Q.01

Identify the number of neutrons in a nucleus of polonium-210 ($^{210}_{84}p$).

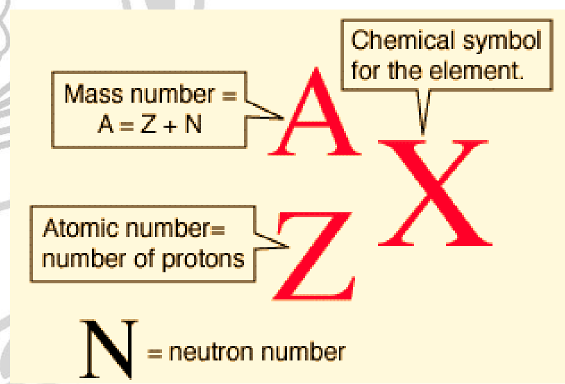
Explanation:

A) 294
B) 210
C) 84
D) 126 √

$N = A - Z$

$= 210 - 84$

$= 126$



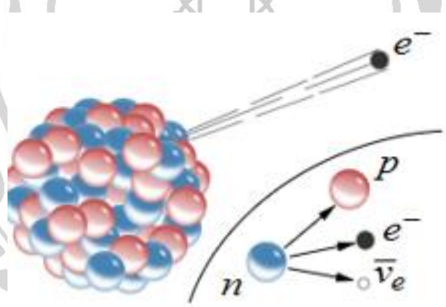
Q.1(2)

A polonium-210 nucleus is formed when a stationary nucleus of bismuth-210 decays.

A beta-minus (β−) particle is emitted in this decay. Outline, with reference to β− decay, why bismuth-210 and polonium-210 have different proton numbers.

Explanation:

- A neutron becomes a proton inside a nucleus during beta decay, which also results in the emission of a beta-minus () particle.
- One of the neutrons in bismuth-210 (Bi-2110) undergoes decay, turning into a proton.
- A particle known as the released during the decay process carries away the extra energy and charge created by the neutron-to-proton conversion.



$$ {}^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e + ({}^{0}_{0}\bar{v}_e) $$

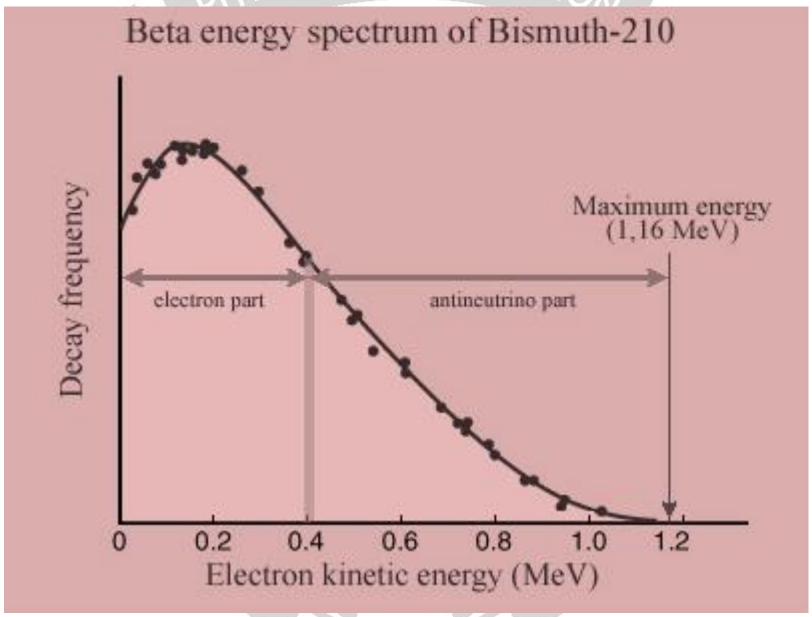
- As a result, the nucleus's proton count (atomic number) rises by one, resulting in the creation of polonium-210 (Po-210).
- Due to the decay process, which entails the conversion of a neutron into a proton and results in a rise in the atomic number of the nucleus, bismuth-210 and polonium-210 have distinct proton numbers.

Q.1(3)

The kinetic energies of β− particles emitted from a sample of bismuth-210 are analysed. These β− particles have a range of kinetic energies.

The total energy released when each nucleus of bismuth-210 decays to a nucleus of polonium-210 is 1.2 MeV.

Figure 1 shows the variation with E_k of the number of β− particles that have the kinetic energy E_k.



Explain how the data in **Figure 1** support the hypothesis that a third particle is produced during β− decay.

Explanation:

- Figure 1 The 1.2 MeV total energy produced during the disintegration of bismuth-210 to polonium-210.
- We would expect to see a constant distribution of kinetic energy for these particles if only particles were emitted during the decay process. As seen in Figure 1, this would result in a smooth curve showing a continuous range of kinetic energy with no discernible characteristics.

