

A LEVEL PHYSICS REVISION ITEMS

CURRENT ELECTRICITY

Question 1:

A boarding secondary school in Mpigi district is installing a backup power system using a diesel generator to ensure continuous electricity supply during frequent outages. The school electrician connects a 240 V generator to several classroom lighting systems and laboratory appliances using long aluminium wires that run across the compound. Each classroom block has a total resistance of $60\ \Omega$ when all bulbs and sockets are in use. After several weeks of operation, the electrician notices that the wires running to the laboratory block become noticeably hot to the touch, especially during evening prep when all classes have lights on. Concerned about energy wastage and potential fire hazards, he is puzzled about how to investigate and solve the problem.

- Help the electrician determine the exact current flowing through a single classroom circuit when the full 240 V is applied across its $60\ \Omega$ resistance. Show your working clearly.
- Calculate the electrical power dissipated in that classroom circuit. Suggest two practical and cost-effective methods the school could implement to reduce energy loss in the long wiring runs.
- If the classroom circuit is used for an average of 5 hours each day, calculate the total electrical energy consumed in kilowatt-hours (kWh) over a 30-day month.
- Explain, using the concepts of current, resistance, and drift velocity, the physical origin of the heating effect observed in the aluminium wires. Why does this heating increase with the length and decrease with the cross-sectional area of the wire?

Question 2:

The matron at a secondary school in Soroti wants to install a small immersion heater in the sickbay to warm water for patients' baths and for sterilising equipment. She has acquired a length of nichrome wire of diameter 0.58 mm and length 5.0 m. The heater will be connected directly to the school's 240 V mains supply. The resistivity of nichrome at room temperature is $1.02 \times 10^{-6}\ \Omega\ \text{m}$. Before installation, she needs to understand the electrical properties of this wire to ensure it will not overheat and cause a fire, and to estimate if it can heat a small bucket of water within a reasonable time.

- Calculate the electrical resistance of the nichrome wire at room temperature.
- Determine the current that will flow through the heater element when it is connected to the 240 V supply.
- Calculate the power rating of this heater. Estimate whether this power is sufficient to heat 10 litres of water from an initial temperature of 25°C to boiling point (100°C) within 30

Best of the best

minutes. Assume no heat losses to the surroundings. (Specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$).

(d) If the heater is used for an average of 2 hours daily, calculate the monthly cost of running it for a 30-day month, assuming the electricity tariff is UGX 850 per kWh.

(e) Explain why the nichrome wire heats up when current passes through it, whereas the copper connecting wires from the socket to the heater remain relatively cool.

Question 3:

During a physics practical examination at a secondary school in Jinja, students are tasked with determining the resistivity of an unknown metallic wire. They set up a metre bridge with a standard 10Ω resistor in the right-hand gap and the test wire, of length 110 cm, in the left-hand gap. The test wire has a diameter of 0.85 mm, measured using a micrometer screw gauge. When the jockey is carefully tapped along the uniform bridge wire, the sensitive centre-zero galvanometer indicates zero deflection exactly at a point 46.7 cm from the left-hand end of the 100 cm bridge wire. The teacher reminds them that this balance condition is based on the Wheatstone bridge principle.

(a) State the balance condition for a Wheatstone bridge and apply it to calculate the resistance of the test wire.

(b) Using the measured dimensions of the wire, calculate the resistivity of the material from which the wire is made.

(c) Explain in detail why the metre bridge method is not suitable for accurately measuring very low resistances (e.g., less than 1Ω) or very high resistances (e.g., greater than $1 \text{ M}\Omega$).

(d) If the experiment were repeated on a very hot afternoon with the same apparatus, explain qualitatively how the balance point might shift and why, considering the temperature coefficient of resistance of the wire.

(e) State two precautions that should be taken during this experiment to ensure an accurate and reliable result.

Question 4:

A rural health centre in Kabale relies on a solar panel system that charges a deep-cycle 12 V lead-acid battery. This battery powers a small submersible water pump that lifts water from a borehole to an overhead tank. The pump motor has an internal resistance of 2.0Ω . Under normal operating conditions, the pump draws a steady current of 3.0 A from the battery. The health worker in charge notices that sometimes, especially on cloudy mornings, the pump runs noticeably slower and the water flow is reduced. She suspects either the battery is ageing or the wiring connections are poor.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (a) Calculate the electromotive force (e.m.f) of the battery when the pump is running and drawing 3.0 A. Explain the difference between the e.m.f and the terminal voltage.
- (b) Determine the mechanical power delivered to the pump (the useful power) and the electrical power wasted as heat inside the battery due to its internal resistance.
- (c) Calculate the efficiency of the battery-pump system under these operating conditions.
- (d) If the connecting cables from the battery to the pump (which is 20 m away) have a total loop resistance of 0.8Ω , calculate the voltage that actually reaches the pump terminals. Explain why the pump runs slower when long, thin extension wires are used instead of short, thick ones.
- (e) Suggest one method to improve the performance of the pump without replacing the battery, and explain the physics principle behind your suggestion.

Question 5:

A trader in the busy Owino market in Kampala is selling strings of imported Christmas decorative lights. Each string contains 40 small, identical incandescent bulbs connected in series, and the string is designed to operate directly from the 240 V mains supply. A customer returns a string, angrily complaining that one bulb blew out and the entire string went dark immediately. The trader, wanting to provide better customer advice, consults his nephew who is a physics student.

- (a) Calculate the operating voltage across each individual bulb when all 40 are working normally in the series string.
- (b) Explain, using the principles of a series circuit, why the failure of just one bulb (an open circuit) causes the entire string to go off.
- (c) If each bulb has a resistance of 14Ω when lit, calculate the total resistance of the string and the current flowing through it when connected to 240 V.
- (d) The trader is considering importing strings with bulbs connected in parallel for the next season. Explain two major advantages and one potential disadvantage of parallel-connected decorative lights compared to series-connected ones.
- (e) If the string were made with 40 identical LEDs instead of incandescent bulbs, each with a forward voltage drop of 3.0 V and a series resistor to limit current, explain how the circuit design would differ and why a simple series connection without resistors would not work for LEDs.

Question 6:

A dairy farmer in the rolling hills of Mbarara is installing an electric fence to protect his improved pasture from stray cattle and wild animals. The fence energiser unit produces a

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

high-voltage pulse of approximately 5000 V but with a very limited current output (less than 5 mA). The fence wire is made of galvanised steel and runs for a total distance of 2 kilometres around the perimeter. The wire has a resistance of 0.025Ω per metre. The farmer's son, a physics student on holiday, explains that the high voltage provides a deterrent shock, while the low current ensures the shock is non-lethal.

- (a) Calculate the total electrical resistance of the 2 km fence wire loop.
- (b) If the energiser delivers a 5000 V pulse across this wire, what is the theoretical peak current? Explain why this current is not lethal to a human or animal despite the extremely high voltage.
- (c) The farmer notices that when tall, wet grass grows up and touches the bottom strand of the fence wire, the fence becomes noticeably less effective at deterring animals. Using the concept of parallel resistances and a potential divider, explain why the voltage on the fence drops significantly when vegetation provides a leakage path to the ground.
- (d) Calculate the instantaneous power dissipated in the fence wire during the brief pulse. Explain why the wire does not heat up significantly or melt, despite this seemingly high power calculation.
- (e) Suggest one simple maintenance practice the farmer should follow to ensure the electric fence remains effective throughout the rainy season.

Question 7:

A university student residing in a private hostel in Wandegeya uses a 2.0 kW, 240 V immersion heater to boil water for her daily bath. One evening, she notices that the water is taking much longer than usual to reach the desired temperature. She suspects that either the mains voltage has dropped due to high demand in the neighbourhood, or the heating element itself has partially burnt out and changed its resistance. She recalls from her A-Level physics class that power depends on both voltage and resistance.

- (a) Calculate the normal resistance of the heating element when it is operating correctly at its rated power and voltage. Also, calculate the current it draws under these conditions.
- (b) If the mains voltage drops to 215 V during the evening peak hours, calculate the new power output of the heater, assuming the resistance of the element remains constant at the value calculated in (a).
- (c) Suppose instead that the heating element has partially corroded, causing its resistance to increase by 25% from its original value. Calculate the new power output of the heater when connected to the full 240 V supply.
- (d) The student needs to heat 18 litres of water from 22°C to 85°C . Calculate the time it would take with the normal heater and the time it would take with the faulty increased-

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

resistance heater. (Assume no heat losses to the surroundings and specific heat capacity of water = $4200 \text{ J kg}^{-1} \text{ K}^{-1}$).

(e) Explain why a heater with a higher resistance actually produces less heat when connected to a constant voltage supply, even though one might intuitively think higher resistance means more "friction" and thus more heat.

Question 8:

A mechanic in the bustling Katwe automotive repair zone is diagnosing a car that has become increasingly difficult to start, especially on cold mornings. The car battery is clearly labelled "12 V, 60 Ah." The starter motor, which cranks the engine, has a very low resistance of only 0.045Ω . When the ignition key is turned to the "start" position, the motor draws an enormous current momentarily. The mechanic uses a voltmeter and observes that the battery terminal voltage drops dramatically to just 9.0 V during the cranking attempt.

(a) Explain the meaning of the "60 Ah" (ampere-hour) rating on the battery. If the starter motor draws an average current of 160 A , calculate the theoretical maximum time (in minutes) the battery could sustain this cranking before being completely discharged.

(b) Calculate the current that the starter motor would theoretically draw if it were connected directly to a perfect 12 V battery with zero internal resistance.

(c) Using the observed voltage drop to 9.0 V and assuming the starter motor's resistance is 0.045Ω , calculate the actual current flowing during cranking and use this to determine the internal resistance of the ageing car battery.

(d) Explain in detail, using the equation $V = E - Ir$, why the battery terminal voltage drops so significantly when the heavy load of the starter motor is applied. Why is this voltage drop problem worse on a cold morning?

(e) The mechanic considers using thicker, shorter jumper cables to connect a booster battery. Explain how this helps, in terms of reducing resistance in the external circuit.

Question 9:

A climate research station located on the slopes of Mt. Elgon uses sensitive thermocouples to monitor soil and air temperatures at various depths and altitudes. The thermocouples generate a very small electromotive force (e.m.f) in the millivolt range. To measure this tiny e.m.f accurately without drawing any current from the thermocouple, the researchers use a laboratory potentiometer. The potentiometer has a driver cell of 2.0 V , a slide wire of length 1.0 m and resistance 12Ω , and a sensitive galvanometer. A standard Weston cell of precisely known e.m.f 1.018 V is used for calibration.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (a) Draw a clearly labelled circuit diagram showing how the standard cell and the thermocouple are connected to the potentiometer for this measurement. Explain the function of the rheostat in series with the driver cell.
- (b) During calibration, the standard cell of 1.018 V is balanced by a length of 76.5 cm on the slide wire. Calculate the potential difference (p.d) per centimetre of the slide wire.
- (c) When the thermocouple is connected, it is balanced by a length of 41.2 cm on the slide wire. Calculate the e.m.f generated by the thermocouple.
- (d) Explain two fundamental advantages of using a potentiometer to measure the thermocouple e.m.f rather than using a standard digital voltmeter.
- (e) Why is it necessary to use a standard cell for calibration each time the potentiometer is used, rather than relying on the marked value of the driver cell's e.m.f?

Question 10:

A family in a modern housing estate in Naalya is experiencing frequent tripping of the circuit breaker protecting the ring main circuit in their kitchen. The circuit is protected by a 30 A fuse or miniature circuit breaker (MCB). The following appliances are plugged into this single circuit: a refrigerator (rated 200 W), a microwave oven (1300 W), an electric kettle (2200 W), a toaster (900 W), and a television (150 W). The mains voltage is 240 V. One busy morning, when the kettle, toaster, and microwave are used simultaneously to prepare breakfast, the circuit breaker trips, plunging the kitchen into darkness.

- (a) Calculate the normal operating current drawn by each of the five appliances individually when they are switched on.
- (b) Determine the total current drawn when the kettle, toaster, and microwave are all operating at the same time, along with the refrigerator (which cycles on) and the television. Explain clearly why this total current exceeds the 30 A rating of the circuit breaker.
- (c) Suggest two practical and safe methods the family could adopt to avoid overloading the kitchen circuit without requiring expensive rewiring or upgrading of the main electrical panel.
- (d) Explain the physical mechanism by which a fuse protects the wiring in the wall from overheating and potentially causing a fire. Why is it dangerous to replace a 30 A fuse with a higher-rated one, such as a 60 A fuse?
- (e) Explain why high-power appliances like electric cookers and water heaters are typically placed on their own dedicated radial circuits with heavier-gauge wiring, rather than being plugged into the general ring main.

Question 11:

By kasumba Najjib
Email: najjibkasumba@gmail.com

Best of the best

An experienced electrician in Lugogo is explaining to his young apprentice why the cable supplying a large 8 kW electric cooker is so much thicker than the cable supplying a simple 60 W light bulb. He mentions the concept of "drift velocity" of electrons and how it relates to heating. They examine a copper cable of cross-sectional area 4.0 mm^2 that supplies a current of 34 A to the cooker. The number of free electrons per cubic metre in copper is approximately $8.5 \times 10^{28} \text{ m}^{-3}$.

- (a) Define the term "current density" and calculate its value (in A m^{-2}) for this cooker cable.
- (b) Calculate the mean drift velocity of the free electrons within the copper wire.
- (c) The apprentice is puzzled: if the electrons move so slowly (a fraction of a millimetre per second), why does the cooker heat up almost instantly when the switch is turned on? Explain this apparent paradox clearly.
- (d) If the 34 A current were instead forced through a much thinner wire of cross-sectional area 1.0 mm^2 , how would the drift velocity change? Explain why using a thinner wire for the cooker would be extremely dangerous, relating your answer to heating power (I^2R) and the increased resistance.
- (e) Explain why the resistance of a metallic conductor increases with temperature, while the resistance of a semiconductor (like the thermistor in the cooker's temperature sensor) decreases with temperature.

Question 12:

A Village Health Team (VHT) worker in a remote part of Apac district relies on a portable radio powered by four 1.5 V zinc-carbon dry cells connected in series to receive health education broadcasts. The radio has an effective resistance of 18Ω when operating at normal volume. After several weeks of daily use, the worker notices that even with brand new batteries installed, the radio's volume is very low and the batteries themselves feel unusually warm to the touch after only a short period of use. His son, a Senior Four physics student, correctly suspects that the cells have developed a high internal resistance due to ageing and chemical depletion.

