

General instructions: Theoretical Examination (30 points)

Failure to comply with any of the following conditions may result in disqualification

July 21, 2025

The theoretical examination lasts for 5 hours and is worth a total of 30 points.

The beginning and end of the examination will be indicated by an announcement, as well as every hour indicating the elapsed time, and thirty, fifteen and five minutes before the end of the examination.

Do not open the envelopes until instructed to do so.

The following items are provided for your use on the table: (1) a ballpoint pen, (2) a mechanical pencil, (3) an eraser, (4) a graduated ruler, (5) a compass, and (6) a scientific calculator.

During the exam

- Use the ballpoint pen provided. If you use the mechanical pencil to draft your notes, figures, tables and graphs, you must trace the outlines of the final version with the ballpoint pen.
- Use the dedicated sheets labeled **A** for your final answers. Fill in appropriate sections with your answers and necessary observations. Draw graphs as required. Cross out anything you do not want marked.
- Blank working sheets labeled **W** are provided for drafting. Use the designated ones. Cross out any unneeded answers and rough work that do not need to be graded. Use only the front face of each sheet and keep the margin outside the border clean.
- Additional working sheets labeled **Z** are available upon request. Raise the "Help" flag and let the Invigilator know.
- Keep your answers concise and legible. Use equations, logical operators, symbols, and sketches that best convey your thoughts. Avoid being lengthy and wordy as the markers may not be multi-lingual.
- Uncertainty quantification is not required unless otherwise specified.
- Do not leave your booth without permission. If you need a washroom break or any other assistance, raise the flag(s) marked "Toilet", "Water", or "Help".

At the end of the exam

- Stop writing immediately when the end of the exam is announced.
- Put all the sheets in the windowed envelope. Organize them faceup in the following order : cover sheet on top, General Instructions, question sheets (**Q**), answer sheets (**A**), working sheets (**W**), and additional working sheets (**Z**), if any. Arrange them according to their page numbers. In the final check, make sure that your ID, name, and seat number on the cover sheet are visible through the window.
- Your Invigilator will let you know when you can leave. You may take the remaining items with you, for example, the ballpoint pen, the mechanical pencil, the graduated ruler, the eraser, the compass, the scientific calculator, the bottle of drinking water, and snacks.

Specific instructions

Throughout the examination, always refer to the quantities indicated in the instructions, unless otherwise stated. In all cases, the units of all quantities used should be given.

General Data Sheet

| Constant | Notation | Value | Unit |
|---|--------------------------|---|--|
| Speed of light in vacuum | c | $2.997\,924\,58 \times 10^8$ | $\text{m} \cdot \text{s}^{-1}$ |
| Planck constant | h | $6.626\,070\,15 \times 10^{-34}$ | $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$ |
| Reduced Planck constant | $\hbar = \frac{h}{2\pi}$ | $1.054\,571\,818 \times 10^{-34}$ | $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$ |
| Boltzmann constant | k_{B} | $1.380\,649 \times 10^{-23}$ | $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} \cdot \text{K}^{-1}$ |
| Avogadro constant | N_{A} | $6.022\,140\,76 \times 10^{23}$ | mol^{-1} |
| Molar gas constant | R | $8.314\,462\,618\,153\,24$ | $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ |
| Elementary charge | e | $1.602\,176\,634 \times 10^{-19}$ | $\text{A} \cdot \text{s}$ |
| Universal constant of gravitation | G | $6.674\,30(15) \times 10^{-11}$ | $\text{m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2}$ |
| Standard acceleration due to gravity | g | $9.806\,65$ | $\text{m} \cdot \text{s}^{-2}$ |
| Stefan Boltzmann constant | σ | $5.670\,374\,419 \times 10^{-8}$ | $\text{kg} \cdot \text{s}^{-3} \cdot \text{K}^{-4}$ |
| Vacuum permeability (magnetic constant) | μ_0 | $1.256\,637\,061\,27(20) \times 10^{-6}$ | $\text{kg} \cdot \text{m} \cdot \text{A}^{-2} \cdot \text{s}^{-2}$ |
| Vacuum permittivity (electrical constant) | ϵ_0 | $8.854\,187\,818\,8(14) \times 10^{-12}$ | $\text{A}^2 \cdot \text{s}^4 \cdot \text{kg}^{-1} \cdot \text{m}^{-3}$ |
| Rydberg constant | R_{∞} | $1.097\,373\,156\,815\,7(12) \times 10^7$ | m^{-1} |
| Mass of the electron | m_e | $9.109\,383\,713\,9(28) \times 10^{-31}$ | kg |
| Mass of the proton | m_p | $1.672\,621\,925\,95(52) \times 10^{-27}$ | kg |
| Mass of the neutron | m_n | $1.674\,927\,500\,56(85) \times 10^{-27}$ | kg |
| Atomic mass constant | m_{u} | $1.660\,539\,068\,92(52) \times 10^{-27}$ | kg |
| Electronvolt | eV | $1.602\,176\,634 \times 10^{-19}$ | $\text{kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$ |