- But above kinetic energy spectrum of the particles may show a clear energy gap or discontinuity in spectrum**.**

As a result: The occurrence of this energy gap supports the existence of the third particle, an electrically neutral and almost massless particle, the neutrino or antineutrino, in decay

Q.1(4)

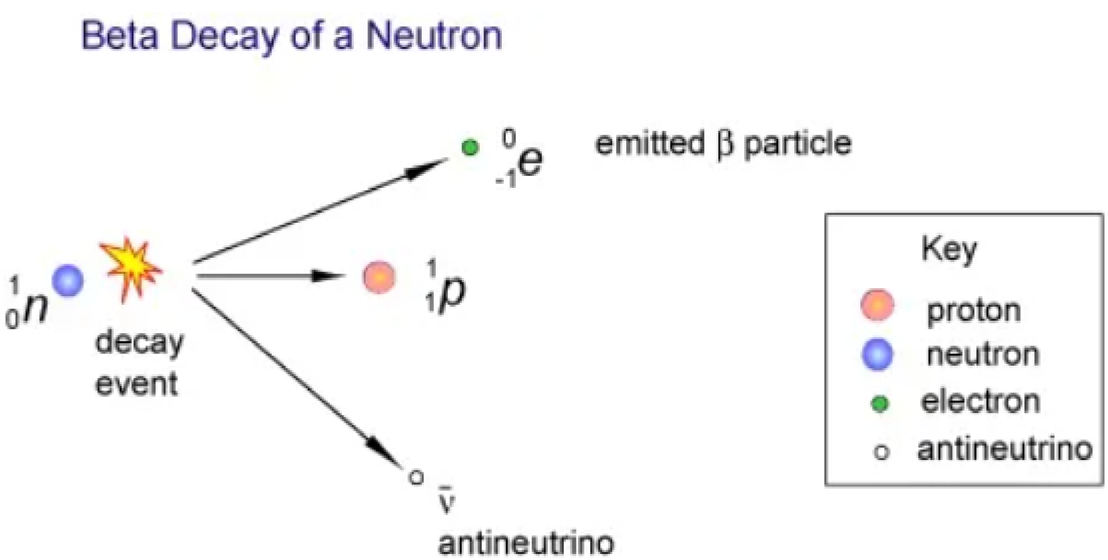
This third particle is an electron antineutrino.

Explain why an electron antineutrino, rather than an electron neutrino, is produced during β− decay.

Explanation:

β− decay involves the conversion of a neutron into a proton.

- The decay process is represented as: n → p + e− + ν̄e.
- Conservation laws dictate the production of an electron and an antineutrino.
- Lepton number must be conserved, resulting in the emission of an electron and an antineutrino.
- Neutrons and protons have a lepton number of 0.
- Electrons have a lepton number of +1, while antineutrinos have a lepton number of -1.
- To conserve lepton number, an antineutrino is produced.
- Electric charge must also be conserved.
- Neutrons have a charge of 0, while protons have a charge of +1.
- An electron with a charge of -1 is emitted to maintain charge conservation.



Formation of Antineutrino from Beta Decay

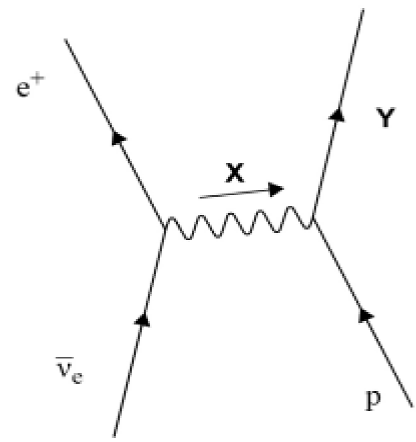
Q.1(5)

A large tank of water is used as part of an electron antineutrino detector. An electron antineutrino $\bar{\nu}_e$ enters the tank and interacts with a proton (p).

Figure 2: represents this interaction

Identify X and Y.

Figure 2



Interaction: The electron antineutrino ($\bar{\nu}_e$) interacts with a proton (p) in the water tank.

$\bar{\nu}_e + p \rightarrow X + Y$

Charge Conservation:

- Initial charge: $\bar{\nu}_e$ (0), p (+1)
- Final charge: e+ (+1), n (0)
- Total charge before interaction: 0 + (+1) = +1
- Total charge after interaction: (+1) + (0) = +1
- Charge conservation is satisfied.

Lepton Conservation:

- Initial Lepton number: ν̅e (-1), p (0)
- Final Lepton number: e+ (-1), n (0)
- Total Lepton Before interaction: (-1) + (0) = -1
- Total Lepton After interaction: (-1) + (0) = -1
- Lepton number conservation is satisfied.

Baryon Conservation:

- Initial baryon number: ν̅e (0), p (+1)
- Final baryon number: e+ (0), n (+1)
- Total baryon number before interaction:(0) + (+1) =+1
- Total baryon number after interaction: (0) + (+1) = +1
- Baryon conservation is satisfied.