- (a) Assuming fresh cells with negligible internal resistance, calculate the total e.m.f of the four-cell battery and the current that would be supplied to the 18Ω radio.
- (b) Each aged cell has now developed an internal resistance of 4.5Ω . Calculate the new total circuit resistance, the new current supplied to the radio, and the terminal voltage across the four-cell battery when the radio is switched on.
- (c) Explain, using the power formula $P = I^2r$, why the batteries themselves feel warm during use. Also, explain why the reduced terminal voltage results in a much lower volume from the radio.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(d) The student suggests connecting two sets of four cells in parallel (each set consisting of four cells in series). Draw the circuit diagram for this arrangement and calculate the new total e.m.f, total internal resistance, and the current delivered to the radio. Explain whether this arrangement successfully restores the radio's performance.

(e) Explain why a lead-acid car battery can deliver hundreds of amperes to a starter motor despite having a similar e.m.f (12 V) to a series string of eight 1.5 V dry cells, which cannot deliver such a high current.

Question 13:

A technician at a motor rewinding workshop in the Ntinda industrial area is carefully rewinding the stator of a burnt-out single-phase induction motor. To ensure the motor will operate safely and not overheat, he needs to estimate the temperature the copper windings will reach under full load. He measures the resistance of the newly wound coil at room temperature (27°C) and records a value of 3.20 Ω. After running the motor at full load for one hour, he quickly disconnects the power and measures the hot resistance, which is now 3.95 Ω. The temperature coefficient of resistance for copper at 20°C is $3.9 \times 10^{-3} \text{ K}^{-1}$.

(a) Using the given temperature coefficient, first calculate the resistance of the coil at the reference temperature of 0°C.

(b) Determine the operating temperature of the hot motor windings using the resistance measurements.

(c) Provide a detailed microscopic explanation for why the electrical resistance of the copper wire increases with temperature. Your answer should refer to the vibration of copper ions in the lattice and the motion of free electrons.

(d) If this motor draws a current of 5.5 A from a 240 V supply when running hot, calculate the back e.m.f generated by the motor at this operating condition.

(e) Explain why electric motors typically draw a "starting current" that is 5 to 7 times higher than their normal full-load running current. Why is this high inrush current potentially damaging to the windings if the motor is started and stopped frequently?

Question 14:

A small-scale maize mill operator in a trading centre near Iganga has his mill located approximately 250 metres away from the main road where the UMEME distribution transformer is mounted. The mill is powered by a 7.5 kW, 240 V single-phase induction motor. The power is supplied through aluminium overhead service cables. The total loop resistance (both the live and neutral conductors) of the 250 m cable run is 0.18 Ω per 100 m. The mill operator complains bitterly that whenever he starts the mill under heavy load, the

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

lights in his nearby house and in the neighbouring shop dim noticeably, and the motor struggles to reach full speed.

- (a) Calculate the total loop resistance of the 250 m aluminium service cable.
- (b) Determine the normal full-load current drawn by the 7.5 kW motor when it is operating at its rated voltage of 240 V. Assume the motor has a power factor of 0.85.
- (c) Calculate the voltage drop that occurs along the supply cable when this full-load current flows through it. Determine the actual voltage that reaches the motor terminals at the mill.
- (d) Explain clearly why the house lights dim when the large mill motor is started. Your answer should refer to the high starting current and the consequent voltage drop along the common service cable.
- (e) Suggest two practical and cost-effective solutions the mill operator could implement to reduce the severity of the voltage drop and improve the motor's starting performance without moving the mill closer to the transformer.

Question 15:

A student in an electronics hobby club at a secondary school in Nsambya is building a simple audio amplifier circuit using a bipolar junction transistor (BJT). The transistor requires a precise DC bias voltage of exactly 1.8 V at its base terminal to operate in its linear amplification region. The power source available is a 9 V battery. The student decides to use a simple resistive potential divider (voltage divider) consisting of two resistors, R_1 and R_2 , connected across the 9 V supply, with the base voltage taken from the junction between R_1 and R_2 .

- (a) Draw a fully labelled circuit diagram of the potential divider, showing the 9 V battery, resistors R_1 and R_2 , and the point where the 1.8 V output is taken relative to the negative battery terminal.
- (b) The student chooses a value of 2.2 k Ω for R_2 . Calculate the precise value of R_1 required to produce an open-circuit output voltage of exactly 1.8 V at the junction.
- (c) When the student connects the transistor's base terminal (which draws a small base current and effectively acts like a load resistance of approximately 15 k Ω in parallel with R_2), the measured voltage drops significantly below 1.8 V. Explain why this "loading effect" occurs, and calculate the new output voltage with the transistor connected.
- (d) To mitigate the loading effect, the student considers using a voltage divider with much lower resistance values (e.g., $R_1 = 220 \Omega$ and $R_2 = 68 \Omega$). Explain why this improves voltage stability, but state the significant disadvantage of this approach in a battery-powered circuit.
- (e) Suggest a more sophisticated solid-state component (other than a simple resistor divider) that could be used to provide a stable 1.8 V reference voltage regardless of the load current drawn, and briefly explain its operating principle.

By kasumba Najjib

Email: najjibkasumba@gmail.com

OPTICS

Question 16:

Mr. Ssemakula, a renowned barber operating a busy salon along William Street in Kampala, has been receiving complaints from his customers that they cannot properly see the back of their heads after he has given them a fresh haircut. His salon is approximately 3.5 metres long, and the customer's chair is positioned exactly 1.5 metres away from a large plane mirror mounted on the front wall. A second plane mirror hangs on the back wall directly behind the customer. Mr. Ssemakula vaguely remembers something from his secondary school physics about multiple reflections but cannot recall the details. He is particularly puzzled because when he uses a thick glass mirror that was donated by a relative, customers report seeing multiple faint images of themselves, which sometimes makes them dizzy. He has called upon you, a bright physics student who happens to be his nephew, to explain the science behind his mirror troubles.

- (a) Using a clear ray diagram, demonstrate to Mr. Ssemakula how a customer sitting between the two plane mirrors can see the back of their own head. Show the path of light rays from the back of the head to the customer's eyes.
- (b) State and explain four distinct properties of the image that the customer sees in the front plane mirror when looking at their own face.
- (c) With reference to partial reflection and transmission at glass surfaces, explain why the thick glass mirror produces multiple faint images. Why are the later images fainter than the first one?
- (d) Mr. Ssemakula has heard that expensive optical instruments like submarine periscopes use reflecting prisms instead of mirrors. Give him three convincing reasons why a high-end salon might consider using front-surface reflecting prisms rather than ordinary silvered plane mirrors.

Question 17

Madam Nambi owns a popular tailoring shop in Jinja town where she designs and sews custom-made gomesi and suits for weddings. She has recently renovated her fitting room and installed a vertical plane mirror on the wall. A bride-to-be who is exactly 1.82 metres tall (with her high heels on) comes for a final fitting. Her eye level is 1.74 metres above the floor. Madam Nambi wants to ensure that the mirror is positioned correctly so that the bride can see her entire elegant outfit from head to toe without having to step back too far, as the fitting room is quite narrow.

- (a) With the aid of a clear ray diagram drawn from the top of the bride's head and from her toes, show mathematically that the minimum vertical length of the plane mirror required for her to see her whole body is exactly half of her height.

Best of the best

- (b) Using the given measurements, calculate the precise minimum length of the mirror required and determine the exact height above the floor at which the bottom edge of the mirror must be placed.
- (c) If Madam Nambi, in a hurry, mounts the mirror 10 centimetres lower than the calculated position, explain which part of her body the bride will no longer be able to see in the mirror.
- (d) The bride asks whether stepping further back from the mirror would allow her to see more of herself. Explain to her whether the minimum required mirror length changes with her distance from the mirror, and why.

Question 18:

A team of surveyors from the Ministry of Lands and Urban Development is conducting a bathymetric survey of Lake Victoria near the Ssesse Islands. To accurately determine their vessel's latitude, they employ a traditional navigational instrument known as a sextant to measure the angle of elevation of the midday sun above the visible horizon. One of the younger surveyors, fresh from university, is curious about how this purely mechanical optical device can provide such precise angular measurements without any electronics. The senior surveyor explains that it relies on the principle of deviation of light by rotating a plane mirror.

- (a) Draw a fully labelled diagram illustrating the optical arrangement within a sextant, clearly showing the horizon glass (half-silvered fixed mirror) and the index mirror (rotatable mirror), as well as the path of light rays from both the horizon and the celestial body (the sun).
- (b) Derive, using geometric optics, the relationship that when a plane mirror is rotated through an angle α , the reflected ray is deviated through an angle of exactly 2α . Explain how this principle is fundamental to the sextant's operation.
- (c) During a measurement, the senior surveyor carefully rotates the index mirror until the image of the sun appears exactly to "kiss" the horizon line. The vernier scale on the sextant indicates that the index mirror was rotated through an angle of 34.5° . What is the angular elevation of the sun above the horizon?
- (d) State two distinct advantages of using a sextant over a simple protractor and plumb line for celestial navigation, particularly on a moving vessel.

Question 19:

Dr. Nakato, a dental surgeon at Mulago National Referral Hospital, uses a small, highly polished concave mirror attached to a slender handle to examine the deep crevices and cavities in her patients' molars. She explains to her intern that the mirror has a focal length of 4.0 cm. For a particular patient with a painful cavity, she positions the mirror approximately 2.8 cm away from the affected tooth to get a good view.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (a) Construct an accurate ray diagram (using at least two principal rays) to show how the image of the tooth is formed by the concave mirror. Clearly label the pole (P), principal focus (F), and centre of curvature (C). Indicate the position of the object relative to F and P.
- (b) Using the mirror formula, calculate the precise image distance and the linear magnification produced by the mirror for this object distance.
- (c) State three key characteristics (location, orientation, size, nature) of the image that Dr. Nakato observes.
- (d) Provide two detailed reasons why a concave mirror is vastly superior to a plane mirror for this specific dental application.
- (e) Later, Dr. Nakato uses the same mirror to get a wider view of the patient's entire dental arch. She moves the mirror to a distance of 9.0 cm from the teeth. Calculate the new image position and fully describe its nature. Why is this position not suitable for detailed cavity inspection?

Question 20:

The management of a newly opened Mega Standard Supermarket in Naalya housing estate is concerned about shoplifting in the tall aisles stacked with expensive imported goods. To assist the security personnel monitoring the CCTV feeds, they have installed large, conspicuous convex mirrors at the junction of each aisle. The mirrors have a radius of curvature of 2.4 metres. A security guard notices a suspicious-looking customer standing approximately 6.0 metres away from one such mirror.

- (a) Draw a ray diagram to show how the convex mirror forms an image of the customer. Use at least two principal rays.
- (b) Calculate the focal length of the convex mirror. Using the mirror formula, determine the exact position (distance from the mirror) of the customer's image.
- (c) State three inherent characteristics of the image formed by the convex mirror.
- (d) Explain in detail two significant advantages that convex mirrors offer over plane mirrors for this specific surveillance task.
- (e) Despite its advantages, convex mirrors have one major drawback that can mislead security staff. State this disadvantage and explain why the warning "Objects in mirror are closer than they appear" is often etched onto such mirrors in vehicles.

Question 21

The Parent-Teacher Association of a rural primary school in Soroti district has embarked on an ambitious project to build a low-cost solar cooker to prepare mid-day porridge for the pupils, thereby reducing the reliance on firewood. They have acquired a large, discarded

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

metallic satellite dish and plan to polish its inner surface to a mirror finish, effectively creating a concave mirror of wide aperture. The radius of curvature of the dish is measured to be 1.8 metres.

- (a) Explain the physics principle that makes a concave mirror ideal for concentrating solar radiation. Where exactly should the cooking pot be positioned relative to the mirror for maximum heating effect? Calculate this distance.
- (b) After polishing, the teachers notice that when sunlight falls on the entire dish, the reflected rays do not all converge to a single sharp point; instead, they form a bright, elongated envelope of light. What is this optical defect called? Explain why it occurs, distinguishing between paraxial and marginal rays.
- (c) Suggest a more suitable geometric shape for the mirror surface that would completely eliminate this defect. Name one practical, large-scale engineering application where such mirrors are employed.
- (d) The dish has a diameter of 1.6 metres. Calculate its surface area. Assuming the solar irradiance (power per unit area) on a clear day in Soroti is approximately 850 W m^{-2} , estimate the theoretical maximum power that could be concentrated onto the cooking pot, assuming the mirror reflects 90% of the incident light.

Question 22:

Mr. Okello, a boda boda rider operating in the congested streets of Kampala's old taxi park, relies heavily on his motorcycle's right-hand wing mirror to navigate through heavy traffic. The mirror is a convex mirror with a radius of curvature of 1.8 metres. One afternoon, a heavily loaded taxi follows him at a distance of about 18 metres. Mr. Okello glances at his mirror and sees the taxi appearing surprisingly small and distant.

- (a) Calculate the focal length of the convex wing mirror.
- (b) Using the appropriate mirror formula, calculate the exact image distance of the taxi and the linear magnification produced.
- (c) The mirror has a printed warning: "OBJECTS IN MIRROR ARE CLOSER THAN THEY APPEAR." Using your calculated magnification from (b), explain the optical justification for this warning and why it is a critical safety message for riders like Mr. Okello.
- (d) Construct a ray diagram showing how the image of the distant taxi is formed by the convex mirror.
- (e) If Mr. Okello replaced his convex mirror with a plane mirror of identical diameter, what significant disadvantage would he experience when trying to assess traffic behind him?

Question 23:

Best of the best

A university student residing in Lumumba Hall at Makerere University is preparing for his graduation ceremony. He uses a small concave shaving mirror that he inherited from his grandfather. The mirror has a stated focal length of 15 cm. To see the fine details of his beard, he brings his face quite close to the mirror, positioning his chin about 9 cm from the mirror's surface.

