SET TWO

KAMSSA PRE REGISTRATION EXAMINATIONS 2026

Uganda Advanced Certificate of Education

PHYSICS

Paper 1 (Theory)

Time: 2 Hours 40 minutes

INSTRUCTIONS:

- *Attempt **four** questions in total.*
- *You must attempt **one question from each of the four sections**:*
- *Section A is compulsory.*
- *Use the provided data and support materials to guide your solutions.*
- *Clearly show all calculations and assumptions.*

SECTION A

ITEM 1

A team of scientists, medical doctors and engineers at Mulago National referral Hospital are collaborating with officials from the ministry of energy to check for volume of blood in patients, improve cancer diagnosis, electricity supply, security and material analysis in Uganda. The hospital has recently acquired X-ray machines, a photoelectric sensor for automatic doors, and radioactive sources for treatment. During a training session, one of the physicists explains that modern understanding of the atom has evolved from Rutherford's atomic model to Bohr's model which successfully explains emission spectra observed in the laboratory experiments. When a gas is heated, it emits light of specific wavelengths forming a line spectrum, these spectral lines are used to identify elements in unknown samples.

Meanwhile the engineering team is using X-rays to inspect cracks in metal pipes and a photoelectric system is installed at the hospital entrance such that electrons are emitted when light of sufficient frequency falls on the metal surface. The hospital also received a radioisotope to help them assess the volume of blood in the patients.

Support information

- Planck's constant = 6.63×10^{-34}Js
- Speed of light in a vacuum = 3.0×10^{8}ms^{-1}
- Work function of the metal = 2.0Ev
- 1eV = 1.6×10^{-19}J
- Half-life of the radioisotope = 1.2 hours

Task

As a physics student attached to the project;

a) help the doctors understand the meaning of half-life and work function.
b) a radioisotope was introduced into the patient, after 5 hours, $2cm^3$of blood was withdrawn and found to have an activity of 400 disintegrations per hour. Establish whether a patient aged 20 years needs a blood transfusion. (Hint: initial activity of the radioisotope is $2.16x10^7$disintegrations per hour, average volume of blood in a normal adult is at least 4.5 litres.)
c) Explain how Rutherford's atomic model led to the discovery of the nucleus and state one limitation that was later addressed by Bohr's model.
d) Explain how Bohr's model accounts for the formation of emission spectra in atoms.
e) X-rays are used to detect cracks in metallic pipes at the hospital. Explain how X-rays are produced and why they are suitable for this purpose.
f) The photoelectric system uses light of frequency $1.2x10^{15}$Hz. Determine;
   i. the energy of the incident photons
   ii. whether photoelectric emission will occur
   iii. the maximum kinetic energy of the emitted electrons.

SECTION B

ITEM 2

Engineers from Kampala Capital City Authority are designing a rotating observation platform on a hill to monitor traffic and support tourism, while also using a communication satellite orbiting the Earth to collect data. During testing, a passenger of mass 60 kg stands at a radius of 4.0 m on the platform moving at 5 m/s, and the coefficient of friction between the passenger and the surface is 0.3. A 50 kg load is lifted vertically to a height of 10 m in 5 s using a motor, and at the same site a stone is released horizontally from the edge of the platform at 5 m/s from a height of 10 m above the ground, while the satellite orbits the Earth at a height of 3.6×10^7 m.

Take $g=10\ m/s^2$, $G=6.67\times10^{-11}\ Nm^2\,kg^{-2}$, $M_E=6.0\times10^{24}$ kg and $R_E=6.4\times10^6$ m

a) Using appropriate physical principles and equations, determine the centripetal force acting on the passenger and the maximum frictional force available, and hence evaluate whether the passenger will maintain stable circular motion or begin to slip, justifying your conclusion with mathematical reasoning and proposing a condition for stability of the system.

b) A stone is projected horizontally from the platform at 5 m/s from a height of 10 m; determine the time taken to reach the ground, the horizontal distance travelled, and the velocity just before impact, and then analyse how this motion compares with the circular motion of the passenger and the orbital motion of the satellite, clearly explaining how gravity influences all three motions.