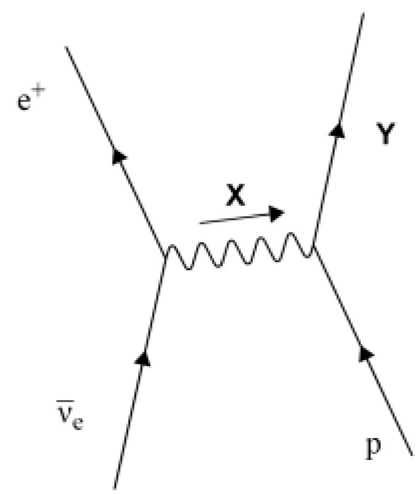
In summary:
the mathematical representation of the interaction is as follows: ν̅e + p → n + W-
where n represents a neutron and W- represents a negatively charged W boson

Q.1(6)

The positron produced in the interaction in Figure 2 slows down and collides with a lepton in a molecule of water.

Describe the process that occurs when the positron collides with this lepton. In your answer you should identify the lepton in the molecule of water.

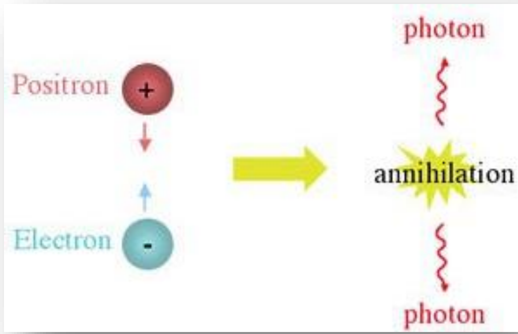
Figure 2

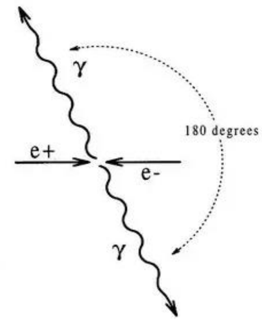


Explanation:

- A positron, which is the antiparticle of an electron, interacts with an electron in a water molecule (H2O).
- The positron and electron, having opposite charges, attract each other due to the electromagnetic force.
- Upon collision, the positron and electron annihilate each other.
- The annihilation process conserves the total charge of the system, resulting in the neutralization of their combined charges (+1 and -1).
- Energy is released during annihilation, typically in the form of gamma rays.
- Gamma rays are high-energy photons with no charge and very short wavelengths.

The gamma rays generated can propagate through the water molecule or interact with other atoms or molecules present in their path.





Q.1(7)

The range of the electromagnetic interaction is infinite.

Table 1: gives the range of the strong nuclear interaction and the range of the weak nuclear interaction.

Table 1

Interaction	**Range / m**
strong nuclear	10^{-15}
weak nuclear	10^{-18}

Deduce whether the positron or the electron antineutrino is likely to travel the shorter distance in the tank of water before interacting.

Explanation:

Factors affecting the distance traveled before interaction in a tank of water:

1. Particle Type:
   - Positron (positively charged particle)

- Electron Antineutrino (negatively charged particle)

2. Interaction Types:
    - Positron: Primarily interacts through the electromagnetic interaction (infinite range).
    - Electron Antineutrino: Primarily interacts through the weak nuclear interaction (range of approximately 10^{-18} meters).

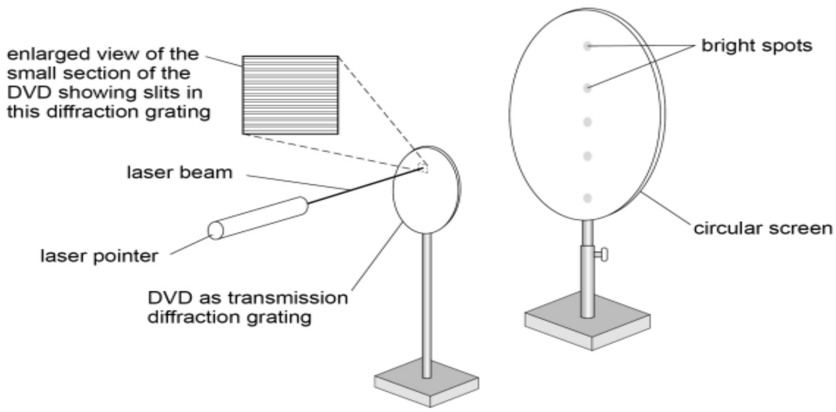
Based on the above information:

- The range of the electromagnetic interaction is infinite, implying that the positron can potentially travel a long distance through water without significant interaction.
- The weak nuclear interaction has a much shorter range (approximately 10^{-18} meters) compared to the electromagnetic interaction.
- Consequently, the electron antineutrino is likely to travel a shorter distance in the tank of water before interacting compared to the positron. The limited range of the weak nuclear interaction would cause the electron antineutrino to interact relatively sooner than the positron.