- (a) Using the mirror formula, determine the precise position of the image of his face and calculate the magnification achieved.
- (b) Fully describe the nature (real or virtual, erect or inverted, magnified or diminished) of the image he observes.
- (c) Derive, from the fundamental mirror formula, the relationship that connects linear magnification m to the image distance v and focal length f , i.e., $m = (v/f) - 1$.
- (d) The student desires an image that is magnified four times ($4x$). At exactly what distance (or distances) from the mirror could he position his face to achieve this? Calculate both possibilities and explain which of these positions is the practical one for shaving and why the other is not.
- (e) Provide a concise physical explanation for why a concave mirror is functionally superior to a plane mirror for the specific task of shaving or applying makeup.

Question 24:

The management of Mandela National Stadium, Namboole, is preparing for a major international night football match. They are testing their powerful searchlights which are used to illuminate the pitch and for ceremonial light beams. The chief electrician explains to a visiting engineering student that the searchlights do not use ordinary concave mirrors but rather precisely engineered parabolic mirrors. The lamp, a high-intensity arc source, is placed exactly at the principal focus of the parabolic mirror.

- (a) With the aid of a clear diagram, explain why a lamp placed at the focus of a wide concave spherical mirror does not produce a perfectly parallel reflected beam. Show the path of both paraxial rays and marginal rays.
- (b) Describe the shape of the caustic surface formed in the case of the spherical concave mirror.
- (c) Explain why a parabolic mirror is specifically chosen for searchlight applications. What advantage does it offer over a spherical concave mirror in terms of the reflected beam's characteristics and intensity over long distances?
- (d) If the parabolic mirror has a focal length of 80 cm, and the arc lamp is inadvertently placed 78 cm from the mirror's vertex, will the reflected beam be perfectly parallel? Explain what will happen to the reflected rays.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(e) State one other significant application where parabolic mirrors are preferred over spherical concave mirrors for reflecting electromagnetic waves.

Question 25:

At a village primary school in Mpigi, pupils are performing a simple but fascinating experiment during their science lesson. They place a 50-cent coin at the bottom of an empty opaque plastic basin. One pupil steps back until the coin just disappears from view behind the rim of the basin. Another pupil then slowly pours clean water from a jerrycan into the basin. To the amazement of the watching children, the coin miraculously "rises" and becomes visible again, even though no one moved the basin or the coin.

(a) Explain, using a clearly labelled ray diagram, why the coin becomes visible when water is added. Account for the bending of light rays at the water-air interface.

(b) Define the term "refractive index" of water. If the actual depth of the coin is 12 cm and the water's refractive index is 1.33, calculate the apparent depth of the coin as seen from directly above.

(c) Calculate the apparent upward displacement of the coin.

(d) If the water were replaced by glycerine, which has a higher refractive index of 1.47, would the coin appear shallower or deeper than it did in water? Explain your reasoning without performing a full calculation.

(e) Explain why a straight stick appears bent and shortened when partially immersed obliquely in the water trough. Support your explanation with a ray diagram.

Question 26:

A family is visiting the Entebbe Botanical Gardens and stops by the large ornamental fish pond. A young boy is fascinated by the colourful koi carp swimming gracefully below the surface. He tries to touch one of the fish by dipping his hand into the water, but he consistently misses, his hand passing well above the actual fish. His older sister, a secondary school student, laughs and explains that the fish is actually deeper than it appears. The water in the pond is clear, and the refractive index of water is 1.33.

(a) Using the principle of refraction and a ray diagram showing light rays travelling from the fish to the boy's eyes, explain why the fish appears to be at a shallower depth than its true position.

(b) Derive the general relationship between real depth, apparent depth, and refractive index: $n = \frac{\text{real depth}}{\text{apparent depth}}$.

(c) If one particular koi carp is swimming at an actual depth of 80 cm below the water surface, calculate its apparent depth as viewed vertically from above by the boy.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(d) The boy also notices that the koi carp appears noticeably larger (magnified) when viewed from above than when he sees it after it is caught in a net out of water. Explain this phenomenon, referring to the water surface acting as a lens.

(e) A watchman standing on the opposite bank observes the boy. Explain, with a ray diagram, why the bottom of the pond appears curved and shallower near the edges than at the centre from his oblique viewpoint.

Question 27:

A curio shop in Kampala sells decorative glass prisms that sparkle brilliantly in sunlight. A tourist purchases an equilateral triangular glass prism with a refractive index of 1.52. Curious about how it works, she shines a narrow laser beam (monochromatic light) onto one face of the prism at an angle of incidence of 50° . She observes that the beam emerges from a different face, having been deviated significantly.

(a) Draw a clear ray diagram showing the path of the laser beam as it enters and emerges from the prism. Label the angles of incidence, refraction, emergence, and deviation.

(b) Using Snell's law, calculate the angle of refraction at the first face, and subsequently determine the angle of incidence at the second face.

(c) Calculate the angle of emergence from the second face.

(d) Determine the total angle of deviation produced by the prism for this ray.

(e) The tourist then rotates the prism slowly. At a certain angle of incidence on the second internal face, the laser beam suddenly stops emerging and is instead reflected back into the glass. Explain what phenomenon has occurred. Calculate the critical angle for this glass-air interface. What condition must be met for this to happen?

Question 28:

A team of technicians from a local internet service provider is installing fibre optic cables in a new housing estate in Najjera to provide high-speed broadband to homes. The cable contains a core of ultra-pure glass with a refractive index of 1.62, surrounded by a cladding material with a slightly lower refractive index of 1.48. The team leader explains to a curious resident that the light signals carrying data travel through the core by bouncing off the core-cladding boundary without escaping, a process called total internal reflection.

(a) With the aid of a labelled diagram showing the cross-section of the optical fibre, explain how light propagates along the fibre via total internal reflection.

(b) State the two essential conditions that must be satisfied for total internal reflection to occur at the core-cladding interface.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (c) Calculate the critical angle for the boundary between the core glass and the cladding material.
- (d) The fibre is designed to accept light entering from air ($n = 1.00$) at one end. Derive an expression for the maximum angle of incidence (acceptance angle) θ in air for which light will be totally internally reflected within the core. Show that $\sin \theta = \sqrt{(n_1^2 - n_2^2)}$, where n_1 is the core index and n_2 is the cladding index.
- (e) Calculate the acceptance angle for this particular fibre.

Question 29:

During a scorching hot afternoon, a bus driver travelling on the long, straight Gulu-Kampala highway notices what appears to be a shimmering pool of water on the tarmac road surface far ahead. As he approaches, the "water" always seems to recede and eventually vanishes, leaving only dry, hot asphalt. An elderly passenger, a retired physics teacher, smiles and explains that this optical illusion is called a mirage.

- (a) Explain, step by step, the formation of a mirage on a hot road surface. Refer specifically to the variation in air density and refractive index of the air layers immediately above the road.
- (b) Draw a clear ray diagram showing the path of light rays from the blue sky as they are curved by the hot air layers to enter the driver's eyes, creating the illusion of water.
- (c) What is the role of total internal reflection in the formation of this mirage?
- (d) Would a mirage be more pronounced on a very hot day or a cool, cloudy day? Justify your answer based on the physics principles involved.
- (e) Name another natural phenomenon that relies on the same principle of total internal reflection and refraction of light through varying density layers.

Question 30:

Students at Nabisunsa Girls' Secondary School are performing a classic experiment in their physics laboratory. They have set up a white light source, a collimator, a glass prism of refracting angle 60° , and a white screen. When the narrow beam of white light passes through the prism, it fans out into a beautiful continuous spectrum of colours on the screen, ranging from red to violet. The teacher, Mrs. Kintu, asks them to explain what they observe and to compare it with what they would see using a diffraction grating.

- (a) Explain why the prism disperses white light into its constituent colours. Which colour is deviated the most, and which is deviated the least? Relate this to the variation of refractive index with wavelength.

Best of the best

- (b) The prism has a refractive index of 1.515 for red light and 1.529 for violet light. For a ray of white light incident at an angle of 45° on one face, calculate the angle of emergence for the red light. (Show all working steps).
- (c) Using the same data, calculate the angle of emergence for the violet light.
- (d) Hence, determine the angular width of the visible spectrum produced by the prism.
- (e) Explain why the spectrum produced by a prism is said to be "impure" compared to that produced by a high-quality diffraction grating. What is the key difference in how they separate colours?

Question 31:

A group of tourists visiting the magnificent Sipi Falls in Kapchorwa on a sunny morning are treated to a spectacular rainbow arching across the misty spray at the base of the falls. A young guide, who recently completed his A-Levels, confidently explains the physics behind the beautiful arcs of colour. He describes how sunlight interacts with the countless spherical water droplets in the mist.

- (a) With the aid of a clear, labelled diagram of a spherical water droplet, trace the path of a ray of sunlight that contributes to the formation of a primary rainbow. Show the refraction upon entry, the single internal reflection, and the refraction upon exit.
- (b) Explain why the primary rainbow displays the colour red on the outer edge of the bow and violet on the inner edge.
- (c) The guide mentions that sometimes a fainter, secondary rainbow can be seen above the primary one, with the colours reversed. Explain the optical difference in the path of light rays inside the water droplets that produces the secondary rainbow.
- (d) Why is the sky inside the primary bow noticeably brighter than the sky outside the bow? (Hint: Consider the concentration of scattered light).
- (e) Calculate the angle of minimum deviation for red light ($n = 1.331$) in a water droplet, assuming the droplet acts like a prism of varying angle. (For a spherical droplet, the angle of minimum deviation for the primary bow is about 138° from the anti-solar point; calculate the corresponding angle for refraction and incidence if needed, but focus on explaining the concept).

Question 32:

A laboratory technician in the Physics Department at Makerere University is tasked with calibrating a student spectrometer before a practical examination. The instrument consists of a collimator, a prism table, and a telescope. The technician must first measure the refracting angle A of a 60° glass prism provided.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (a) Describe, in a sequential and detailed manner, the initial adjustments that must be made to the spectrometer before it is ready for use. Explain the purpose of each adjustment.
- (b) Explain the procedure for measuring the refracting angle A of the prism using the spectrometer. Include a diagram showing the position of the prism relative to the collimator and the two positions of the telescope. Show that the angle of the prism A is equal to half the angle through which the telescope is rotated between the two reflected images of the slit.
- (c) After measuring A , the technician then determines the angle of minimum deviation D for a specific wavelength of light. Describe the method for locating the position of minimum deviation accurately.
- (d) Derive the formula that relates the refractive index n of the prism material to the refracting angle A and the angle of minimum deviation D : $n = \sin((A+D)/2) / \sin(A/2)$.
- (e) If the technician finds $D = 48.2^\circ$ for a particular spectral line using a prism with $A = 60^\circ$, calculate the refractive index of the glass for that wavelength.

Question 33:

Mzee Kasule, a 72-year-old respected elder in a village near Mityana, has been finding it increasingly difficult to read his daily newspaper, the Bukedde. He has to hold the paper at arm's length to see the small print clearly. His grandson, a physics student on holiday, correctly diagnoses that Mzee Kasule is suffering from presbyopia (long-sightedness) and needs a pair of reading glasses with converging lenses. The grandson wants to determine the appropriate power of lens needed so that Mzee Kasule can comfortably read at a distance of 25 cm, which is the normal near point.

- (a) Explain, using ray diagrams, the eye defect known as long-sightedness (hypermetropia). Why is the image of a near object formed behind the retina in such an eye?
- (b) How does a converging lens correct this defect? Draw a ray diagram showing how the lens forms a virtual image of an object placed at 25 cm, which then acts as an object for the eye at the person's actual near point.
- (c) If Mzee Kasule's uncorrected near point is 80 cm, determine the focal length of the converging lens required to allow him to read clearly at 25 cm. (Use the lens formula with the object distance $u = 25$ cm and the image distance $v = -80$ cm).
- (d) Calculate the power of this lens in dioptries (D).
- (e) Explain why a person with short-sightedness (myopia) requires a diverging (concave) lens for correction, whereas Mzee Kasule requires a converging lens.

Question 34:

Best of the best

The entertainment prefect at St. Mary's College Kisubi is setting up the school's LCD projector to show a movie to the boarding students on a large white screen in the main hall. The projector uses a powerful projection (convex) lens of focal length 10 cm to throw a greatly magnified image of the small LCD panel (the object) onto the screen, which is 5.0 metres away from the lens. He needs to focus the image sharply and ensure it fills the screen appropriately.

- (a) Using the thin lens formula, calculate the exact distance from the projection lens to the LCD panel (the object distance u) required to produce a sharply focused image on the screen 5.0 m away.
- (b) Calculate the linear magnification produced by the projector in this setup.
- (c) The LCD panel has dimensions of 18 mm by 14 mm. Determine the dimensions of the projected image on the screen in metres. Will it fit on a screen that is 1.5 m wide and 1.2 m high?
- (d) The prefect notices that the projected image is inverted (upside down). Explain why this occurs for a real image formed by a convex lens, and describe the simple physical adjustment he must make to the LCD panel to ensure the movie appears upright to the audience.
- (e) Derive the expression relating magnification m to the image distance v and focal length f : $m = (v/f) - 1$. Use this to verify your calculated magnification in part (b).

Question 35:

Students at Gayaza High School are using a compound microscope in their biology practical to observe the cellular structure of an onion epidermis. The microscope has an objective lens of focal length 1.6 cm and an eyepiece lens of focal length 5.0 cm. The distance between the objective and the eyepiece is fixed at 22 cm for this particular model. The students adjust the focus by moving the entire body tube closer to or further from the specimen slide.

- (a) Draw a labelled ray diagram showing the formation of the final virtual image by a compound microscope in normal adjustment (final image at the near point). Clearly indicate the objective, eyepiece, intermediate real image, and final virtual image.
- (b) For the microscope to be in normal adjustment, the final image should be formed at a distance of 25 cm from the eyepiece. Determine the object distance (the distance from the specimen to the objective lens) required for this condition. (Hint: First find the image distance for the eyepiece, then use that as the object distance for the objective's image).
- (c) Calculate the magnifying power (angular magnification) of this microscope when used in normal adjustment. Use the formula $M = (v_o/f_o - 1) \times (D/f_e - 1)$, where $D = 25$ cm.
- (d) Explain why both the objective and the eyepiece of a compound microscope have very short focal lengths.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(e) If the students use a blue filter instead of a red filter over the light source, will the resolving power of the microscope increase, decrease, or remain the same? Explain your answer.

