosmology, and Hubble's law**.

Physics I for Space Technologies: spacecraft dynamics and orbital mechanics



Physical question

How do force, momentum, rotation, and gravity determine a spacecraft's trajectory and orientation?

We will cover: Newtonian mechanics; center of mass; linear and angular momentum; torque; rigid-body rotation; moment/tensor of inertia; gravitation; Kepler and two-body motion; variable-mass propulsion.

Two useful roadmap relations

$$v_{\text{circ}} = \sqrt{\frac{GM}{r}}, \quad L = I\omega.$$

Why it matters

Orbital motion, attitude dynamics, propulsion, and spacecraft control all depend on the mechanics developed through the course.

Physical question

How does energy move through a spacecraft system, and how do thermal and transport processes approach equilibrium?

We will cover: thermodynamic equilibrium; heat and work; the first law; specific heat; conduction; diffusion; Fick's law; entropy and irreversibility.

Transport anchors

$$\dot{Q} = -kA \frac{dT}{dx}, \quad \mathbf{J} = -D \nabla c.$$

Why it matters

Thermal design and material transport require energy balances, constitutive laws, and a correct understanding of equilibrium and irreversibility.

Physics I for Space Technologies: Sun, stars, and the cosmic environment



Physical question

What physical processes power the Sun, shape stellar evolution, and place space systems in a broader astrophysical and cosmological environment?

We will cover: solar interior and atmosphere; solar energy production; proton–proton cycle; stellar evolution; cosmology; expansion of the Universe; Hubble’s law.

A cosmological anchor

$$v = H_0 d.$$

Why it matters

Space Technologies connects local engineering systems to the solar environment, stellar physics, and the large-scale evolution of the Universe.

Measurement, units, uncertainty, and physical modelling



Physical question

How do we turn a physical question into a measurable quantity, a model, and a result whose units and uncertainty have meaning?

We will cover: physical models and measurands; SI quantities and units; unit conversion; dimensional analysis and scaling; estimates; resolution, precision, accuracy and calibration; error vs uncertainty; significant figures; model testing.

Two compact anchors

$$q = \{q\}_u u, \quad m = \rho V.$$

Why it matters

Every later mechanics or thermal calculation depends on a correct quantity definition, unit system, model boundary, and evidence check.

Textbook support: Chapter 1.

Motion along a straight line



Physical question

How do position measurements become velocity and acceleration, and how do graphs encode the history of motion?

We will cover: position, displacement and distance; average and instantaneous velocity; acceleration; motion diagrams; $x-t$ and $v-t$ graphs; constant acceleration; free fall; integration of general motion.

Rate relations

$$v = \frac{dx}{dt}, \quad a = \frac{dv}{dt}.$$

Why it matters

Kinematics separates the description of motion from its causes and provides the language used by all later dynamics.

Textbook support: Chapter 2.

Vectors and motion in two and three dimensions



Physical question

How do we represent magnitude-and-direction quantities and describe motion that is not confined to one line?

We will cover: scalars and vectors; components and unit vectors; vector addition; dot and cross products; position, velocity and acceleration vectors; projectile motion; circular motion; relative motion.

Vector kinematics

$$\mathbf{r} = x\hat{\mathbf{i}} + y\hat{\mathbf{j}} + z\hat{\mathbf{k}}, \quad \mathbf{v} = \frac{d\mathbf{r}}{dt}.$$

Why it matters

Vectors are the natural language of forces, velocities, torques, orbital motion, and multidimensional engineering models.

Textbook support: Chapters 3–4. The optional advanced vector-calculus supplement is a prerequisite.

Newton's laws and applications



Physical question

How do interactions change motion, and how do we translate a real situation into a correct force model?

We will cover: systems and inertial frames; Newton's three laws; mass and weight; normal force; tension; springs; friction; free-body diagrams; connected systems; circular dynamics; drag and terminal behavior.

Dynamics anchor

$$\sum \mathbf{F} = m\mathbf{a}.$$

Why it matters

Correct system boundaries and free-body diagrams underpin spacecraft dynamics, mechanisms, structural loads, and motion-control models.

Textbook support: Chapters 5–6.

Work, kinetic energy, potential energy, and conservation



Physical question

When is an energy description more efficient than solving directly for force components and accelerations?

We will cover: work; kinetic energy; work–energy theorem; power; potential energy; conservative and non-conservative forces; mechanical-energy conservation; energy diagrams and stability.