Q. 2

A student removes the reflective layer from a DVD. She uses the DVD as a transmission diffraction grating.
Figure 3 shows light from a laser pointer incident normally on a small section of this diffraction grating. The grooves on this section act as adjacent slits of the transmission diffraction grating.
A vertical pattern of bright spots (maxima) is observed on a circular screen behind the disc.

Figure 3



Q.2(1)

Light of wavelength λ travels from each illuminated slit, producing maxima on the screen. State the path difference between light from adjacent slits when this light produces a first-order maximum on the screen.

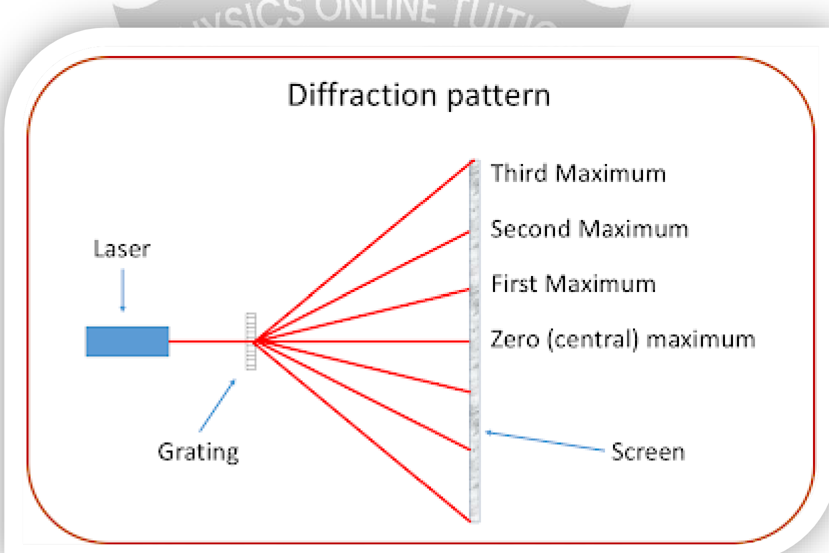
Explanation:

- A student removes the reflective layer from a DVD to use it as a transmission diffraction grating.
- Light from a laser pointer is incident normally on a small section of the diffraction grating.
- The grooves on this section act as adjacent slits of the transmission diffraction grating.
- A circular screen is placed behind the disc to observe the diffraction pattern.
- The observed pattern consists of a vertical arrangement of bright spots (maxima).

- We are interested in the path difference between light from adjacent slits when it produces a first-order maximum on the screen.
- Path Difference = λ

  $d \sin(\theta) = m\lambda$

- For the first-order maximum ($m = 1$), the path difference is equal to one wavelength (λ).



Q.2(2)

Explain how light from the diffraction grating forms a maximum on the screen.

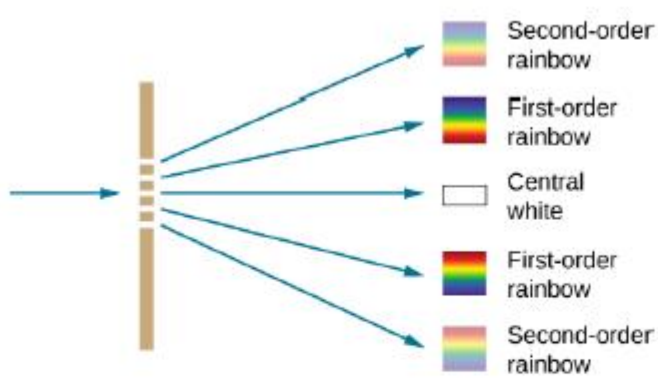
Explanation:

The superposition of waves and constructive interference play a fundamental role in this phenomena.

1. Superposition: When waves from multiple sources overlap, they combine or superimpose to create a resultant wave.
2. Constructive Interference: It occurs when waves align in phase, resulting in reinforcement and increased amplitude (intensity) of the resultant wave.

As a result

At certain angles or positions on the screen, the waves from the adjacent slits arrive in phase (with the same phase) and superimpose constructively. This constructive interference leads to the formation of bright spots or maxima on the screen. These maxima correspond to regions where the intensity of light is enhanced due to the superposition of waves.



Q.2(3)

The student has three discs: a Blu-ray disc, a DVD and a CD. She removes the reflective coating from the discs so that they act as transmission diffraction gratings. These diffraction gratings have different slit spacings. The student also has two laser pointers A and B that emit different colours of visible light.

Table 2 and Table 3 show information about the discs and the laser pointers

Table 2

Disc	Slit spacing / μm
Blu-ray disc	0.32
DVD	0.74
CD	1.60

Table 3

Laser pointer	Wavelength of light emitted / 10^{-7} m
A	4.45
B	6.36

Deduce the combination of disc and laser pointer that will produce the greatest possible number of interference maxima.

