

General Instructions

Failure to comply with one or more of the following conditions may result in disqualification.

The exam is worth a total of 30 points and lasts five hours.

When to start and finish up the examination and when 15 minutes remain before the end of the examination will be indicated by your Invigilator.

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) a plastic eraser, (4) a scale ruler, (5) a scientific calculator, and (6) a digital table clock.

During the exam:

- Use the ballpoint pen provided. If you use the mechanical pencil to draft your notes, figures, tables, and graphs, never fail to 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 any unneeded answers.
- 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.
- You will be video-recorded for fairness and security purposes. 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 for each question. Organize them faceup in the following order: cover sheet on top, 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. Leave only the General Instructions (yellow sheets stapled) on the table.
- 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 plastic eraser, the scale ruler, the scientific calculator, the digital table clock, the bottle of drinking water, and snacks.

Physical Constants

Below is the list of physical constants you might use in your solution in addition to the quantities given in the body text.

Physical constant	Notation	Numerical value
Speed of light in vacuum	c	299 792 458 m/s
Vacuum permeability (magnetic constant)	μ_0	$1.256\,637\,062\,12(19) \times 10^{-6} \text{ N/A}^2$; [1 N/A ² = 1 V · s/(A · m)]
Vacuum permittivity (electric constant)	ϵ_0	$8.854\,187\,8128(13) \times 10^{-12} \text{ F/m}$; [1 F/m = 1 A · s/(V · m)]
Elementary charge	e	$1.602\,176\,634 \times 10^{-19} \text{ C}$; [1 C = 1 A · s]
Electron mass	m_e	$9.109\,383\,7015(28) \times 10^{-31} \text{ kg}$
Newtonian constant of gravitation	G	$6.674\,30(15) \times 10^{-11} \text{ m}^3/(\text{kg} \cdot \text{s}^2)$
Avogadro constant	N_A	$6.022\,140\,76 \times 10^{23} \text{ mol}^{-1}$
Molar gas constant	R	8.314 462 618 ... J/(K · mol)
Boltzmann constant	k	$1.380\,649 \times 10^{-23} \text{ J/K}$
Stefan–Boltzmann constant	σ	$5.670\,374\,419 \dots \times 10^{-8} \text{ W}/(\text{m}^2 \cdot \text{K}^4)$
Planck constant	h	$6.626\,070\,15 \times 10^{-34} \text{ J} \cdot \text{s}$
Reduced Planck constant	$\hbar = h/(2\pi)$	$1.054\,571\,817 \dots \times 10^{-34} \text{ J} \cdot \text{s}$