Question 36

An amateur astronomy club at a secondary school in Nsambya has constructed a simple refracting astronomical telescope using two converging lenses. The objective lens has a focal length of 100 cm and a diameter of 10 cm. The eyepiece has a focal length of 5 cm. The students are excited to observe the craters on the moon and the Galilean moons of Jupiter.

(a) Draw a fully labelled ray diagram showing the action of an astronomical telescope in normal adjustment (final image at infinity). Show the path of light rays from a distant object through the objective and eyepiece.

(b) Determine the magnifying power (angular magnification) of this telescope when it is in normal adjustment. Also, calculate the separation between the objective and eyepiece lenses in this setting.

(c) The students decide to adjust the telescope so that the final image is formed at their near point of 25 cm, allowing them to see the image with maximum detail. Determine the new separation required between the lenses for this condition.

(d) Calculate the position and diameter of the exit pupil (eye ring) for this telescope when in normal adjustment. Why is it important for the observer to place their eye exactly at the eye ring?

(e) State two distinct disadvantages of using an astronomical telescope for terrestrial viewing (e.g., bird watching) and explain how a terrestrial telescope (using an erecting lens or prism) overcomes these disadvantages.

Question 37:

During a performance of a play at the Uganda National Cultural Centre (National Theatre), a patron in the back row uses a small pair of opera glasses to get a closer view of the actors' facial expressions. The opera glasses are, in essence, a Galilean telescope consisting of a converging objective lens of focal length +30 cm and a diverging eyepiece lens of focal length -5 cm.

(a) Draw a ray diagram showing the action of a Galilean telescope in normal adjustment (final image at infinity). Clearly show how the diverging eyepiece intercepts the converging rays from the objective before they form a real image, resulting in an erect final virtual image.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(b) Calculate the magnifying power (angular magnification) of these opera glasses when used in normal adjustment. Also, determine the physical length of the instrument (the separation between the objective and eyepiece lenses).

(c) Compare this Galilean telescope with a standard astronomical telescope of the same magnifying power (using a +5 cm eyepiece). State two distinct advantages of the Galilean design for terrestrial use and one significant disadvantage.

(d) If the patron adjusts the opera glasses so that the final virtual image is formed at her near point of 25 cm, explain whether the length of the instrument needs to be increased or decreased, and why.

(e) Explain why the Galilean telescope has a much smaller field of view compared to an astronomical telescope, and why it lacks an accessible exit pupil (eye ring).

Question 38:

A professional wedding photographer in Kampala is using a high-end DSLR camera with a large-aperture $f/1.4$ lens. While reviewing his photos on a large monitor, he notices that in areas of high contrast, there are faint coloured fringes—purple and green—around the edges of objects. He consults a camera technician who explains that this is due to chromatic aberration in the lens, a defect that is more pronounced in lenses with large apertures.

(a) Explain the origin of chromatic aberration in a simple converging lens. Use a ray diagram showing the paths of red and violet light rays to illustrate why they are focused at different points along the principal axis.

(b) Define the term "longitudinal chromatic aberration" and indicate it on your diagram as the distance

(c) Describe, with the aid of a diagram, how an achromatic doublet (a combination of a convex crown glass lens and a concave flint glass lens) can significantly reduce chromatic aberration. Explain the principle behind this correction.

(d) Explain why lenses with wide apertures suffer more noticeably from chromatic aberration than lenses with narrow apertures.

(e) The photographer also notices that in some shots taken at the widest aperture, the image is slightly "soft" or blurred, even when focused correctly. The technician explains this is spherical aberration. Describe what spherical aberration is and explain two practical methods used in camera lens design to minimise it.

Question 39:

Mr. Opio, a night watchman at a warehouse in Jinja, has always prided himself on his keen distance vision, easily spotting people approaching from far away. However, he finds it

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

impossible to read the small print on his mobile phone screen or the logbook entries he is required to make each night. Conversely, his colleague, a young man named Sula, can read books and his phone perfectly well but struggles to identify the number plates of distant lorries approaching the gate.

- (a) Identify the specific eye defect Mr. Opio suffers from (presbyopia/hypermétropia) and the defect Sula suffers from (myopia). Draw simple diagrams showing how parallel rays from a distant object are focused by each of their defective eyes (relative to the retina).
- (b) Explain what type of lens (converging or diverging) is required to correct Mr. Opio's vision for reading. Draw a ray diagram to illustrate the correction.
- (c) Explain what type of lens is required to correct Sula's distance vision. Draw a ray diagram to illustrate the correction.
- (d) Mr. Opio's reading glasses have a power of +2.5 D. Calculate the focal length of these lenses in centimetres. What does the positive sign signify?
- (e) Sula's distance glasses have a power of -1.5 D. Calculate the focal length. If he can see objects clearly only up to a maximum distance of 1.5 m without glasses, determine the new far point when he wears these glasses.

Question 40:

A physics teacher at King's College Budo wants to demonstrate the concept of conjugate points and determine the focal length of a thick convex lens that has inaccessible surfaces (it is mounted inside a protective housing). She uses an illuminated object and a screen placed a fixed distance $L = 90$ cm apart. She finds that there are two positions of the lens between the object and screen where a sharply focused image is formed: a magnified image when the lens is at position A, and a diminished image when the lens is at position B. The distance between these two lens positions is $d = 30$ cm.

- (a) Draw a ray diagram showing the formation of the images in the two lens positions, illustrating the principle of reversibility of light paths.
- (b) Derive the formula relating the focal length f to L and d : $f = (L^2 - d^2) / 4L$.
- (c) Using the given values of $L = 90$ cm and $d = 30$ cm, calculate the focal length f of the thick lens.
- (d) Explain why this method is particularly useful for determining the focal length of a lens mounted inside a tube or for a thick lens where the principal planes are not easily accessible.
- (e) Calculate the magnifications produced in the two conjugate positions (m_1 and m_2) and show that their product $m_1 \times m_2 = 1$.

Question 41:

By kasumba Najjib
Email: najjibkasumba@gmail.com

Best of the best

A minor earthquake with an epicentre near Kisoro is detected by a seismograph station in Kampala, 400 km away. The seismograph records two distinct sets of waves arriving at different times: the fast-moving P-waves (longitudinal) and the slower S-waves (transverse). The P-waves arrive first, followed by the S-waves 45 seconds later. The geophysicists know that P-waves travel through the Earth's crust at approximately 8.0 km/s, while S-waves travel at 4.5 km/s.

- Distinguish clearly between longitudinal waves and transverse waves, using P-waves and S-waves as your examples. Describe the nature of particle vibration in each case.
- Using the time difference and the given speeds, calculate the actual distance from the seismograph station to the earthquake's epicentre. (Set up simultaneous equations for the travel times of P and S waves).
- If the frequency of the S-waves is 2 Hz, calculate their wavelength.
- Explain why sound waves from the earthquake cannot be heard by humans in Kampala, even though they are detected by sensitive instruments.
- A displacement-time graph of the P-wave at the station shows a sinusoidal pattern. If the amplitude is 0.5 mm, write an equation for the displacement y of a particle as a function of time t , assuming a frequency of 5 Hz and zero initial displacement.

Question 42

A talented guitarist in a church choir in Mbarara is tuning his acoustic guitar. He plucks the low E string, which has a length of 65 cm between the bridge and the nut, and a mass per unit length of $4.5 \times 10^{-3} \text{ kg m}^{-1}$. The string is under a tension of 75 N. The guitarist knows that the string vibrates to produce a fundamental frequency and several overtones, creating the rich timbre of the instrument.

- Calculate the velocity of transverse waves along this guitar string.
- Draw labelled diagrams showing the standing wave patterns on the string for the fundamental frequency (first harmonic), the first overtone (second harmonic), and the second overtone (third harmonic). Indicate nodes (N) and antinodes (A).
- Calculate the fundamental frequency (in Hz) produced by the string.
- Determine the frequencies of the first and second overtones.
- The guitarist tightens the tuning peg, increasing the tension in the string. Explain qualitatively how this affects the velocity of the wave and the fundamental frequency of the note heard.

Question 43:

Best of the best

Students at Ntare School are conducting an experiment to determine the speed of sound in air using a resonance tube. The tube is a long, transparent cylinder filled with water, and the water level can be lowered to vary the length of the air column above it. They hold a vibrating tuning fork of frequency 512 Hz over the open end of the tube and slowly lower the water level. They hear the first loud resonance when the air column length is 15.8 cm, and the second loud resonance when the length is 49.2 cm. The room temperature is 25°C.

- Draw a labelled diagram of the experimental setup. Indicate the positions of nodes and antinodes in the air column for the first and second resonances.
- Using the measurements for the first and second resonance lengths, calculate the wavelength of the sound wave in the air column. (Remember the relationship $l_2 - l_1 = \lambda/2$).
- Hence, calculate the experimental value for the speed of sound in air at the room temperature.
- Determine the end correction 'c' for this resonance tube. (Use the fact that $l_1 + c = \lambda/4$).
- Explain why the end correction is necessary and why it is more significant for a tube with a larger diameter.

Question 44:

A patient is being rushed to Mulago Hospital in an ambulance travelling at a steady speed of 90 km/h (25 m/s) along Jinja Road. The ambulance siren emits a continuous sound with a frequency of 800 Hz. A stationary pedestrian waiting to cross the road hears the pitch of the siren change dramatically as the ambulance approaches and then passes him. The speed of sound in air that afternoon is 345 m/s.

- State the Doppler effect. Explain why the pedestrian hears a higher pitch as the ambulance approaches and a lower pitch after it has passed.
- Calculate the apparent frequency heard by the pedestrian as the ambulance approaches him.
- Calculate the apparent frequency heard by the pedestrian after the ambulance has passed him and is moving away.
- Inside the ambulance, the paramedic also hears the siren. Explain, without calculation, what frequency the paramedic hears compared to the actual 800 Hz emitted.
- The ambulance passes a stationary police car parked by the roadside, which is also emitting a siren of 700 Hz. Describe what the ambulance driver hears regarding the police siren as they approach and pass it.

Question 45:

Best of the best

In a small village in Busoga, there are two old church bells that are rung simultaneously to call congregants for the Sunday service. One bell has a slightly different tone from the other, and when both are rung together, the congregation hears a distinct "wah-wah-wah" pulsating sound, with the loudness rising and falling 4 times every second. The sexton, who rings the bells, knows that one of the bells produces a note of 280 Hz, but the other bell's frequency is unknown.

- (a) Explain the phenomenon of beats. What causes the periodic variation in loudness when two notes of slightly different frequencies are sounded together?
- (b) Determine the two possible frequencies of the second bell.
- (c) To identify the exact frequency, the sexton attaches a small lump of clay (plasticine) to the rim of the unknown bell, which slightly lowers its frequency. He then rings both bells again and finds that the beat frequency increases to 6 beats per second. What is the actual frequency of the second bell? Explain your reasoning clearly.
- (d) Calculate the beat period (the time between successive loud beats) for the original 4 beats per second.
- (e) If the speed of sound is 340 m/s, calculate the wavelengths of the sound waves produced by the 280 Hz bell and by the second bell (using the frequency you determined in part c).

Question 46:

Traffic police officers on the Entebbe Expressway are using a radar gun to monitor the speed of vehicles. The radar gun transmits a continuous microwave signal of frequency 10.525 GHz towards an oncoming car. The signal reflects off the moving car and is received back at the radar gun. By mixing the transmitted and received signals, the radar gun detects a beat frequency (Doppler shift) of 1.75 kHz. The speed of all electromagnetic waves, including microwaves, is 3.0×10^8 m/s.

- (a) Explain how the radar gun uses the Doppler effect to measure the speed of the vehicle. Why does the frequency of the reflected wave change twice?
- (b) Derive the formula relating the beat frequency Δf to the speed of the vehicle v , the transmitted frequency f_0 , and the speed of light c : $v = (c \times \Delta f) / (2 \times f_0)$.
- (c) Using the given data, calculate the speed of the oncoming car in metres per second, and convert this to kilometres per hour.
- (d) If the speed limit on the expressway is 100 km/h, determine whether the driver is speeding.
- (e) Explain one other practical application of the Doppler effect in science or technology, detailing how the frequency shift is used to derive useful information.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

Question 47:

The magnificent pipe organ at Namirembe Cathedral has hundreds of pipes, some of which are open at both ends (open pipes) and some closed at one end (stopped pipes). An organ tuner is working on a particular stopped pipe (closed at one end) that has a length of 2.4 metres. The speed of sound in the warm cathedral air is 343 m/s.

- (a) Draw diagrams showing the standing wave patterns for the fundamental frequency and the first two overtones in a pipe closed at one end. Indicate the positions of nodes (N) and antinodes (A).
- (b) Calculate the fundamental frequency (first harmonic) of this stopped pipe.
- (c) Determine the frequencies of the first and second overtones that this pipe can produce.
- (d) The tuner then works on an open pipe of the same length (2.4 m). Calculate its fundamental frequency and explain why open pipes produce both odd and even harmonics, whereas stopped pipes produce only odd harmonics.
- (e) Explain why the timbre (quality) of a note played on a stopped pipe sounds different from the same note played on an open pipe, even if they have the same fundamental frequency.

Question 48:

At the physics laboratory of Kyambogo University, students are performing Kundt's tube experiment to measure the speed of sound in a solid metal rod. A long glass tube is laid horizontally, and fine cork dust is sprinkled evenly along its interior. A metal rod, clamped at its midpoint, has one end projecting into the tube. When the rod is vigorously stroked with a resined cloth, it vibrates longitudinally, and the cork dust inside the tube settles into a series of small, evenly spaced heaps. The distance between five consecutive heaps is measured to be 42.0 cm. The frequency of the vibrating rod is known to be 2.2 kHz from a previous calibration. The length of the rod is 1.2 m.

