P510/1
PHYSICS
Paper 1
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3 Hours

AITEL JOINT MOCKS ASSESSMENTS 2026

Uganda Advanced Certificate of Education

PHYSICS

PAPER 1

3 Hours

INSTRUCTIONS TO CANDIDATES:

This examination paper consists of two sections; **A** *and* **B**. *It has* **six** *items.*
Section **A** *has* **two compulsory** *items.*
Section **B** *has two parts;* **I** *and* **II**. *Respond to only* **one** *item from* **each** *part.*
Respond to **four** *items in all.*
Any additional item(s) responded to, will **not** *be scored.*
Responses to **each** *item should start on a* **fresh** *page.*
Silent non-programmable scientific calculators may be used.

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SECTION A

Respond to both items

Item 1

An engineering cooperative in Nebbi district is installing a high-velocity centrifugal honey extractor to process raw combs from local bee farmers. The extractor consists of a cylindrical drum of radius 0.4 m that spins horizontally.

The technician places a mesh basket containing a batch of honeycombs at the outer edge of the drum. For the honey to be efficiently flung out of the combs without crushing the wax structure, the system must maintain specific operational thresholds:

- The drum must achieve a minimum steady rotational speed so that the centripetal acceleration acting on the outer basket is exactly 160 m s^{-2}.
- The supporting central steel drive shaft (which experiences a maximum motor torque of 48 N m) must be strong enough to accelerate the entire spinning assembly which has a total moment of inertia of 12 kg m^2 from rest to its maximum operating speed within 3.5 seconds.
- The project team needs to mathematically evaluate these rotational parameters to ensure the electric motor is properly calibrated.

Once the honey is extracted from the combs, it drains into a collection pipe at the bottom of the machine. The pipe has a non-uniform cross-section, tapering from a wide inlet where the honey flows slowly, to a narrow nozzle that fills the packaging jars.

The packaging team notices a major operational issue: during cold mornings, the honey thickens significantly, causing the flow rate to drop drastically and sometimes stall completely. The plant manager wants to know how changes in temperature affect the viscosity and flow behaviour of a highly viscous fluid like honey through a pipe, and needs a physical strategy to maintain a steady flow rate throughout the day without replacing the piping system.

Task:

(a) Analyse the mechanics of the centrifugal extractor to determine the required angular velocity for efficient extraction, and evaluate whether the drive shaft can reach its operating speed within the safety time limit.

(b) Account for the flow issues observed by the packaging team on cold mornings by explaining the relationship between temperature and fluid viscosity, and propose a practical engineering solution to ensure consistent flow through the tapered pipe.

Item 2.

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A sound technician is designing the acoustics for a community indoor theatre hall in Jinja. The stage features a long, narrow decorative alcove that acts exactly like a pipe closed at one end. The total length of this acoustic alcove is 1.75 m.

During sound checks, the technician notices that when the main speakers play specific bass frequencies, the alcove vibrates violently, creating an uncomfortably loud booming sound at a fundamental frequency that disrupts the audience's experience. The stage manager wants to know the exact frequency causing this resonance. To fix the issue, the technician proposes installing a sound-absorbing barrier right at the open mouth of the alcove to force a change in the boundary conditions of the standing wave pattern, but needs to verify how this modification alters the resonant frequencies of the space. (Take the speed of sound in air as 343 m s^{-1}).

Meanwhile, in an adjacent digital media laboratory, researchers are testing an advanced electron-beam etching tool used to print microscopic serial numbers on security badges. The tool accelerates electrons through an anode potential difference of 800 V.

The electron beam passes through a thin crystalline graphite foil, creating a sharp pattern of concentric bright and dark rings on a fluorescent observation screen placed further down the path. The lead researcher notes that this phenomenon cannot be explained if electrons are viewed simply as hard, tiny spheres of matter, because the pattern behaves exactly like light passing through a diffraction grating. The laboratory assistants are confused about how solid particles can produce a wave-like interference pattern, and they want to calculate the equivalent wavelength of the moving electrons to optimize the sharpness of the printed serial numbers.