c) Using the law of gravitation, determine the orbital radius and orbital speed of the satellite, and hence calculate the centripetal force acting on a 100 kg satellite, and critically explain why no friction is required for its motion while also predicting the effect on its orbit if either its speed increases or the gravitational force decreases.

d) Calculate the work done in lifting the 50 kg load to a height of 10 m and determine the power output of the motor if the lifting takes 5 s, then analyse the energy transformations involved in the system and evaluate the efficiency of the process, suggesting a realistic improvement to reduce energy losses and enhance performance.

e) Compare the projectile motion of the stone, the circular motion of the passenger, and the orbital motion of the satellite in terms of velocity, acceleration, and forces acting on each, and evaluate the role of gravity in unifying these motions while explaining which motion is most stable and which is most energy dependent, supporting your reasoning with physics principles.

f) As a physics consultant, analyse how friction, gravity, and energy interact within the entire system to influence motion, stability, and safety, and propose a mathematically justified engineering modification that improves both the rotating platform and the satellite system in terms of efficiency, stability, and safety.

ITEM 3

Engineers working with Kampala Capital City Authority are upgrading a smart transport and drainage system along the Northern Bypass in Kampala. A curved section of radius 40 m is constructed as a banked track to allow vehicles to move safely at 20 m/s. During rainfall, the coefficient of friction reduces from 0.6 to 0.3, causing vehicles to skid. Engineers are debating whether to increase the banking angle or improve the road surface. Two vehicles approach each other at speeds of 20 m/s and 15 m/s respectively, and their motion is analysed relative to each other. During heavy rainfall, water accumulates on the road and flows through drainage channels. Engineers observe that small insects float on the water surface due to surface tension. A thin rectangular metal plate of mass 0.12 kg, length 0.20 m, width 0.10 m and thickness 0.002 m is placed on water. Some similar plates are seen to sink while others float depending on their material. Floating debris partially blocks drainage pipes, reducing water flow and increasing accident risks. At the same time, a tool falls freely from a height of 20 m during installation. Traffic monitoring is carried out using a communication satellite, and engineers compare its motion with that of vehicles on the curved road.

Take:

$g = 10\ m/s^2$

density of water = $1000\ kg/m^3$

surface tension of water = 0.07 N/m

a) **i)** Define banking of a track and relative velocity
ii) Determine the banking angle required for safe motion without friction, compare with the case when friction is present, analyse the effect of reduced friction during rainfall, evaluate the engineers' disagreement, and recommend a solution.

b) Determine the relative velocity of the two vehicles, analyse its effect on collision severity, evaluate road safety, and propose a control measure.

c) Explain surface tension. Determine the maximum force due to surface tension acting on a 5 cm long edge of the plate. analyse whether surface tension alone can support the plate, evaluate the observation of insects floating, and suggest one practical application.

d) State the law of flotation. Determine whether the plate floats or sinks. Calculate the volume of water displaced if it floats. Analyse blockage due to floating debris, evaluate its impact on drainage, and propose a solution.

e) Determine the velocity of the falling tool just before impact, analyse motion under gravity, evaluate safety risks, and propose a preventive measure.

f) Explain how circular motion applies to both vehicles and satellites. Determine the centripetal force acting on the vehicle. analyse similarities and differences between vehicle and satellite motion, evaluate communication effectiveness, and propose an improvement.

SECTION C

ITEM 4

A multidisciplinary research team in Uganda is developing a dual observational system for both thermal radiation detection and astronomical observation. The system consists of:

- A bolometer with a blackened absorbing surface of emissivity, $\varepsilon=0.90$ and effective area 1.5cm^2, used to detect thermal radiation from heated objects and biological tissues. The bolometer operates between temperatures 300 K and 315 converting absorbed radiation into electrical signals through a Wheatstone bridge.
- An astronomical telescope designed to observe distant celestial objects such as stars. The telescope consists of:
  - An objective lens of focal length 100cm
  - An eyepiece of focal length 10cm

The telescope is adjusted such that the final image is formed at the near point of the eye allowing maximum strain-free viewing by the observer. The system is used to observe a star whose radiation peaks at a wavelength of 9.3×10^{-6}m, while the surrounding environment is at 300K.