Explanation:

In a diffraction grating, the greatest possible number of interference maxima is determined by the formula:

$N = (2d\sin\theta) / \lambda$

Where:

N is the number of interference maxima,

d is the spacing between the lines of the grating,

θ is the angle of diffraction

λ is the wavelength of light.

put $\sin\theta = 90$

For the Blu-ray disc and Laser Pointer A:

N_A = (2 * 0.32 * sin(90°)) / 4.45

N_A = (2 * 0.32 * 1) / 4.45

N_A = 0.144

For the Blu-ray disc and Laser Pointer B:

N_B = (2 * 0.32 * sin(90°)) / 6.36

N_B = (2 * 0.32 * 1) / 6.36

N_B = 0.101

For the DVD and Laser Pointer A:

N_A = (2 * 0.74 * sin(90°)) / 4.45

N_A = (2 * 0.74 * 1) / 4.45

N_A = 0.332

For the DVD and Laser Pointer B:

N_B = (2 * 0.74 * sin(90°)) / 6.36

N_B = (2 * 0.74 * 1) / 6.36

N_B = 0.232

For the CD and Laser Pointer A:

N_A = (2 * 1.60 * sin(90°)) / 4.45

N_A = (2 * 1.60 * 1) / 4.45

N_A = 0.718

For the CD and Laser Pointer B:

N_B = (2 * 1.60 * sin(90°)) / 6.36

N_B = (2 * 1.60 * 1) / 6.36

N_B = 0.505

Table for Laser Pointer A:

Disc	Slit spacing (μm)	N (Laser A)
Blu-ray disc	0.32	0.72
DVD	0.74	0.42
CD	1.60	0.72

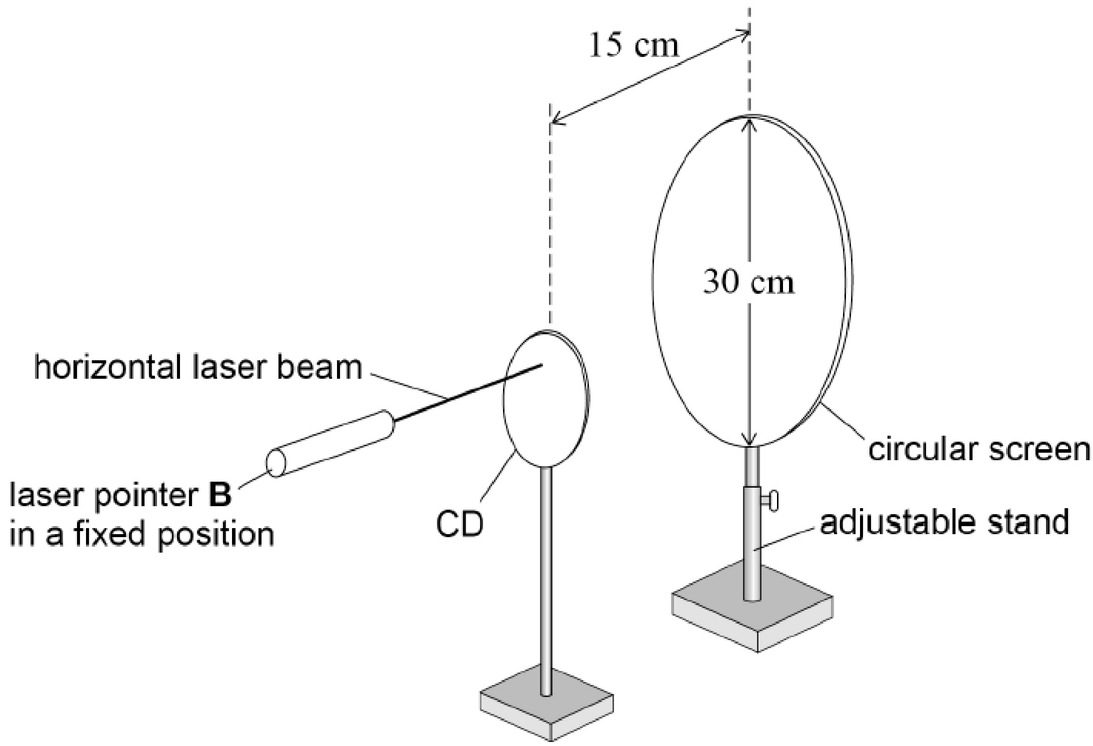
Table for Laser Pointer B:

Disc	Slit spacing (μm)	N (Laser B)
Blu-ray disc	0.32	0.31
DVD	0.74	0.23
CD	1.60	0.50

Q.2(4)

The student uses the CD and laser pointer **B** as shown in **Figure 4**. A diffraction pattern is produced on the screen. Laser pointer **B** and the CD are in fixed positions. The laser beam is horizontal and incident normally on the CD. The height of the screen can be adjusted

Figure 4



The screen has a diameter of 30 cm and is positioned behind the CD at a fixed horizontal distance of 15 cm.
The student plans to adjust the height of the screen until she observes the greatest number of spots.
The student predicts that, using this arrangement, the greatest number of spots on the screen will be 3.
Determine whether the student's prediction is correct.