- (a) Explain the formation of the dust heaps in Kundt's tube. Why does the dust settle at the nodes of the standing wave in the air column?
- (b) Using the dust heap spacing, calculate the wavelength of the sound wave in the air column, and hence determine the speed of sound in air at the laboratory temperature.
- (c) Knowing the length of the metal rod, determine the wavelength of the standing wave in the rod. (Hint: The rod is clamped at its midpoint and is free at both ends).
- (d) Assuming the frequency of vibration is the same in both the rod and the air column, calculate the speed of sound in the metal rod.
- (e) State one major source of error in this experiment and suggest how it can be minimised.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

Question 49:

A researcher studying bats in Mabira Forest uses an ultrasonic detector to record the echolocation calls of a small insectivorous bat. The bat emits short pulses of high-frequency sound and listens for the echoes reflected from its prey (a tiny moth). One recorded pulse has a frequency of 78 kHz and a duration of 2 milliseconds. The bat is flying at a steady speed of 4 m/s directly towards a stationary moth. The speed of sound in the humid forest air is 345 m/s.

- (a) Calculate the wavelength of the emitted ultrasonic pulse in air.
- (b) Explain why the bat uses such high frequencies (ultrasound) rather than audible sound for echolocation. Relate your answer to diffraction and the size of the prey.
- (c) Calculate the frequency of the echo that the bat hears after the sound reflects off the stationary moth. (Remember the double Doppler shift: first the moth receives a higher frequency, then reflects it, and the bat is moving towards the reflected wave).
- (d) The bat can detect the time delay between emitting a pulse and receiving its echo. If the moth is 1.5 metres away, calculate the time delay the bat experiences.
- (e) Explain how the bat uses the Doppler shift of the echo to determine whether the moth is flying towards it or away from it.

Question 50:

Students at a secondary school in Lira are investigating the relationship between the frequency of a vibrating stretched string and its length. They use a sonometer, which consists of a horizontal wire stretched over two bridges, with a pulley and hanging masses to provide tension. The wire is plucked, and its frequency is matched to a tuning fork. They keep the tension and mass per unit length constant and vary the vibrating length l by moving one of the bridges. They find that the frequency f is inversely proportional to the length l .

- (a) Derive the formula for the fundamental frequency of a stretched string: $f = (1/2l) \sqrt{T/\mu}$, where T is the tension and μ is the mass per unit length.
- (b) The students plot a graph of frequency f against $1/l$. Describe the shape of the graph and state what the slope of the graph represents.
- (c) In a second experiment, they keep the length constant and vary the tension T by adding masses to the hanger. What graph would they plot to obtain a straight line? Explain how the mass per unit length μ can be determined from the slope of this graph.
- (d) The wire has a mass of 2.5 g and a length of 1.2 m between the bridges. The tension is provided by a mass of 4.0 kg hanging over the pulley. Calculate the expected fundamental frequency. (Take $g = 9.81 \text{ m/s}^2$).

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(e) Explain why the wire should be plucked gently at its centre to produce a pure fundamental note, and why plucking it near the bridge produces a harsher, brighter sound with more harmonics.

Question 51:

During a violent thunderstorm in Tororo, a lightning bolt strikes the copper lightning conductor of a tall building. The massive current pulse, estimated at 30,000 A, travels down the vertical conductor to the ground. At that moment, the conductor experiences a sudden, powerful sideways force due to its interaction with the Earth's magnetic field. The Earth's magnetic field at that location has a horizontal component of 3.0×10^{-5} T directed North, and the lightning conductor runs vertically. The conductor segment between the roof and ground is 15 m long.

(a) Explain why a current-carrying conductor placed in a magnetic field experiences a force. Draw a diagram showing the relative directions of the magnetic field (North), the current (downwards), and the resulting force (using Fleming's Left-Hand Rule).

(b) Calculate the magnitude of the maximum horizontal force exerted on the 15 m vertical section of the conductor during the lightning strike.

(c) In which cardinal direction (East, West, North, or South) is this force directed? Explain your reasoning using Fleming's Left-Hand Rule.

(d) If the lightning current was an oscillating AC current instead of a unidirectional pulse, how would the force on the conductor behave?

(e) State two practical safety considerations for installing lightning conductors on tall buildings, based on the principle of electromagnetic forces.

Question 52:

A physics teacher at King's College Budo is demonstrating the principle of a moving coil galvanometer to his class. He has a rectangular coil of 200 turns, with a width of 2.0 cm and a height of 3.0 cm, suspended in a radial magnetic field of flux density 0.15 T. The coil is connected to a pair of hair springs that provide a restoring torque. The teacher explains that the deflection of the pointer is directly proportional to the current passing through the coil.

(a) Explain, with a labelled diagram, the construction and mode of operation of a moving coil galvanometer. Why is a radial magnetic field essential for a linear scale?

(b) Derive the relationship between the current I flowing through the coil and the angular deflection θ of the pointer: $I = (k / BNA) \theta$, where k is the torsional constant of the springs, B is the flux density, N is the number of turns, and A is the area of the coil.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(c) A current of 1.5 mA is passed through the galvanometer coil, causing a deflection of 36° . If the torsional constant k of the springs is $2.5 \times 10^{-8} \text{ N m rad}^{-1}$, verify that this current produces the stated deflection.

(d) Describe, with calculations, how this galvanometer (which has a coil resistance of 25Ω and gives full-scale deflection at 1.5 mA) can be converted into an ammeter capable of reading up to 3.0 A. Calculate the value of the required shunt resistor.

(e) Describe, with calculations, how the same galvanometer can be converted into a voltmeter capable of reading up to 15 V. Calculate the value of the required multiplier resistor.

Question 53:

A farmer in Kasese uses a 2.0 kW, 240 V DC electric motor to pump water from a borehole to irrigate his passion fruit orchard. The motor has an armature resistance of 1.2Ω . When operating under full load, the motor draws a current of 10.5 A from the 240 V supply. The farmer notices that sometimes when the pump is starting, the lights in his house momentarily dim.

(a) Draw a simple circuit diagram representing the DC motor, showing the applied voltage V , the armature resistance R_a , and the back e.m.f E_b .

(b) Calculate the back e.m.f (E_b) generated by the motor when it is running at full load.

(c) Determine the mechanical power developed by the motor and its efficiency at full load.

(d) Explain why the motor draws a very large current at the moment it is switched on (when it is stationary). Calculate this theoretical starting current.

(e) Explain the origin of the back e.m.f in the motor and why the current decreases as the motor speeds up. What would happen if the motor were stalled (prevented from rotating) while power was still applied?

Question 54:

A boda boda motorcycle mechanic in Katwe is explaining to an apprentice how the motorcycle's electrical system works without a large battery. He points to the magneto, a small permanent-magnet AC generator mounted on the engine's crankshaft. As the engine spins, the magneto produces an alternating current that powers the headlight and charges a small battery through a rectifier. The magneto's coil has 500 turns and an effective area of 20 cm^2 . The magnetic flux density from the permanent magnets is 0.45 T. The engine idles at 1200 revolutions per minute.

(a) Describe the construction and principle of operation of a simple AC generator (dynamo). Use Faraday's law of electromagnetic induction to explain how the e.m.f is induced.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(b) Calculate the frequency of the AC voltage produced by the magneto when the engine is idling at 1200 rpm. (Assume the magneto has two poles, so one revolution produces one cycle).

(c) Derive the expression for the peak e.m.f induced in the coil: $E_0 = NAB\omega$. Using this, calculate the peak voltage generated by the magneto at idle speed.

(d) Explain why the brightness of the motorcycle's headlight increases as the rider accelerates and the engine speed increases. Relate this to the rate of change of magnetic flux.

(e) The mechanic replaces the magneto's rectifier. Explain the function of the rectifier in converting the magneto's AC output to DC for charging the battery. Sketch the output voltage waveform before and after rectification.

Question 55:

A small trading centre in Kiboga is supplied with electricity from the main grid via a long 11 kV distribution line. A step-down transformer mounted on a pole reduces the voltage to 240 V for the shops and homes. The transformer is rated at 25 kVA and has 5000 turns on the primary winding. One evening, a shop owner plugs in a heavy-duty welding machine, and the lights in the entire trading centre dim noticeably.

(a) Calculate the number of turns on the secondary winding of the transformer.

(b) Assuming the transformer is 100% efficient, calculate the full-load current it can deliver on the 240 V secondary side. Also, calculate the corresponding current drawn from the 11 kV primary line.

(c) Explain, using the principles of electromagnetic induction, why the secondary voltage of a real transformer decreases (sags) when a heavy load like the welding machine is connected. Refer to the internal resistance of the windings and leakage flux.

(d) State two main sources of power loss in this transformer and explain the practical measures taken in its construction to minimise each loss.

(e) The shop owner wants to use a 3 kW, 240 V machine that was imported from a country with a 60 Hz mains frequency. Explain whether this is advisable to use on Uganda's 50 Hz supply without modification, considering the effect on the machine's transformer and motor.

Question 56:

A materials science researcher at Kyambogo University is using a Hall probe to measure the magnetic flux density between the pole pieces of a powerful electromagnet. The probe consists of a thin rectangular slice of a semiconductor material through which a constant DC current of 25 mA is passed. When the probe is placed in the unknown magnetic field with its plane perpendicular to the field, a Hall voltage of 85 μV is measured across the width of the

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

slice. The semiconductor has a thickness of 0.2 mm and a charge carrier density of $8.5 \times 10^{22} \text{ m}^{-3}$.

- (a) Explain the physical origin of the Hall effect. Why does a transverse voltage develop across a current-carrying conductor when placed in a perpendicular magnetic field?
- (b) Derive the expression for the Hall voltage: $V_H = (B I) / (n e t)$, where B is the magnetic flux density, I is the current, n is the charge carrier density, e is the electronic charge, and t is the thickness of the slice.
- (c) Using the provided data, calculate the magnetic flux density B between the pole pieces of the electromagnet. (Take $e = 1.6 \times 10^{-19} \text{ C}$).
- (d) Explain why a semiconductor is preferred over a metal for the sensing element in a Hall probe, even though metals have a much higher number of charge carriers.
- (e) State two practical applications of the Hall effect in modern technology, other than measuring magnetic fields.

Question 57:

In the main switchroom of a large factory in the Namanve Industrial Park, two long, straight, parallel copper busbars carry extremely high currents to distribute power to various sections. Busbar A carries a current of 5000 A, and Busbar B, running parallel to it at a distance of 20 cm, carries a current of 3000 A in the same direction. During a short-circuit fault, the currents momentarily spike to much higher values. The engineer is concerned about the mechanical forces between the busbars, which could cause them to bend or break their supports.

- (a) Explain why two parallel conductors carrying current in the same direction experience an attractive force. Use the concepts of interacting magnetic fields to support your explanation.
- (b) Derive the formula for the force per unit length between two long, straight, parallel current-carrying conductors: $F/l = (\mu_0 I_1 I_2) / (2\pi d)$.
- (c) Calculate the force per metre length acting between the two busbars under normal operating currents of 5000 A and 3000 A.
- (d) During a short circuit, the current in Busbar A spikes to 50,000 A. Assuming the current in Busbar B remains at 3000 A, calculate the new force per metre. Explain why the busbars must be securely braced to withstand such electromagnetic forces.
- (e) If the current in Busbar B were reversed to flow in the opposite direction, what would be the nature (attractive or repulsive) of the force? Sketch the magnetic field pattern between the two wires for this opposite-current case and indicate the location of a neutral point.

Question 58:

Best of the best

A community micro-hydro project on a stream in Kasese generates 15 kW of mechanical power from a turbine. This turbine drives a single-phase AC generator (alternator) that produces a sinusoidal voltage. The generator has a rectangular coil of 250 turns, each of area 0.15 m^2 , rotating in a uniform magnetic field of flux density 0.8 T. The generator's output is connected to a village mini-grid.

- (a) Derive the expression for the instantaneous induced e.m.f in the rotating coil: $E = NAB\omega \sin(\omega t)$.
- (b) If the generator is to produce an RMS voltage of 240 V at a frequency of 50 Hz, calculate the required angular velocity ω and the rotational speed in revolutions per minute (rpm).
- (c) Using the given parameters ($N=250$, $A=0.15 \text{ m}^2$, $B=0.8 \text{ T}$), verify that the magnetic field is sufficient to generate the required 240 V RMS at the calculated speed.
- (d) Sketch a graph of the induced e.m.f against time for one complete cycle. On the same axes, sketch the output of the generator after it has been passed through a full-wave bridge rectifier (before smoothing).
- (e) Explain why the generator's terminal voltage drops when a heavy electrical load (e.g., a maize mill) is connected, even if the turbine speed remains constant. Refer to armature reaction and internal impedance.

Question 59:

At a busy intersection along Jinja Road in Kampala, the traffic lights are equipped with inductive loop sensors embedded in the asphalt just behind the stop line. These sensors are simply one or more turns of insulated wire forming a large rectangular coil. When a car (a large metal object) stops over the loop, the traffic light controller detects its presence and eventually changes the light to green. A curious driver wonders how a simple buried wire can "see" his car without any physical contact.

- (a) Explain the principle by which the inductive loop detects the presence of a vehicle. Your answer must include the concepts of inductance, magnetic fields, and the effect of a ferromagnetic/conducting object on the coil's impedance.
- (b) The loop is part of an oscillator circuit whose frequency is determined by the inductance of the loop. When a car is not present, the oscillator runs at a specific frequency. Describe what happens to the inductance of the loop and the oscillator frequency when a car's steel chassis is positioned directly over it.
- (c) Why does an aluminium-bodied car (e.g., some models of Land Rovers) still trigger the sensor, even though aluminium is not ferromagnetic? Explain the role of eddy currents induced in the aluminium body.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(d) A bicycle or a motorcycle sometimes fails to trigger the sensor, leaving the rider stranded at a red light. Explain why a smaller metallic mass is less effective at changing the loop's inductance compared to a large car.

(e) Suggest one simple modification to the loop design or the detection circuit that could improve the sensitivity for detecting bicycles and motorcycles.

Question 61:

A vendor in a mobile phone shop on Ben Kiwanuka Street is demonstrating a new smartphone to a customer. He shows how a light touch of a finger on the glass screen can open apps, scroll, and type messages. The customer, a physics teacher, is curious about the technology and asks the vendor how the phone "knows" where his finger is touching. The vendor, having read the specifications, explains that it uses a "capacitive touch screen."

(a) Explain the basic construction of a capacitive touch screen. It consists of a grid of transparent conductive electrodes embedded under the glass, forming an array of tiny capacitors.

(b) Describe what happens, in terms of capacitance and charge, when a human finger approaches or touches a specific point on the screen. Why does the capacitance at that point change?