Tasks

a) Explain the working principle of the bolometer and how it converts thermal radiation into an electrical signal. Using the given emissivity, evaluate how effectively the device absorbs radiation and justify its suitability for detecting weak infrared signals.

b) Calculate the net thermal radiation absorbed by the bolometer. Evaluate whether the bolometer is gaining or losing thermal energy and justify your answer.

c) Determine the temperature of the star based on the wavelength of maximum radiation given. Evaluate whether the star emits predominantly in the visible or infrared region and justify your answer.

d) determine the angular magnification of the telescope when the final image is formed at the near point. Explain the condition required for this configuration and analyse why this arrangement reduces eye strain.

e) Evaluate how combining a bolometer and an astronomical telescope enhances both thermal detection and astronomical observation, and propose a scientific improvement to increase the accuracy of measurements in both systems.

ITEM 5

Engineers at a research centre in Gulu are developing a hybrid optical–thermodynamic communication system to support emergency services in rural areas. However, the system is experiencing inefficiencies and instability that must be resolved. Light signals are directed using a concave mirror before entering optical fibres. Despite this, only about 60% of the initial light intensity is transmitted over a distance of 500 m, indicating significant signal loss due to improper reflection and incomplete total internal reflection. The fibre material has a refractive index of 1.5, and light enters the fibre at angle close to 45°. The system also transmits waves of frequency 150 Hz and speed 300 m/s, but interference between overlapping waves is reducing signal clarity. A sealed gas chamber consisting of four stages, in the system operates through a complete thermodynamic cycle as shown below;

1. Isothermal compression at constant temperature from a volume of 0.020 m^3 to 0.010 m^3 at 300 K
2. Isobaric expansion from 0.010 m^3 to 0.025 m^3 at a constant pressure of 2.0×10^5 Pa
3. Isochoric heating at constant volume where pressure increases from 2.0×10^5 Pa to 3.0×10^5 Pa
4. Adiabatic expansion back to the original volume (0.020 m^3)

(For the adiabatic process, the gas has a ratio of specific heats (γ) = 1.4, and molar gas constant $R=8.31 Jmol^{-1}K^{-1}$).

Engineers must determine the work done in each stage, including the adiabatic process, and evaluate the total work done over the entire cycle, which determines the system's efficiency and stability. Due to budget constraints, only one major system redesign can be implemented. Engineers must analyse the system, perform all necessary calculations, evaluate the thermodynamic performance, and propose the most effective improvement to enhance both energy efficiency and signal reliability.

Tasks

a) Using the concave mirror in the system, define reflection and derive the mirror formula, then calculate the image position for an object placed 20 cm from a concave mirror of focal length 10 cm, determine the nature of the image formed, analyse how the mirror improves signal direction in the system, and propose one justified modification to enhance optical performance and reduce signal loss.

b) calculate the critical angle and determine whether total internal reflection occurs when light enters the fibre at 45°, analyse how this principle ensures efficient signal transmission, evaluate the effects of environmental variations on fibre performance, and propose a redesign to minimize signal loss and improve transmission efficiency.

c) determine the wavelength and wave number, then analyse how interference between waves affects signal clarity, evaluate the impact of interference on system performance, and propose a practical solution to reduce interference and improve signal quality in the system.

d) calculate the work done in each thermodynamics process, clearly showing the use of appropriate formulas and assumptions, and analyse how each stage contributes to the energy changes within the system.

e) Using the results obtained from all four processes, evaluate the total work done over the thermodynamic cycle, clearly showing how the individual work values combine to give the network, and analyse whether the system produces network or consumes energy, justifying your conclusion in the context of system efficiency and performance.

f) Evaluate the overall performance of the optical–thermodynamic system, identify the main sources of inefficiency such as signal loss, interference, resonance, and thermodynamic instability, and propose a single, well-justified redesign that improves both signal transmission and energy efficiency while considering the budget constraint of implementing only one major improvement.