Energy anchors

$$W = \int \mathbf{F} \cdot d\mathbf{r}, \quad K = \frac{1}{2}mv^2.$$

Why it matters

Energy methods expose what can change, what is conserved, and which transformations are possible without following every intermediate force in detail.

Textbook support: Chapters 7–8.

Center of mass, momentum, collisions, and variable-mass systems



Physical question

How do we simplify the motion of many-particle systems and analyze impacts or propulsion?

We will cover: center of mass; linear momentum; impulse; system momentum balance; elastic and inelastic collisions; multidimensional collisions; variable-mass motion and rocket propulsion at roadmap level.

System anchors

$$\mathbf{p} = m\mathbf{v}, \quad \mathbf{R}_{\text{CM}} = \frac{1}{M} \sum_i m_i \mathbf{r}_i.$$

Why it matters

Momentum methods organize collisions, recoil, docking, staging, and the first principles behind variable-mass propulsion.

Textbook support: Chapter 9.

Fixed-axis rotation, rolling, torque, and angular momentum



Physical question

How do translational ideas generalize when extended bodies rotate, roll, and exchange angular momentum?

We will cover: angular variables; rotational kinematics; moment of inertia; rotational kinetic energy; torque; rolling without slipping; angular momentum; conservation of angular momentum; precession/gyroscopic ideas at roadmap level.

Rotational anchors

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}, \quad \mathbf{L} = \mathbf{r} \times \mathbf{p}.$$

Why it matters

Wheels, rotors, reaction wheels, flywheels, attitude control, and gyroscopic behavior require the rotational analogues of force, momentum, and energy.

Textbook support: Chapters 10–11.

Rigid bodies, inertia tensor, equilibrium, and elasticity



Physical question

What conditions keep an extended body in equilibrium, and how do orientation and material response affect its mechanics?

We will cover: force and torque balance; center of gravity; static equilibrium; stress and strain; elastic moduli; elastic energy; inertia-tensor and principal-axis ideas as an MSc-level extension.

Equilibrium and rigid-body anchors

$$\sum \mathbf{F} = 0, \quad \sum \boldsymbol{\tau} = 0, \quad \mathbf{L} = \mathbf{I}\boldsymbol{\omega}.$$

Why it matters

Structural stability and spacecraft attitude mechanics depend on force balance, torque balance, stiffness, and how mass is distributed in three dimensions.

Textbook support: Chapter 12 plus advanced rigid-body material.

Gravitation, Kepler's laws, orbits, and two-body motion



Physical question

How does gravity organize motion from near-Earth trajectories to satellite and planetary orbits?

We will cover: universal gravitation; gravitational field and potential; orbital energy; Kepler's laws; satellite motion; circular/escape speed; two-body and reduced-mass ideas at MSc roadmap level.

Orbital anchors

$$F = \frac{GMm}{r^2}, \quad T^2 = \frac{4\pi^2}{GM}a^3$$

for the dominant-central-mass limit.

Why it matters

This block connects classical mechanics directly to satellite motion, mission geometry, orbital energy, and the two-body idealization central to astrodynamics.

Textbook support: Chapter 13.

Physical question

How do pressure, buoyancy, and flow connect forces to continuous media?

We will cover: density and pressure; hydrostatics; Pascal's principle; Archimedes' principle; continuity; Bernoulli's equation; viscosity, drag and flow regimes at roadmap level.

Fluid anchors

$$p = p_0 + \rho gh, \quad A_1 v_1 = A_2 v_2.$$

Why it matters

Fluid mechanics supports pressure systems, buoyancy, flow measurements, drag interpretation, and the bridge from particle models to continuous media.

Textbook support: Chapter 14.

Physical question

Why do so many systems oscillate near stable equilibrium, and how do damping and forcing modify that motion?

We will cover: simple harmonic motion; spring oscillator; energy exchange; pendulum; damping; forced oscillations; resonance; quality-factor ideas where appropriate.

Oscillation anchors

$$x(t) = A \cos(\omega t + \phi), \quad \omega_0 = \sqrt{\frac{k}{m}}.$$

Why it matters

Resonance and damping recur in structures, sensors, mechanical subsystems, wave generation, and stability analysis.

Textbook support: Chapter 15.

Mechanical waves, superposition, and sound



Physical question

How do disturbances propagate, interfere, form standing patterns, and carry energy through a medium?