(c) The screen controller measures the change in capacitance at each node of the grid. Explain why a stylus made of plastic or a gloved finger usually does not work on a capacitive touch screen, whereas a special conductive stylus or a bare finger does.

(d) If a particular sensing capacitor has an initial capacitance of 10 pF in air, and the presence of a finger increases its capacitance by 2 pF due to the finger acting as a second "plate" with the glass as a dielectric, explain why the system can detect this tiny change.

(e) State one advantage and one disadvantage of a capacitive touch screen compared to an older "resistive" touch screen (which relies on physical pressure to bring two conductive layers together).

Question 62:

A young man in Arua enjoys listening to his favourite local FM station, Radio Pacis, which broadcasts at 94.5 MHz. His portable radio uses a simple LC (inductor-capacitor) tuning circuit in the front end to select the desired station from the multitude of radio waves in the air. The circuit consists of a fixed inductor of 0.15 μH and a variable capacitor whose capacitance can be adjusted by turning the tuning knob.

(a) Explain the principle of electrical resonance in an LC circuit. At resonance, what is the relationship between the inductive reactance (X_L) and the capacitive reactance (X_C)?

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (b) Derive the formula for the resonant frequency f_0 of an LC circuit: $f_0 = 1 / (2\pi\sqrt{LC})$.
- (c) Calculate the exact capacitance value required for the variable capacitor to tune the circuit to resonate at 94.5 MHz, using the given inductance.
- (d) The young man notices that when he is in a valley or behind a hill, the signal from Radio Pacis becomes weak and is sometimes overtaken by a stronger signal from a distant station on a nearby frequency. Explain what determines the "selectivity" or "sharpness" of the tuning circuit. What component parameter (the Q-factor) is responsible for this?

QUESTION 63

A taxi driver operating in the Kampala-Jinja route uses a heavy-duty battery charger at his garage to recharge his car's 12 V, 70 Ah lead-acid battery overnight. The charger plugs into the 240 V AC mains and has a large, heavy transformer inside, along with a metal rectifier unit and a big capacitor. He notices that the charger hums softly and becomes slightly warm during operation.

- (a) The transformer steps down the 240 V rms mains voltage to 15 V rms AC. Calculate the peak voltage of this secondary AC waveform.
- (b) The rectifier is a full-wave bridge rectifier using four silicon diodes. Draw the circuit diagram and explain how it converts the AC voltage to a pulsating DC voltage. Sketch the input and output voltage waveforms.
- (c) Explain why a large electrolytic capacitor (typically 10,000 μF or more) is connected across the output of the rectifier. What would be the consequence for the battery if this capacitor were faulty (open circuit)?
- (d) Calculate the approximate peak-to-peak ripple voltage across the capacitor if the load current is 5 A and the mains frequency is 50 Hz. (Use the approximation $V_{\text{ripple}} \approx I_{\text{load}} / (f \times C)$, where f is the ripple frequency, which is 100 Hz for full-wave rectification).
- (e) The charger's transformer core is made of laminated iron sheets. Explain why a solid iron core is not used, referring to the phenomenon of eddy currents and their effect on efficiency and heating.

Question 64:

An amusement park in Entebbe is installing a new roller coaster ride. To ensure a smooth and silent braking system without the wear and tear of friction pads, the engineers have designed an eddy current braking system. The system consists of powerful permanent magnets mounted on the track and a thick aluminium fin attached to the bottom of the roller coaster train. As the fin passes between the magnets at high speed, the train slows down smoothly and rapidly.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (a) Explain the physical origin of eddy currents. Why are circulating currents induced in the solid aluminium fin as it moves through the magnetic field?
- (b) State Lenz's law and use it to explain why the eddy currents produce a force that opposes the motion of the train (a braking force). Draw a simple diagram showing the direction of the magnetic field, the motion of the fin, and the direction of the induced eddy currents and resulting magnetic force.
- (c) Why is aluminium, a non-magnetic metal, chosen for the fin rather than a ferromagnetic metal like steel? Explain the role of the material's electrical conductivity.
- (d) What happens to the kinetic energy of the moving roller coaster train as it is slowed down by the eddy current brake? Explain why the aluminium fin becomes warm after repeated braking.
- (e) The fin is designed as a solid slab rather than a laminated stack of thin insulated sheets (which is how transformer cores are built). Explain why lamination would be counterproductive for an eddy current brake, even though it is essential for reducing losses in a transformer.

ELECTROSTATICS AND CAPACITORS

Question 66:

An NGO is building a new community health centre in a remote village in Karamoja. The main building has a corrugated iron sheet roof, but the adjacent latrine block has a thatched grass roof. The electrical engineer insists that a lightning conductor must be installed on the main building and that it must be properly earthed with a thick copper strip running to a copper plate buried deep in moist soil. The project manager questions the cost, but the engineer explains the physics of lightning strikes and the principle of action at sharp points.

- (a) Explain, using the concept of electric fields and charge distribution, how a lightning conductor protects a building from being damaged by a lightning strike. Include a diagram showing the charged cloud, the induced charges on the building and conductor, and the "space charge."
- (b) Why does a lightning conductor have a sharp spike (or multiple spikes) at its top rather than a rounded dome? Relate your answer to surface charge density and corona discharge.
- (c) The engineer explains that during a storm, a large electric field builds up between the negatively charged base of a thundercloud and the ground. If the electric field reaches a critical value of about 3.0×10^6 V/m, the air breaks down and a lightning strike occurs. If the cloud base is 800 m above the ground, estimate the potential difference between the cloud and the ground just before the strike.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(d) Why is it crucial that the copper earthing strip has a low resistance and that the buried copper plate is in contact with moist soil?

(e) The thatched latrine block does not have a lightning conductor. Explain why it is still at risk of catching fire from a nearby lightning strike, even if not directly hit, due to side flashes or induced voltages.

Question 67:

At the National Science and Technology Fair in Kampala, a group of students from a school in Mbale is demonstrating a small Van de Graaff generator. The machine consists of a rubber belt driven by a hand crank, which carries electric charge up into a large hollow aluminium sphere. As they turn the crank, the sphere charges up to a high voltage, and they can draw long, impressive sparks from it. A visitor's hair stands on end when she touches the sphere.

(a) Explain, step-by-step, how the Van de Graaff generator produces a very high voltage on the spherical dome. Describe the role of the sharp metal combs at the bottom and top in spraying and collecting charge.

(b) If the aluminium sphere has a radius of 15 cm and the maximum electric field strength that air can withstand without breaking down is 3.0×10^6 V/m, calculate the maximum potential (voltage) to which the sphere can be charged before it starts sparking into the surrounding air.

(c) Calculate the maximum charge that can be stored on the sphere under these conditions. (Assume the sphere is isolated and use the formula for the capacitance of an isolated sphere, $C = 4\pi\epsilon_0 r$).

(d) Calculate the electrical energy stored in the sphere when it is charged to this maximum potential.

(e) Explain why the visitor's long hair stands on end and spreads out radially when she touches the charged sphere, even though she is standing on an insulating platform.

Question 68:

A technician in a small electronics repair shop in Kikuubo is fixing a faulty mobile phone charger. He opens the plastic casing and identifies a small transformer, four diodes arranged in a bridge, and a cylindrical electrolytic capacitor rated at 1000 μ F, 16 V. He explains to his apprentice that the capacitor is crucial for "smoothing" the rectified DC voltage to provide a steady supply to the phone's battery charging circuit.

(a) Draw the circuit diagram of a full-wave bridge rectifier connected to the secondary of a transformer, showing the four diodes and the load resistor R_L . Indicate the path of current during one half-cycle.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(b) Sketch the output voltage waveform across the load resistor R_L before the smoothing capacitor is connected. Explain why this waveform is not suitable for charging a sensitive lithium-ion battery.

(c) Explain the function of the electrolytic capacitor connected across the output of the rectifier. How does it reduce the "ripple" in the DC voltage? Use the terms "charging" and "discharging" in your explanation.

(d) Sketch the smoothed output voltage waveform. Explain why there is still a small residual ripple, even with a large capacitor.

(e) The technician replaces the $1000\ \mu\text{F}$ capacitor with a new one. He warns the apprentice to observe the correct polarity when installing an electrolytic capacitor. What would happen if the capacitor were connected with reverse polarity?

Question 69:

A wildlife photographer in Queen Elizabeth National Park is preparing to photograph a nocturnal leopard. His professional camera flash unit uses a large electrolytic capacitor of $2200\ \mu\text{F}$. The capacitor is charged from the camera's $6.0\ \text{V}$ battery through a DC-DC converter that steps up the voltage to $330\ \text{V}$. When the shutter is pressed, the capacitor discharges rapidly through a xenon flash tube, producing an intense burst of light lasting about 1.5 milliseconds.

(a) Calculate the maximum energy stored in the flash capacitor when it is fully charged to $330\ \text{V}$.

(b) Determine the total charge stored on the capacitor plates at this voltage.

(c) The flash tube has an effective resistance of $0.8\ \Omega$ during the discharge. Estimate the peak current that flows through the tube at the instant the discharge begins. (Assume the initial voltage is $330\ \text{V}$).

(d) Calculate the average power delivered by the capacitor during the $1.5\ \text{ms}$ flash duration. (Use the total stored energy divided by time).

(e) After the flash fires, the capacitor must be recharged for the next shot. The DC-DC converter charges the capacitor with an average current of $120\ \text{mA}$ from the $6.0\ \text{V}$ battery. Estimate the time it takes to fully recharge the capacitor (ignore the fact that charging rate slows down as voltage increases; use total charge divided by average current). Explain why it takes longer in reality.

Question 70:

A small internet cafe in a trading centre in Mubende experiences frequent brief power cuts (lasting 2-3 seconds) which cause their computers and router to reboot, losing customer data

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

and interrupting downloads. The owner wants a simple, cheap solution and is advised by a technician to install a large capacitor bank across the DC output of the computer power supply units (PSUs). The capacitor bank has a total capacitance of 0.5 Farads and is charged to 12 V.

- (a) Calculate the total energy stored in the capacitor bank when fully charged to 12 V.
- (b) The computer and router together consume an average power of 60 W from the 12 V supply. Calculate the average current drawn.
- (c) If the mains power cuts out, the capacitor bank must supply this 60 W of power for 3 seconds to bridge the gap until the power returns or the backup generator starts. Assuming the capacitor discharges at a constant power, estimate the final voltage of the capacitor bank after 3 seconds. (Hint: Energy used = $P \times t$; remaining energy = initial energy - energy used; then find voltage from remaining energy).
- (d) In reality, the capacitor voltage decays exponentially. Explain why a constant power discharge is a simplification, and what the actual voltage-time curve would look like.
- (e) Explain why a capacitor bank is suitable only for very short-term power bridging (a few seconds), and why a battery (which stores chemical energy) is required for longer outages.

Question 71:

A large cement factory in Tororo is required by environmental regulations to drastically reduce the amount of fine dust particles emitted from its smokestacks. The factory installs an electrostatic precipitator in the chimney. The precipitator consists of a grid of vertical wires maintained at a high negative potential (around -50 kV) and large, flat, earthed metal collection plates on either side. As the dust-laden flue gas passes through, the dust particles are removed with high efficiency.

- (a) Explain the principle of operation of the electrostatic precipitator. Describe the process of corona discharge from the sharp wire electrodes and how this charges the passing dust particles.
- (b) Why is a high voltage (tens of kilovolts) used in this process? What is the significance of using a negative polarity on the discharge wires?
- (c) Once the dust particles acquire a negative charge, explain the electrostatic force that causes them to migrate towards and adhere to the earthed collection plates.
- (d) Periodically, the collection plates are mechanically "rapped" or vibrated. Explain the purpose of this rapping process.
- (e) Estimate the electric field strength at the surface of a discharge wire that has a radius of 1.5 mm, if the applied voltage is -50 kV and the distance to the collection plate is 25 cm. (Assume the field near a cylindrical wire can be approximated by $E \approx V / (r \ln(d/r))$, but a

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

simpler approximation is acceptable for a qualitative discussion. Focus on explaining why the field is highest at the sharp wire.)

Question 72:

The Uganda Cancer Institute at Mulago Hospital is considering acquiring a small Van de Graaff particle accelerator for research and potentially for radiation therapy. The machine uses a high-voltage terminal (a large metal sphere) to accelerate protons or other ions to high energies. The terminal is charged by a moving belt, similar to the classroom demonstration model, but on a much larger scale.

(a) Draw a simplified diagram of a Van de Graaff accelerator, showing the high-voltage terminal, the moving belt, the corona discharge combs, and the ion source and acceleration tube.

(b) The high-voltage terminal is a hollow metal sphere of radius 1.2 m. If the maximum electric field at the surface of the sphere before sparking occurs is 3×10^6 V/m, calculate the maximum potential (voltage) to which the terminal can be raised.

(c) A proton (charge $+e = 1.6 \times 10^{-19}$ C, mass $= 1.67 \times 10^{-27}$ kg) is released from the ion source inside the terminal and accelerated down an evacuated tube to a target at ground potential (0 V). Calculate the kinetic energy (in joules and electron-volts) gained by the proton.

(d) Using your answer from (c), calculate the final speed of the proton just before it strikes the target.

(e) Explain one major advantage of using an electrostatic accelerator like the Van de Graaff over other types of particle accelerators for certain precision nuclear physics experiments.

Question 73:

In a grain storage silo in Jinja, there is a significant risk of dust explosions caused by static electricity. As wheat grains are poured down a metal chute, friction causes the grains and the resulting fine dust particles to become electrically charged. The dust cloud can accumulate a net charge, and if a spark occurs, it can ignite the flammable dust. Safety inspectors measure the electric field and find that two small dust particles, each carrying a charge of approximately $+3.5$ nC, are suspended 8.0 mm apart in the air.

(a) State Coulomb's Law. Calculate the magnitude of the electrostatic force (either repulsion or attraction) between these two charged dust particles.

(b) If the two particles have identical charges, will they attract or repel each other? Explain why this mutual repulsion can help keep the dust cloud suspended in the air for long periods.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

- (c) Explain how earthing (grounding) the metal chute and the storage silo helps to mitigate the risk of static electricity buildup. Where do the excess charges go?
- (d) In addition to earthing, some silos inject a small amount of humid air or use ionising bars. Explain how increasing the humidity or introducing ions into the air can help dissipate static charges on the dust particles.
- (e) If one of the particles in part (a) has a mass of 0.02 mg, calculate the upward electrostatic force required to just balance its weight (assuming the electric field is vertical). What electric field strength E would be required to levitate this particle? (Ignore the force from the other particle for this part.)