SECTION D

ITEM 6

Engineers working with UEDCL are upgrading a power distribution and backup system at a hospital in Kampala to ensure reliable electricity supply. During installation, insulated cables transmit current to different wards. When several machines are switched on, current increases and wires begin to heat up, raising concerns about energy loss. To provide backup power, a generator produces electricity through a rotating coil in a magnetic field. Transformers with soft iron cores are used to regulate voltage, and engineers note that magnetic properties affect efficiency. In the hospital laboratory, a potentiometer is used to test cells used in sensitive medical equipment. The e.m.f of a cell is first measured under open circuit conditions, giving a balance length of 100 cm. When the cell is connected across a known resistor, the balance length reduces to 80 cm. Engineers suspect that internal resistance of the cell may affect performance. Elsewhere, dust particles are attracted to charged surfaces, indicating electrostatic effects. Capacitors are installed to stabilize voltage in critical machines.

Support information

Resistance of cable = 5 Ω
Potential difference = 100 V
Capacitance = 200 μF
Charge = 0.02 C
External resistor = 4 Ω
Balance length (open circuit) = 100 cm
Balance length (with load) = 80 cm

As a physics student attached to the project:

a) Define electric current and capacitance.

ii) Using the cable system, determine the current flowing, explain why heating occurs, analyse energy losses, evaluate risks, and propose a method to reduce losses.

b) Using the generator system, explain how electromagnetic induction produces electricity, analyse factors affecting induced e.m.f, evaluate efficiency, and suggest an improvement.

c) Using the transformer system, explain magnetism in matter, analyse why soft iron is used, evaluate its effectiveness, and propose an alternative material.

d) Using the potentiometer data determine the ratio of e.m.f and terminal p.d, calculate the internal resistance of the cell, explain the principle of operation of a potentiometer, analyse why it is more accurate than a voltmeter, evaluate its usefulness in medical equipment, and suggest an improvement.

e) From the electrostatic observations, explain charging, analyse dust attraction, evaluate risks to equipment, and suggest a control method.
f) Using the capacitor data, determine the potential difference, explain energy storage, analyse its role in voltage stabilization, evaluate system performance, and propose an improvement.

ITEM 7

Engineers working with UEDCL are installing an advanced electrical training and diagnostic system at a technical institute in Kampala to train technicians in modern power systems. During testing, a capacitor is connected across an AC supply of 240 V and it is observed that current leads the voltage. Engineers explain that this behaviour is due to capacitive reactance and contributes to the overall impedance of the circuit. In another section, an alternating current of 2 A flows through the system, and engineers analyse the impedance to understand how it limits current flow. A straight conductor of length 0.2 m carrying a current of 3 A is placed in a uniform magnetic field of 0.5 T perpendicular to the field, producing a force used in a motor demonstration. A slide wire metre bridge is used to determine an unknown resistance. Balance is obtained when the lengths of the wire are 40 cm and 60 cm. The system also includes two coils placed close together. When current in one coil is switched on and off rapidly, an induced e.m.f is observed both in the same coil and in the neighbouring coil, affecting circuit behaviour.

Support information

Capacitance = 100 μF
Charge = 0.01 C
AC voltage = 240 V
AC current = 2 A

As a physics student attached to the project:

a) **i)** Define capacitance and reactance
ii) Using the capacitor data, determine the potential difference across the capacitor, calculate the capacitive reactance, explain why current leads voltage in this case, analyse the effect of capacitance on impedance, evaluate its role in AC systems, and propose an improvement.
b) Using the AC data, determine the impedance of the circuit, explain the relationship between impedance, voltage and current, analyse how impedance limits current flow, evaluate system efficiency, and suggest a method to optimize performance.
c) Using the conductor in the magnetic field, determine the force acting on it, explain the principle involved, analyse how changing current or field affects the force, evaluate its application in motors, and propose an improvement.
d) Using the metre bridge data, determine the unknown resistance, explain the principle of the slide wire metre bridge, analyse why the null point gives accurate results, evaluate its limitations, and suggest an improvement.
e) Using the first coil, explain self-induction, analyse why the induced e.m.f opposes the change in current, evaluate its effect on circuit performance, and suggest a method to control it.

f) Using both coils, explain mutual induction, analyse how energy is transferred between coils, evaluate its application in transformers, and propose a method to increase efficiency.

END