(Physical constants provided: Electron charge, $e = 1.6\times10^{-19}$ C; Mass of an electron, $m_e = 9.11\times10^{-31}$ kg; Planck's constant, $h = 6.63\times10^{-34}$ J s).

Task:

(a) Evaluate the acoustic behaviour of the theatre stage alcove by calculating the fundamental booming frequency that causes the resonance disturbance, and explain how changing the boundary conditions alters the standing wave properties.

(b) Explain the physical mechanism behind the ring pattern formed on the screen by the electron beam, and calculate the de Broglie wavelength of the accelerated electrons to help the research team optimize the etching tool.

SECTION B

PART I

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Respond to one item from this part.

Item 3

An engineering firm is inspecting a geothermal power facility near Lake Katwe. The technical team is examining a heavy-duty steel storage cylinder containing an industrial gas used in the cooling loop. At an ambient morning temperature of 27˚C, the gas inside the cylinder exerts a pressure of 2.0×10^6 Pa.

The plant's junior technician attempts to model the behaviour of the gas using the ideal gas equation, PV=nRT. However, the senior consultant points out that because the gas is stored under extremely high pressure and low temperature conditions, the molecules are forced close together, meaning their actual behavior deviates significantly from an ideal gas due to intermolecular forces and the finite volume occupied by the molecules themselves. The consultant insists that the team must apply the van der Waals equation of state:

$$\left(P + \frac{a}{V^2}\right)(V - b) = \text{RT}$$

To prevent a catastrophic calculation error regarding the cylinder's structural limits.

Later in the afternoon, as the geothermal pumps heat up, a specific volume of 0.04 m^3 of this gas at an initial pressure of 1.5×10^6 Pa enters an expansion chamber. The gas undergoes a rapid thermodynamic cycle consisting of two stages:

- It first expands adiabatically to a volume of 0.08 m^3 (where the ratio of principal molar heat capacities, γ=1.4).
- It is then compressed isothermally back to its original volume of 0.04 m^3.

The plant operations manager needs to evaluate the net energy changes in this system. The company's environmental safety policy states that if the net work done by the gas during such a thermal cycle drops below zero (requiring external mechanical energy input) or if the internal energy of the system fluctuates unpredictably, the expansion chamber layout must be redesigned.

Task: Help the technical team and the operations manager make informed engineering decisions by providing a comprehensive thermodynamic report that:

(a) Explains the physical justification for using the van der Waals equation over the ideal gas equation under high-pressure conditions, detailing the significance of the correction terms.

(b) Determines the final pressure of the gas after the adiabatic expansion, and calculates the total work done during each stage of the cycle to deduce whether the current expansion chamber layout complies with the company's energy policy.

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Item 4

A coastal fishing village in Kalangala frequently experiences heavy storms that disrupt mobile network signals, making rescue operations difficult during emergencies. To solve this, the community tech-club set up a local light-based communication system to send emergency alerts between a hilltop lighthouse and a marine rescue station 150 meters away.

They laid out a line of solid glass rods exposed to the air to guide light flashes from a powerful LED at the lighthouse to a light sensor at the rescue station. However, during the first test run at night, the rescue station received very faint, blurry signals, and during day-time tests, the system failed completely.

Tasks:

(a) Using your knowledge of light propagation, explain to the village tech-club how the light signals travel through the glass rods from the lighthouse to the rescue station, and account for the failure of the system during the day.

(b) Write a technical recommendation to the village council suggesting at least **two** practical improvements to the setup to increase the clarity and strength of the signals, explaining the physics behind each adjustment.

Item 4

An electronics manufacturing start up in the Namanve Industrial Park is designing an automated electrostatic paint-spraying system for vehicle chassis. The system relies on a specialized parallel-plate capacitor unit that establishes a highly uniform electric field to guide charged paint droplets accurately onto the metal target.

The two parallel aluminium plates are separated by a air gap of 5.0 mm and connected to a high-voltage DC power supply of 6.0 kV. To enhance the charge storage capability without increasing the physical size of the machine, a design engineer proposes sliding a solid sheet of ebonite (which has a dielectric constant/relative permittivity, $\varepsilon_r = 3.0$) of thickness 3.0 mm into the space between the plates while the system remains continuously connected to the 6.0 kV power supply. The workshop head wants to know precisely how this structural modification alters the capacitance, the total energy stored in the system, and the electric field strength in the remaining air gap to ensure the insulation does not suffer an electrical breakdown.