Question 74:

Residents in a village near the Bujagali-Kampala high-voltage transmission line (132 kV) have noticed that sometimes, when they stand directly under the power lines on a humid day, they can hear a faint buzzing or crackling sound, and if they hold up a fluorescent tube, it glows dimly even though it is not connected to any socket. They are concerned about possible health effects and ask a visiting engineer from UMEME for an explanation.

- (a) Explain the origin of the buzzing/crackling sound (corona discharge) heard near high-voltage transmission lines. Why is this effect more pronounced on humid or rainy days?
- (b) The transmission line consists of three parallel conductors for the three phases. Sketch the electric field lines in a plane perpendicular to the conductors, showing the general direction of the field between a conductor and the ground.
- (c) Explain why a fluorescent tube held under the power line glows faintly. What is the role of the alternating electric field from the transmission line in causing the gas inside the tube to ionise and emit light?
- (d) If the height of the conductor above the ground is 12 m, and the voltage between the conductor and ground is 132 kV rms, calculate the average electric field strength at ground level directly under the conductor. (Assume a simplified uniform field for estimation: $E \approx V / d$.) Discuss whether this field strength is strong enough to cause the observed effects.
- (e) The engineer assures the residents that the electric field strength at ground level is well within international safety guidelines. Explain why the field strength decreases rapidly with distance from the conductor. (Use the concept that for a long wire, $E \propto 1/r$.)

Question 75:

At a major UMEME substation in Kampala, large, cylindrical devices called Capacitive Voltage Transformers (CVTs) are connected to the 132 kV busbars. These devices serve two purposes: they accurately step down the extremely high transmission voltage to a safe, measurable low voltage (e.g., 110 V) for metering and protection relays, and they also

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

provide a path for high-frequency power line carrier communication signals used for telemetry and control.

(a) Explain the basic principle of a capacitive voltage divider. A CVT consists of a stack of high-voltage capacitors (C_1) in series with a lower-voltage capacitor (C_2). Derive the formula for the output voltage V_{out} across C_2 in terms of the input voltage V_{in} : $V_{out} = V_{in} \times [C_1 / (C_1 + C_2)]$.

(b) A particular CVT is designed for a 132 kV line-to-ground voltage. The high-voltage capacitor stack has an equivalent capacitance $C_1 = 2000$ pF. If the desired output voltage across C_2 is 11 kV, calculate the required value of C_2 .

(c) The 11 kV intermediate voltage is then further stepped down to 110 V using a conventional precision electromagnetic transformer. Explain why it is impractical and unsafe to use a conventional transformer directly on the 132 kV line without the capacitive divider.

(d) The CVT also incorporates a "drain coil" or tuning inductor in parallel with C_2 . What is the purpose of this inductor? (Hint: It compensates for the phase shift introduced by the capacitive divider and ensures accurate voltage magnitude and phase angle for metering).

(e) Explain why CVTs are preferred over conventional inductive voltage transformers (magnetic PTs) for very high voltage systems (above 100 kV) due to their lower cost, smaller size, and inherent ability to withstand transient over voltages.

Question 76:

A startup company in Kampala is prototyping an electric hybrid boda boda (motorcycle) that uses a small petrol engine coupled with an electric motor for boost and regenerative braking. Instead of a heavy chemical battery, the prototype uses a bank of supercapacitors (also called ultracapacitors) rated at 3000 Farads, 2.7 V each, connected in series to achieve a 48 V working voltage. The supercapacitors are charged rapidly during braking and discharge quickly to provide acceleration boost.

(a) Calculate the total capacitance of a bank of 18 identical 3000 F supercapacitors connected in series. Also, calculate the maximum energy that can be stored in this bank when charged to 48 V.

(b) Explain the fundamental difference between energy storage in a conventional electrolytic capacitor and in a supercapacitor. What gives the supercapacitor its enormously high capacitance (thousands of Farads)? (Hint: Mention the electric double layer and porous carbon electrodes.)

(c) During regenerative braking, the kinetic energy of the boda boda is converted to electrical energy and stored in the supercapacitor bank. If the boda boda has a mass of 180 kg (including rider) and is travelling at 40 km/h, calculate its kinetic energy. What percentage of this energy could theoretically be captured if the supercapacitor bank stores the energy calculated in (a)?

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(d) Explain why supercapacitors are ideal for this "start-stop" and "boost" application, whereas they would be unsuitable for long-term energy storage (e.g., powering the boda boda for an hour-long journey). Compare their energy density and power density with those of lithium-ion batteries.

(e) The supercapacitor bank uses active balancing circuitry. Explain why series-connected supercapacitors require voltage balancing circuits, especially given their relatively low individual voltage rating of 2.7 V.

Question 77

A vintage radio enthusiast in Muyenga is restoring a beautiful 1960s valve (vacuum tube) radio. The tuning mechanism consists of a variable air-gap capacitor. It has a set of fixed semicircular metal plates (stator) and a set of interleaving movable plates (rotor) that can be rotated by the tuning knob. As the rotor plates mesh more or less with the stator plates, the overlapping area changes, thereby varying the capacitance and tuning the radio to different stations.

(a) Explain, using the formula for a parallel plate capacitor $C = \epsilon_0 A / d$, how rotating the plates changes the capacitance of this variable capacitor. What is the dielectric material in this case?

(b) The radio's tuning circuit consists of this variable capacitor in parallel with a fixed inductor of 180 μH . The capacitor has a maximum capacitance of 365 pF when the plates are fully meshed, and a minimum capacitance of 10 pF when fully unmeshed. Calculate the tuning range (minimum and maximum frequencies) of this radio.

(c) Determine whether this radio can tune into the entire FM broadcast band (88 MHz to 108 MHz) or the AM (Medium Wave) broadcast band (530 kHz to 1600 kHz).

(d) The enthusiast notices that the plates of the capacitor are carefully shaped (not simple semicircles). Explain why the plates are shaped to provide a "straight-line frequency" or "straight-line wavelength" tuning characteristic, so that stations are evenly spaced along the dial.

(e) The capacitor plates are separated by air. Explain why a high-quality tuning capacitor must have clean, dust-free plates and why it is often enclosed to prevent dust accumulation. What would be the effect of a conductive dust particle bridging the narrow gap between a stator and rotor plate?

Question 78

At a research laboratory at Makerere University, sensitive electronic measurements are being conducted that are susceptible to interference from external electric fields. The researchers place the experimental setup inside a large, earthed metal enclosure known as a Faraday cage.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

When the door of the cage is closed, the instruments inside show a dramatic reduction in electrical noise. A student visiting the lab is curious about how a simple metal box can block electric fields.

- (a) Explain the principle of electrostatic shielding. When a hollow conductor is placed in an external electric field, what happens to the free charges within the conductor?
- (b) Draw a diagram showing a hollow metal sphere placed in a uniform external electric field. Indicate the distribution of induced charges on the surface of the sphere and the electric field lines both outside and inside the sphere.
- (c) Why is the electric field strength exactly zero everywhere inside the enclosed cavity of the conductor, regardless of the strength of the external field?
- (d) The researchers ensure that the Faraday cage is properly earthed (connected to ground). Explain why earthing is essential for effective shielding, especially when the internal equipment generates its own electric fields.
- (e) State two practical, everyday examples of electrostatic shielding that people encounter or use.

Question 79:

Construction workers building a new road near the 132 kV transmission lines from Bujagali to Kampala are instructed to maintain a strict minimum safe clearance distance from the overhead conductors. A site safety officer explains that even without touching the wires, a person or a metal crane boom can suffer a fatal electric shock if brought too close to the high-voltage line.

- (a) Define electric potential and explain why the potential of the high-voltage conductor is 132 kV relative to the distant ground (which is at 0 V).
- (b) Describe the distribution of the electric field and equipotential surfaces around a single cylindrical high-voltage conductor. Explain why the equipotential surfaces are cylindrical near the conductor and become distorted as they approach the ground.
- (c) Using the approximate formula for the electric field at a distance r from a long charged cylinder ($E = \lambda / (2\pi\epsilon_0 r)$), explain why the electric field strength is highest at the surface of the conductor and decreases rapidly with distance.
- (d) Explain the phenomenon of "step potential" and "touch potential" around a downed power line. Why is it dangerous to walk away from a fallen wire with large steps?
- (e) The safety officer emphasises that even if a crane boom does not touch the wire, a "flashover" or arc can occur if it comes within a certain distance. For a 132 kV line, this minimum approach distance is approximately 3 metres. Explain why the air, which is normally an excellent insulator, can break down and become conductive when the electric field exceeds approximately 3×10^6 V/m.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Question 80

A small metal fabrication workshop in Katwe uses a capacitor discharge spot welder to join thin sheets of stainless steel. The welder uses a bank of 10 large electrolytic capacitors, each rated at $4700\ \mu\text{F}$ and $400\ \text{V}$, connected in parallel. The capacitor bank is charged to $380\ \text{V}$ and then discharged rapidly through a step-down pulse transformer and copper welding electrodes, producing a massive current pulse of several thousand amperes for a few milliseconds to fuse the metal sheets together.

- (a) Calculate the total capacitance of the 10-capacitor bank when connected in parallel. Also, calculate the total electrical energy stored in the bank when charged to $380\ \text{V}$.
- (b) Explain why the capacitors are connected in parallel rather than in series for this application, even though series connection would yield a higher voltage rating.
- (c) During the weld, the stored energy is discharged into the weld nugget. If the discharge lasts for 8 milliseconds and the total resistance of the discharge circuit (including the transformer primary and capacitor ESR) is $0.12\ \Omega$, estimate the average power delivered during the pulse. (Hint: The discharge is an exponential RC decay; for a rough estimate, you can use Energy / time).
- (d) The welding operator notices that if the welder is fired without the metal sheets properly clamped, the electrodes spark and the weld is weak. Explain the importance of low contact resistance between the electrodes and the workpiece for delivering maximum energy to the weld zone.
- (e) After the weld, the capacitor bank must be recharged. The charging circuit draws $2.5\ \text{A}$ from the $240\ \text{V}$ mains. Estimate the minimum time required to fully recharge the bank from zero to $380\ \text{V}$. (Use $Q = CV$ and $I = Q/t$). Explain why a current-limiting resistor or circuit is essential during the charging phase to protect the rectifier and the capacitors.

INTERFERENCE, DIFFRACTION, AND POLARISATION

Question 81:

At Gayaza High School, the physics students have repeated Young's double slit experiment, but this time they have replaced the monochromatic laser with a bright white light source (a halogen bulb with a pinhole aperture). They observe a striking and beautiful pattern on the screen: a brilliant white central fringe, flanked on either side by spectra of colours, with the blue/violet end of each spectrum closest to the centre and the red end furthest away. However, they also notice that after a few coloured fringes, the pattern becomes a muddy, uniform white wash.

- (a) Explain why the central fringe is white rather than coloured. Relate your answer to the condition for constructive interference and path difference.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(b) For the first-order spectrum, explain why the blue/violet light appears closer to the central white fringe than the red light. Derive the relationship between fringe position y , wavelength λ , slit separation a , and screen distance D to justify your answer.

(c) Using the formula $y = n\lambda D / a$, calculate the angular separation between the first-order violet fringe ($\lambda = 400$ nm) and the first-order red fringe ($\lambda = 700$ nm) if the slit separation $a = 0.20$ mm and the screen is 1.8 m away.

(d) Explain why the higher-order spectra ($n = 2, 3, \dots$) begin to overlap and eventually produce a uniform white illumination rather than distinct coloured fringes.

(e) Describe how you could modify this white-light experiment to measure the wavelength range of an unknown light source, such as a coloured LED.

Question 82

In a university optics laboratory at Mbarara University of Science and Technology, a student is using a high-quality diffraction grating with 1200 lines per millimetre to study the spectrum of a sodium vapour lamp. With a spectrometer, she observes that the familiar yellow line is actually two very closely spaced lines (the sodium D-lines) with wavelengths of 589.0 nm and 589.6 nm. She is tasked with measuring the angular separation between these two lines in the second-order spectrum.

(a) Write down the diffraction grating equation and explain why a grating with a large number of lines per millimetre is essential for resolving closely spaced spectral lines like the sodium doublet.

(b) Define the resolving power R of a diffraction grating and state the formula $R = \lambda / \Delta\lambda = nN$, where n is the order and N is the total number of illuminated lines.

(c) Calculate the minimum number of lines on the grating that must be illuminated to just resolve the sodium doublet in the first order. If the grating has 1200 lines/mm, what is the minimum width of the illuminated area required?

(d) Calculate the angular separation (in degrees) between the two sodium lines in the second-order spectrum for this grating.

(e) Explain why the second-order spectrum provides better resolution than the first-order, but why the intensity of the lines is lower.

Question 83

A technician at a precision engineering workshop in Ntinda is using an optical flat (a perfectly flat glass disc) and monochromatic light from a sodium lamp to check the flatness of a newly machined metal surface plate. He places the optical flat on the metal surface, creating a thin wedge of air between them due to a tiny speck of dust at one edge. He

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

observes a pattern of straight, parallel interference fringes across the surface. However, in one region of the metal plate, the fringes are distinctly curved, forming a "hill" or "valley" shape.

- (a) Explain how interference fringes are formed in the air gap between the optical flat and the metal surface. What does a straight, parallel fringe pattern indicate about the metal surface?
- (b) The technician observes that in a localised region, the fringes curve away from the line of contact (the thin edge of the wedge). Does this indicate a raised bump or a depressed hollow in the metal surface? Explain your reasoning using the concept of path difference and wedge thickness.
- (c) If the distance between adjacent straight fringes is 2.5 mm, and the wavelength of the sodium light is 589 nm, calculate the angle of the wedge.
- (d) In the defective region, the fringe is displaced sideways by 1.5 fringe widths. Calculate the height (or depth) of the irregularity on the metal surface.
- (e) Explain why this optical method of testing flatness is vastly superior to using a mechanical dial gauge or a straight edge for high-precision surfaces.

