General Instructions

Failure to comply with any of the following instructions may lead to disqualification.

- The exam is worth a total of 50 points and will last 5 hours.
- The start and end times of the examination will be announced, hourly announcements will be made, and a reminder will be provided when there are 15 minutes remaining.
- Do not open the exam envelopes until instructed to do so.
- The following items are provided in your exam kit:
  - 1 ballpen
  - 1 pencil
  - 1 eraser
  - 1 ruler
  - 1 scientific calculator

During the exam:

- Use the ballpen provided. If you use the pencil to draft your notes, figures, tables, and graphs, make sure to trace the outlines of the final version with the ballpen.
- Use the Answer Sheets for your final answers. Fill in appropriate sections with your answers. Draw graphs as required. Cross out any unneeded answers.
- Blank working sheets are provided. Additional sheets are available upon request. Raise the "KIT" flag to notify the proctors.
- Keep your answers concise and legible. Use equations, operators, symbols, and sketches to convey your thoughts effectively.
- Uncertainty quantification is not required unless specified otherwise.
- Write numerical answers with 4 significant figures unless specified otherwise or when limited by the number of significant figures given in the problem. Use scientific notation as necessary, particularly for small (<0.01) and large numbers (>999).
- Do not leave your booth without permission. If you need a washroom break or other assistance, raise the appropriate flag(s) marked "Toilet", "Kit", "?", or “Medic”.

At the end of the exam:

- Stop writing immediately when the end of the exam is announced.
- Place all answer sheets in the red envelope and seal. Sign across the envelop flap. Your proctor will assist you in securing the sheets in the envelope and will collect them afterwards.
- Place all the sheets (question paper, scratch paper, etc.) in their original envelope and leave on the table.
- Leave the exam kit on your table. You may take the remaining items with you, for example, the bottle of drinking water, and snacks.
- Your Proctor will let you know when you can leave.

Useful Information

Below is a list of information that could be helpful for your solution, in addition to what is provided in the questions.

Physical Constants

Constant	Symbol	Value
Avogadro's constant	N_A	$6.02214 \times 10^{23}\ \mathrm{mol}^{-1}$
Boltzmann constant	k_B	$8.61733 \times 10^{-5}\ \mathrm{eV\ K}^{-1}$
Coulomb's constant	k_e	$8.98755 \times 10^{9}\ \mathrm{N\ m^2\ C^{-2}}$
Electron mass	m_e	$9.10938 \times 10^{-31}\ \mathrm{kg}$
Elementary charge	q	$1.60218 \times 10^{-19}\ \mathrm{C}$
Proton mass	m_p	$1.67262 \times 10^{-27}\ \mathrm{kg}$
Speed of light in vacuum	c	$299\ 792\ 458\ \mathrm{m\ s^{-1}}$

Conversion Factors

Quantity	Conversion Factors
Energy	$1\ \mathrm{kWh} = 2.24694 \times 10^{19}\ \mathrm{MeV}$ $1\ \mathrm{eV} = 1.60218 \times 10^{-19}\ \mathrm{joules\ (J)\ or\ kg\ m^2\ s^{-2}}$
Mass	$1\ \mathrm{u} = 1.66057 \times 10^{-27}\ \mathrm{kg}$
Mass-energy	$1\ \mathrm{u} = 931.5\ \mathrm{MeV}\ c^{-2}$
Nuclear cross-section	$1\ \mathrm{barn\ (b)} = 10^{-28}\ \mathrm{m^2}$

Formulas

Quantity	Formula	Definition of quantities
Bragg-Kleeman range	$R = N_R \times {E_K}^{\beta_e}$	N_R =proportionality factor E_k =kinetic energy β_e =exponent factor of incident energy
Centripetal force	$F_C = \frac{mv^2}{r}$	m =mass v =velocity r =radius
Electric field between parallel plates	$E = \frac{V}{d}$	V =potential difference between the plates d =distance between charges
Electric potential energy	$U = \frac{k_e q_1 q_2}{d}$	k_e =Coulomb's constant q_i =electric charge of particle i d =distance between charges
Kinetic energy	$E_K = qU$ $E_K = \frac{1}{2}mv^2$	q =elementary charge U =electric potential energy
Lorentz factor	$\gamma = 1/\sqrt{1 - \nu^2/c^2}$	v =velocity of particle
Magnetic Lorentz force	$F_B = qvB$	q =charge of particle B =magnetic field strength
Oscillation frequency	$f = \frac{1}{T}$	T =period
Period	$T = \frac{2\pi r}{v}$	
Radius of a nucleus	$r = r_0 A^{1/3}$	$r_0 = 1.2 \times 10^{-15}\mathrm{m}$ (empirical constant) A =atomic mass number

Quantity	Formula	Definition of quantities
Relativistic kinetic energy	$E_K = (\gamma - 1)m_0c^2$	γ =Lorentz factor m_0 =rest mass
Relativistic mass	$m_r = \gamma m_0$	m_r =relativistic mass of particle
Relativistic total energy	$E^2 = \left(m_0c^2\right)^2 + \left(pc\right)^2$	p =momentum of particle
Total energy	$E \equiv E_K + E_0 = E_K + m_0c^2$	E_K =kinetic energy of particle E_0 =rest mass energy of paticle m_0 =rest mass of paticle
Velocity of incident particle	$\beta_v \equiv \frac{v}{c} = \frac{pc}{E}$	