Explanation:

To determine whether the student's prediction is correct and find the angles for the zeroth and second-order spots on the screen, we can use the principles of diffraction.

The number of spots observed on the screen is determined by the interference pattern created by the diffracted light from the CD. The number of spots is related to the number of bright fringes, which depends on the angle of diffraction and the wavelength of the laser.

To calculate the angles for the zeroth and second-order spots, we can use the formula for the angle of diffraction in the case of a single slit:

$\sin(\theta) = m * \lambda / d$

where θ is the angle of diffraction, m is the order of the fringe, λ is the wavelength of the laser, and d is the spacing of the diffracting elements (in this case, the CD).

Given:
$\lambda = 6.36 \times 10^{-7}$ m
$d = 1.6 \times 10^{-6}$ m

Zeroth-order spot (n = 0):
$\sin(\theta_0) = 0 * \lambda / d = 0$

First-order spot (n = 1):
$\sin(\theta_1) = 1 * \lambda / d$

$\theta_1 = \sin^{-1}(1 * \lambda / d)$
$= \sin^{-1} (1 * 6.36 \times 10^{-7} / 1.6 \times 10^{-6})$
$\approx \sin^{-1} (0.396)$
≈ 22.89 degrees

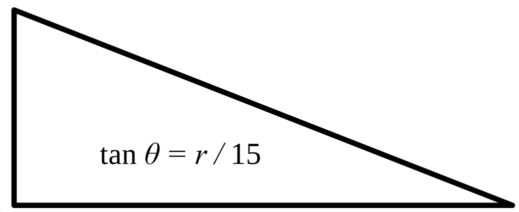
Second-order spot (n = 2):
$\sin(\theta_2) = 2 * \lambda / d$

$\theta_2 = \sin^{-1} (2 * \lambda / d)$
$= \sin^{-1} (2 * 6.36 \times 10^{-7} / 1.6 \times 10^{-6})$
$\approx \sin^{-1} (0.8)$
≈ 53.13 degrees

Therefore, the calculated angles for the zeroth, first, and second-order spots are approximately:

According to this relation $\tan \theta = r / 15$

Zeroth-order spot: $\theta_0 = 0$ degrees
First-order spot: $\theta_1 \approx 23$ degrees
Second-order spot: $\theta_2 \approx 53$ degrees



Angles:
Zeroth-order spot: $\theta_0 = 0$ degrees
First-order spot: $\theta_1 \approx 23$ degrees
Second-order spot: $\theta_2 \approx 53$ degrees

Lengths:
Zeroth-order spot: 15 cm
First-order spot: (15 cm) * tan(23 degrees) ≈ 6.32 cm
Second-order spot: (15 cm) * tan(53 degrees) ≈ 20.96 cm

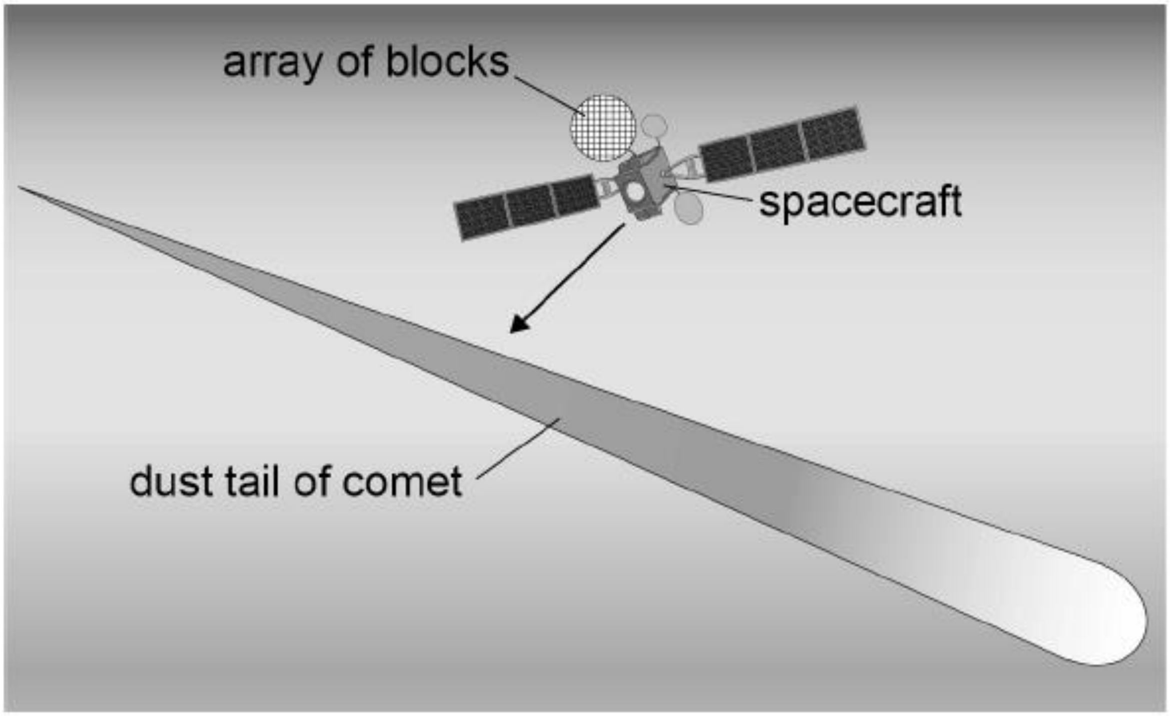
To summarise, the distances from the CD to each spot on the circular screen are approximately:

Zeroth-order spot: 15 cm
First-order spot: 6.32 cm
Second-order spot: 20.96 cm

Q.3

Figure 5 shows a spacecraft travelling towards a comet.
The spacecraft has an array of blocks designed to capture small dust particles from the comet's tail

Figure 5



To test the blocks before launch, a spherical dust particle **P** is fired at a right angle to the surface of a fixed, stationary block.
P has a mass of 1.1 × 10−9 kg. It has a speed of 5.9 × 103 m s−1 when it hits the surface of the block.
P comes to rest inside the block.

Explanation:

To find the energy loss of the particle in terms of kinetic energy, we need to calculate the initial kinetic energy of the particle and subtract the final kinetic energy.

The initial kinetic energy of the particle can be calculated using the formula:

Initial Kinetic Energy = (1/2) * mass * velocity^2

Given:

Mass of the particle, m = 1.1 × 10^(-9) kg

Velocity of the particle, v = 5.9 × 10^3 m/s

Initial Kinetic Energy = (1/2) * (1.1 × 10^(-9) kg) * (5.9 × 10^3 m/s)^2

Calculating the initial kinetic energy:

Initial Kinetic Energy = (1/2) * (1.1 × 10^(-9)) * (34.81 × 10^6) J

Next, since the particle comes to rest inside the block, its final kinetic energy is zero. Therefore, the energy loss can be calculated as:

Energy Loss = Initial Kinetic Energy - Final Kinetic Energy

Energy Loss = Initial Kinetic Energy - 0

Finally, substituting the values:

Energy Loss = (1/2) * (1.1 × 10^(-9)) * (34.81 × 10^6) J - 0

Energy Loss ≈ 0.019 J

Therefore, the energy loss of the particle is approximately 0.019 Joules,

Q.3(2)

P travels a distance of 2.9 cm in a straight line inside the block before coming to rest. The resultant force on **P** varies as it penetrates the block.
Calculate the average force acting on **P** as it is brought to rest

Explanation:

Scenario:

- A spacecraft is traveling towards a comet.
- The spacecraft has an array of blocks designed to capture small dust particles from the comet's tail.
- A spherical dust particle P is fired at a right angle to the surface of a fixed, stationary block.
- Particle P has a mass of 1.1 × 10^(-9) kg and a speed of 5.9 × 10^3 m/s when it hits the block.
- Particle P comes to rest inside the block.

Calculations:

1. Energy Loss of Particle P:

- Initial Kinetic Energy = (1/2) * (1.1 × 10^(-9) kg) * (5.9 × 10^3 m/s)^2
- Energy Loss = Initial Kinetic Energy - Final Kinetic Energy
- Energy Loss ≈ 0.019 J

The work done on the particle is given by:

Work = Force * Distance

Since the resultant force on the particle varies as it penetrates the block, we need to consider the average force over the given distance.

Average Force = Work / Distance

2. Average Force Acting on Particle P:

- Distance Traveled by Particle P = 0.029 m
- Average Force = Energy Loss / Distance
- Average Force = 0.019 J / 0.029 m
- Average Force ≈ 0.655 N