We will cover: traveling waves; wave speed; wave equation; energy and power; superposition; standing waves; resonance; sound; intensity; beats; Doppler effect; shock-wave ideas where appropriate.

Wave anchors

$$v = f\lambda, \quad \frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 y}{\partial t^2}.$$

Why it matters

Wave thinking unifies oscillatory systems, acoustics, resonance, signal propagation, and many measurement techniques.

Textbook support: Chapters 16–17.

Generalized coordinates, Lagrangian mechanics, and least action



Physical question

Can we formulate mechanics directly in the coordinates that best describe a constrained system, without solving explicitly for every constraint force?

We will cover: generalized coordinates q_i ; Lagrangian $L = T - V$ where applicable; action; Hamilton's principle; Euler-Lagrange equations; relation to Newtonian mechanics; constrained and multi-degree-of-freedom systems.

Analytical-mechanics anchors

$$S[q] = \int_{t_1}^{t_2} L(q, \dot{q}, t) dt, \quad \frac{d}{dt} \left(\frac{\partial L}{\partial \dot{q}_i} \right) - \frac{\partial L}{\partial q_i} = 0.$$

Why it matters

This is the analytical bridge from elementary Newtonian mechanics toward constrained, orbital, and rigid-body models used in advanced engineering.

Thermodynamic equilibrium, temperature, heat, work, and the first law



Physical question

How do we describe macroscopic systems by state variables and track energy transfer as heat and work?

We will cover: thermal equilibrium and temperature; state variables; thermal expansion; heat and internal energy; specific heat and calorimetry; thermodynamic work; first law; ideal-gas process diagrams; elementary heat transfer.

State and energy anchors

$$PV = nRT, \quad \Delta E_{\text{int}} = Q - W_{\text{by}}.$$

Here heat into the system is positive and work done by the system is positive.

Why it matters

Thermodynamics provides the bookkeeping language for energy storage, process paths, heat transfer, and efficiency limits.

Textbook support: Chapter 18.

Ideal gases, kinetic theory, equipartition, conduction, diffusion, and Fick's law



Physical question

How do molecular motion and transport processes generate macroscopic thermal behavior?

We will cover: ideal-gas molecular model; pressure and temperature from microscopic motion; rms speed; translational kinetic energy; mean free path; degrees of freedom and equipartition; specific heats; adiabatic behavior; conduction; diffusion; Fick's law.

Microscopic and transport anchors

$$\langle K_{\text{trans}} \rangle = \frac{3}{2} k_B T, \quad \mathbf{J} = -D \nabla c.$$

Source note

Kinetic theory and equipartition are supported by the current thermal architecture; **diffusion and Fick's law** are explicit formal-course requirements that need dedicated course supplementation.

Textbook support: Chapter 19.

Entropy, the second law, engines, refrigerators, and irreversibility



Physical question

Why do macroscopic processes have a preferred direction, and what limits the conversion of heat into useful work?

We will cover: entropy; second law; reversible and irreversible processes; entropy generation; statistical interpretation; heat engines; Carnot limit; refrigerators and heat pumps; efficiency and coefficient of performance.

Second-law anchors

$$\Delta S_{\text{universe}} \geq 0, \quad \eta = \frac{W_{\text{out}}}{Q_H}.$$

Why it matters

The second law distinguishes what conserves energy from what is actually achievable and sets the performance limits of thermal machines.

Textbook support: Chapter 20.

Solar physics, solar energy, and stellar evolution



Physical question

How does a star maintain structure and produce energy over astronomical timescales?

We will cover: solar interior and atmosphere; surface/photosphere; energy transport at overview level; nuclear fusion; proton–proton cycle; solar energy; stellar formation and evolution toward different end states.

Physics themes

Gravity sets the large-scale structure; thermodynamics determines pressure and energy transport; nuclear reactions supply the long-term energy source.

Why it matters

Solar and stellar physics connect gravitation, thermal physics, and nuclear energy to the environment in which space systems operate.

Cosmology, evolution of the Universe, Hubble's law — and where we start next



Physical question

What observational relation reveals cosmic expansion, and how does it connect local physics to the evolution of the Universe?

We will cover: cosmological expansion at roadmap level; Hubble's law; the distance–recession relation; evolution of the Universe as a formal course topic; links between local physical laws and cosmic scales.

Cosmological anchor

$$v = H_0 d.$$

Next

We begin the detailed teaching sequence with **Lecture 1: Measurement, Units, and Physical Modelling**, establishing the quantitative language used throughout the course.