Simultaneously, in the assembly section of the plant, a high-current overhead power line carries a direct current of 120 A horizontally from East to West across the room. Due to the high power demands of the industrial machinery, the heavy copper cable sags slightly, placing it exactly parallel to and 0.15 m directly above a sensitive,

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parallel communication wire that carries a micro current of 2.5 A in the opposite direction.

The safety officer notices that whenever both systems are active, the communication wire experiences an unexpected mechanical vibration and a steady vertical force. The officer is deeply concerned that this electromagnetic interaction will cause physical fatigue in the communication wire hangers over time. According to the factory equipment manual, the structural hangers can safely withstand a maximum magnetic force per unit length of $3.5\times10-4$ N m^{-1} before failing.

(Take permeability of free space, $\mu_0=4\pi\times10^{-7}$ T m A^{-1}; permittivity of free space,

$\varepsilon_0 =8.85\times10^{-12}$ F m^{-1}).

Task:

Help the design engineer and the safety officer safeguard the plant's operations by providing a technical safety assessment that:

(a) Evaluates the structural modifications of the capacitor unit by calculating the changes in capacitance, stored energy, and the electric field intensity in the air gap after the dielectric sheet is introduced.

(b) Analyses the magnetic interaction between the parallel industrial wires to determine the direction and magnitude of the magnetic force per unit length acting on the communication wire, and deduces whether the structural hangers are safe from failure.

Item 6

A student innovation hub in Fort Portal is designing an eco-friendly bicycle speedometer for rural delivery riders. The system works by attaching a small, powerful cylindrical permanent neodymium magnet to the spokes of the front wheel. Every time the wheel completes a full turn, the magnet passes directly through the center of a small, stationary copper wire coil of 150 turns fixed to the bicycle frame.

The riders notice a strange physical effect: when coasting down a steep hill at high speeds, the bicycle feels a tiny, momentary braking jerk exactly at the instant the magnet passes through the coil, even though the coil is not touching the wheel at all. The junior designer explains that as the magnet approaches and leaves the coil, an electromotive force (e.m.f.) is induced, which drives a current through the circuit. The technical lead wants the team to mathematically model the peak induced e.m.f. to ensure it does not fry the low-voltage microchip logging the data. According to the design specifications, the microchip can safely handle a maximum induced voltage

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pulse of 4.5 V. At peak riding speed, the magnetic flux through the coil changes at a maximum rate of $\frac{d\Phi}{dt}$ =0.025 Wb s^{-1}.

Simultaneously, the hub is setting up a low-power FM transmitter for a local community radio station. The broadcast antenna relies on a tuning circuit consisting of a 0.5 mH inductor, a variable capacitor, and a 12 Ω resistor connected in series across an alternating current (a.c.) signal generator that provides an output voltage of r.m.s. value 6.0 V.

The radio operator is trying to tune the transmitter to the assigned regional frequency of 95.0 kHz. The operator notices that if the variable capacitor is not adjusted perfectly to achieve a state of electrical resonance at this exact frequency, the current in the circuit drops significantly, resulting in a very weak, static-filled broadcast signal that fails to reach the surrounding villages. The safety coordinator is also concerned that at peak resonance, the voltage drop across the inductor might exceed the insulation breakdown limit of the components, which is rated at 200 V.

Task:

As the lead electronics engineer, help the innovation hub optimize their designs by preparing a comprehensive technical evaluation report that:

(a) Explains the physical origin of the temporary braking jerk felt by the riders using the laws of electromagnetic induction, and calculates the peak induced e.m.f. to determine if the speedometer microchip remains within its safe operational limit.

(b) Calculates the exact capacitance value required to tune the radio transmitter to the resonant frequency of 95.0 kHz, and determines both the maximum circuit current and the r.m.s. voltage drop across the inductor at resonance to verify if the components are safe from electrical insulation breakdown.

END

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