Question 84:

A wildlife photographer in Bwindi Impenetrable National Park has just purchased an expensive telephoto lens for his camera. He notices that the front element of the lens has a faint purplish or greenish reflection when held under a light. The salesperson explained that the lens is "multi-coated" or "bloomed" to reduce reflections and increase light transmission. The photographer wants to understand the physics behind this thin, transparent coating.

- (a) Explain the phenomenon of reflection loss at an air-glass interface. Approximately what percentage of incident light is reflected from a single uncoated glass surface ($n \approx 1.5$)?
- (b) Describe the principle of "blooming" a lens. A thin transparent film (e.g., magnesium fluoride, MgF_2 , $n \approx 1.38$) is evaporated onto the glass surface. Explain how destructive interference between the light reflected from the air-film interface and the film-glass interface can eliminate reflections.
- (c) Derive the condition for destructive interference for reflected light from a thin film: $2nt = (m + \frac{1}{2})\lambda$, where n is the refractive index of the film, t is its thickness, and λ is the wavelength.
- (d) Calculate the minimum thickness of a MgF_2 coating required to eliminate reflection of green light of wavelength 550 nm at normal incidence.
- (e) Explain why a single-layer coating can only perfectly eliminate reflection for one specific wavelength and at normal incidence. Why do high-end lenses use "multi-coatings" (up to 7 or more layers)?

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

Question 85:

A student in a physics class at Namilyango College is using a basic scientific calculator with an LCD (Liquid Crystal Display). He notices that when he tilts the calculator and views the screen through his polaroid sunglasses, the digits appear to fade and almost disappear at a certain angle. Intrigued, he asks his teacher how the display works and why the polaroid glasses affect it.

- (a) Describe the basic construction of a Twisted Nematic (TN) LCD pixel. Your description should include two crossed polarisers, the liquid crystal layer, and transparent electrodes.
- (b) Explain how the liquid crystal molecules rotate the plane of polarisation of light by 90° when no voltage is applied. Why does this allow the pixel to appear bright (or dark, depending on the polariser arrangement)?
- (c) When a voltage is applied across the electrodes, the liquid crystal molecules realign. Explain how this changes the polarisation state of the transmitted light and causes the pixel to switch to the opposite state (dark or bright).
- (d) The student observes the screen through his polaroid sunglasses, which act as an external analyser. Explain why rotating the calculator (or his head) causes the display to fade. What does this reveal about the polarisation state of the light emitted from the LCD screen?
- (e) State one major advantage of LCD technology over older LED or CRT displays in terms of power consumption and portability.

Question 86

Civil engineering students at Kyambogo University are testing a scale model of a bridge truss made from a transparent plastic material (e.g., perspex or polycarbonate). They place the model between two large crossed polaroid sheets and illuminate it from behind with a diffuse white light. When no load is applied, the model appears dark. However, when they apply a load to simulate the weight of traffic, a beautiful, complex pattern of coloured fringes appears within the plastic model. The pattern changes as the load is increased or shifted.

- (a) Explain the physical phenomenon of photoelasticity. Why does the stressed plastic become birefringent (doubly refracting) and thus able to rotate the plane of polarised light?
- (b) What do the coloured fringes represent in a photoelastic stress analysis? Explain why white light produces coloured fringes, whereas monochromatic light would produce only dark and bright bands.
- (c) The students observe that the fringes are tightly packed (closely spaced) near the joints and sharp corners of the model. What does a high fringe density indicate about the stress in that region?
- (d) How does this optical method allow engineers to identify potential "stress concentration" points in a design that might be prone to failure or cracking?

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(e) State one practical advantage of using photoelastic stress analysis over computational Finite Element Analysis (FEA) for complex or novel geometries.

Question 87:

A biology teacher at a school in Fort Portal is explaining the remarkable navigation abilities of honeybees. He mentions that even on a cloudy day when the sun is obscured, bees can still determine the direction of the sun by detecting the polarisation pattern of the blue sky. A student, curious about physics, asks how the sky light becomes polarised and how a bee's compound eye can detect it.

(a) Explain the physical process by which sunlight is scattered and polarised by the Earth's atmosphere. Why is the light from a patch of sky 90° away from the sun strongly linearly polarised?

(b) What is the orientation of the plane of polarisation of this scattered skylight relative to the sun's direction?

(c) Describe the structure in a bee's compound eye that allows it to detect the plane of polarisation. (Mention the specialised ommatidia in the dorsal rim area and the alignment of microvilli in the photoreceptor cells).

(d) If a bee is trained to fly to a food source in a particular direction, and a polaroid sheet is placed over the hive entrance with its transmission axis rotated by 45° , what will happen to the bee's initial flight direction when it leaves the hive? Explain your reasoning.

(e) How have human navigators (e.g., Viking seafarers) possibly used a similar principle? What simple optical device, using a naturally occurring birefringent crystal, could have been used to locate the sun's direction on an overcast day?

Question 88

A telecommunications company is laying a submarine fibre optic cable across a narrow section of Lake Victoria between Entebbe and the Ssesse Islands to provide high-speed internet to the island communities. The fibre has a core of ultra-pure glass (refractive index $n_1 = 1.48$) and a cladding ($n_2 = 1.46$). The engineers must ensure that light signals can travel the 40 km distance with minimal attenuation and without excessive pulse broadening (dispersion).

(a) Calculate the critical angle for total internal reflection at the core-cladding interface of this optical fibre.

(b) Determine the maximum acceptance angle (half-angle of the acceptance cone) for light entering the fibre from air ($n = 1.00$) so that it is guided along the core. Use the formula $NA = \sqrt{(n_1^2 - n_2^2)}$ for the numerical aperture.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

(c) Explain the phenomenon of modal dispersion in a step-index multimode fibre. Why does this limit the bandwidth (data rate) of the fibre over long distances?

(d) To minimise dispersion, the company uses a single-mode fibre for this long link. Explain the structural difference between a multimode and a single-mode fibre. Why does a single-mode fibre have a much smaller core diameter (about 8-10 μm) compared to a multimode fibre (50-62.5 μm)?

(e) Even in a single-mode fibre, chromatic dispersion occurs. Explain what causes chromatic dispersion and why it can be minimised by using a laser diode with a very narrow spectral linewidth instead of an LED.

Question 89:

In a forensic science lab in Kampala, a technician receives a small fragment of metal recovered from a crime scene. To identify the metal, she decides to determine its composition by optical emission spectroscopy. She vaporises a tiny amount of the metal in an electric arc, and the emitted light is passed through a spectrometer with a diffraction grating. The resulting spectrum consists of a series of bright, discrete lines at specific wavelengths. By comparing these wavelengths to a reference database, she can identify the elements present.

(a) Explain the physical origin of line emission spectra. Why do atoms of a specific element emit light only at certain discrete wavelengths, rather than a continuous spectrum?

(b) In the spectrometer, the light is collimated and then falls normally onto a diffraction grating with 1800 lines per millimetre. The technician observes a prominent blue line in the first-order spectrum at an angle of 22.3° on one side of the central maximum. Calculate the wavelength of this spectral line.

(c) Using the grating equation, determine the angular position of this same blue line in the second-order spectrum.

(d) The technician also observes a green line at 19.8° in the first order. Calculate its wavelength. By comparing with known data, she suspects the metal contains copper (Cu) which has strong lines at 510.5 nm, 515.3 nm, and 521.8 nm. Which of these lines does the observed green line most likely correspond to?

(e) Explain why a diffraction grating spectrometer provides a linear dispersion (wavelength is proportional to $\sin \theta$), whereas a prism spectrometer provides non-linear dispersion. Why is linear dispersion an advantage for precise wavelength measurement?

Question 90:

At the main gate of a modern housing estate in Najjera, residents use small passive RFID (Radio Frequency Identification) tags attached to their car windshields to automatically open the boom barrier. The tag contains no battery. Instead, it consists of a small antenna coil and a

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

tiny silicon chip. The reader at the gate emits a radio frequency signal at 13.56 MHz. When the tag comes within range, the reader detects the tag's unique identification code and opens the gate.

- (a) Explain how the passive RFID tag is powered. Your explanation must include the concepts of electromagnetic induction and resonance in an LC circuit.
- (b) The tag's antenna coil forms the inductor (L) of a parallel LC resonant circuit, with the chip's input capacitance providing C. Explain why the circuit is designed to resonate precisely at the reader's frequency of 13.56 MHz. What is the advantage of resonance for both power transfer and signal communication?
- (c) If the tag's coil has an inductance of $3.8 \mu\text{H}$, calculate the capacitance required to achieve resonance at 13.56 MHz.
- (d) Once powered, the chip transmits its stored digital code back to the reader. This is achieved by "load modulation." Explain briefly what load modulation means and how it allows the tiny tag to communicate with the powerful reader.
- (e) State two practical advantages of passive RFID tags over active battery-powered tags for this access control application.

Question 91:

Students at a secondary school in Gulu are using a ripple tank to study the behaviour of water waves. They generate straight plane waves using a vibrating bar and observe how the waves reflect off a straight barrier placed at an angle in the tank. The teacher asks them to explain their observations using Huygens' principle.

- (a) State Huygens' principle. Use this principle to explain why the angle of incidence of a plane wavefront equals the angle of reflection when it strikes a plane barrier.
- (b) Draw a clear diagram showing a plane wavefront incident on a plane barrier at an angle. Show the secondary wavelets and the new reflected wavefront envelope.
- (c) Using the same principle, explain what happens when circular waves (generated by a point source) reflect off a plane barrier. Sketch the pattern of the incident and reflected circular waves.
- (d) If the barrier is curved, describe what happens to the reflected plane waves. Name the point where the waves converge and explain why this shape is used in satellite dishes and radio telescopes.
- (e) Explain why Huygens' principle, in its original form, could not account for the diffraction of waves (the spreading of waves into the geometric shadow), and what modification (by Fresnel) was necessary to explain diffraction.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Best of the best

Question 92:

A student walking through the corridor of a school building in Hoima can clearly hear the conversation of two teachers inside a classroom even though the door is only slightly ajar and the speakers are not in her direct line of sight. This phenomenon, she recalls from physics class, is due to the diffraction of sound waves.

- (a) Explain what is meant by the diffraction of waves. Why are sound waves (with frequencies around 500 Hz to 2 kHz) able to diffract significantly around everyday obstacles like doorways and corners?
- (b) Calculate the wavelength of a 1000 Hz sound wave in air, assuming the speed of sound is 340 m/s. Compare this wavelength to the typical width of a doorway (about 0.9 m).
- (c) State the general condition for significant diffraction to occur. Relate this to the size of the obstacle or aperture compared to the wavelength.
- (d) Explain why light waves, which have much shorter wavelengths (~ 500 nm), do not appear to bend around corners in the same way, producing sharp shadows instead.
- (e) A public address system in a stadium uses large loudspeakers to project sound to the far stands. However, low-frequency bass notes tend to "spill" around the sides of the speaker enclosures and are less directional than high-frequency treble notes. Explain this observation using the principle of diffraction.

Question 93:

In an advanced physics practical at Makerere University, students use a microwave transmitter (3 cm wavelength) and a receiver to demonstrate two-slit interference. The transmitter is placed behind a metal barrier with two narrow vertical slits separated by 12 cm. The receiver is moved along an arc at a fixed distance of 1.5 m from the slits. The students detect a series of maxima and minima in the received signal strength.

- (a) Explain why microwaves are particularly suitable for demonstrating interference in a classroom setting, compared to using visible light or sound waves.
- (b) Using the formula for constructive interference ($d \sin \theta = n\lambda$), calculate the angular position of the first-order maximum ($n = 1$).
- (c) Determine the linear distance along the arc from the central maximum ($n = 0$) to the first-order maximum.
- (d) The students then cover one of the slits with a metal plate. Describe the new pattern they observe with the receiver. Explain why the sharp interference fringes disappear and what single-slit diffraction pattern is seen instead.
- (e) If the slit separation d were reduced to 6 cm, predict how the angular separation between adjacent maxima would change. Explain your reasoning.

By kasumba Najjib

Email: najjibkasumba@gmail.com

Question 94:

An optician in Kampala is testing the curvature of a high-precision convex lens surface by placing it on a flat glass test plate and observing Newton's Rings under sodium light. He notices that at the very centre, where the lens should be in contact with the plate, the fringe is not perfectly black but a dark grey colour. He realises this indicates that there is not perfect "optical contact" and a tiny dust particle or an imperfection is present.

- (a) Explain why the centre of the Newton's Rings pattern is normally a dark spot. Refer to the phase change of π upon reflection at the lower glass-air interface.
- (b) If the central spot is not perfectly dark, what does this imply about the separation between the lens and the flat plate at the point of closest approach?
- (c) The optician counts 25 dark rings outwards from the centre over a radial distance of 6.2 mm. If the wavelength of the sodium light is 589 nm, calculate the radius of curvature of the convex lens surface. (Use the formula for the radius of the m -th dark ring: $r_m^2 = m\lambda R$).
- (d) Explain why the fringes become progressively closer together as one moves further from the centre.
- (e) If the air gap between the lens and the plate were filled with a transparent oil of refractive index 1.6, how would the appearance of the rings change? Would the rings be more closely spaced or more widely spaced? Explain your answer using the condition for interference.

Question 95:

A mineralogy student at the Department of Geological Survey and Mines in Entebbe is examining a clear rhombohedral crystal of calcite (Iceland spar). She places the crystal over a printed dot on a piece of paper and is amazed to see two distinct images of the dot. When she rotates the crystal, one image remains stationary while the other image appears to orbit around it.

- (a) Explain the phenomenon of double refraction (birefringence) exhibited by calcite. What property of the crystal structure causes it to split an incident ray into two refracted rays?
- (b) Name the two refracted rays and describe how they differ in terms of their polarisation state and their adherence to Snell's law.
- (c) The stationary image is produced by the "ordinary" ray (o-ray), and the orbiting image by the "extraordinary" ray (e-ray). Explain why the e-ray does not obey the ordinary Snell's law of refraction and why its deviation depends on the orientation of the crystal.
- (d) If a polaroid filter is placed over the calcite crystal and rotated, one of the two images can be made to disappear, then the other. Explain why this happens. What does this demonstrate about the polarisation of the o-ray and the e-ray?

Best of the best

(e) State one practical application of birefringent materials, such as in optical filters or in liquid crystal displays (LCDs).