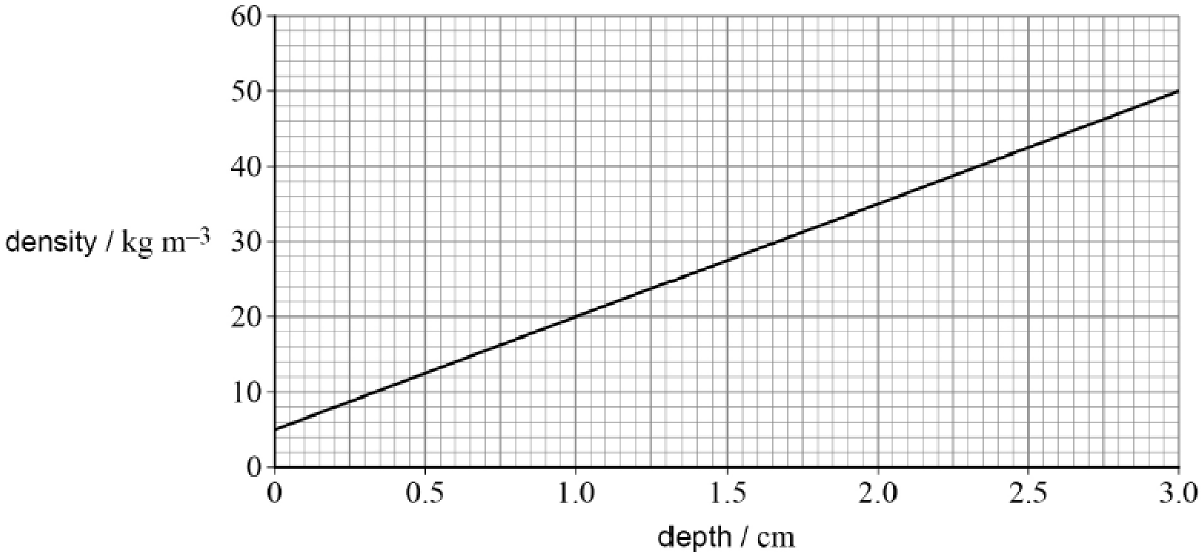
Q.3(4)

The block is rectangular with an area of cross-section of 8.0 cm2 and a thickness

of 3.0 cm.

Figure 6 shows how the density of the block varies with depth up to its maximum thickness.

Figure 6



Explanation:

Calculate the mass of the block.

1. Given the area of cross-section and thickness of the block:
   - Area of cross-section = 8.0 * 10^-4 m²
   - Thickness = 3.0 * 10^-2 m
2. Calculate the volume of the block:
   - Volume = Area of cross-section * Thickness
   - Volume = (8.0 * 10^-4 m²) * (3.0 * 10^-2 m)
   - Volume = 2.4 * 10^-5 m³
3. Find the average density of the block:

- Average density = (50 kg/m³ + 5 kg/m³) / 2
- Average density = 27.5 kg/m³

4. Calculate the mass of the block:
    - Mass = Average density * Volume
    - Mass = (27.5 kg/m³) * (2.4 * 10^-5 m³)
    - Mass = 6.6 * 10^-4 kg

The final answer is a mass of 6.6 * 10^-4 kg for the block.

Q.3(5)

In another test, a spherical particle **Q** is fired at a right angle to the surface of an identical block.
Q has the same mass as **P** and is travelling at the same speed as **P** when it strikes the surface of the block.
Q is made from a less dense material than **P**.
Compare the distance travelled by **Q** with that travelled by **P** as they are brought to rest.

Explanation:

1. Particle Q and particle P have the same initial mass and are traveling at the same speed when Q strikes the surface of the block.
2. Particle Q is made of a less dense material than particle P, implying that Q has a larger volume for the same mass.
3. Due to its larger volume, particle Q will experience a greater air resistance as it travels through the air.

4. Air resistance is a force that opposes the motion of an object moving through the air. It depends on factors such as the shape and size of the object.

5. Particle Q, with its larger volume and higher air resistance, is expected to decelerate more quickly compared to particle P.

6. As a result, particle Q is likely to travel a shorter distance before coming to rest compared to particle P.

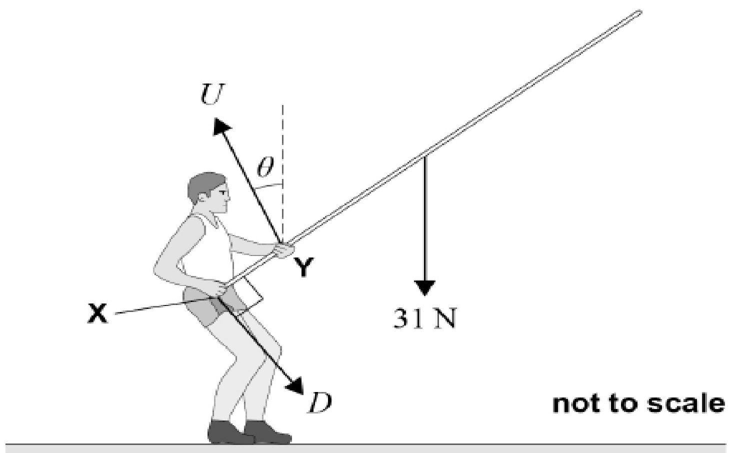
Conclusion

particle Q is projected to travel a shorter distance than particle P before coming to rest due to its bigger volume and higher air resistance. Because particle P is formed of a denser material, it will encounter less air resistance and will likely travel a greater distance before coming to rest.

Q.4

Figure 7 shows an athlete holding a vaulting pole at an angle of 40° to the horizontal.

Figure 7



Forces D and U are exerted on the pole by the athlete's right and left hands respectively.

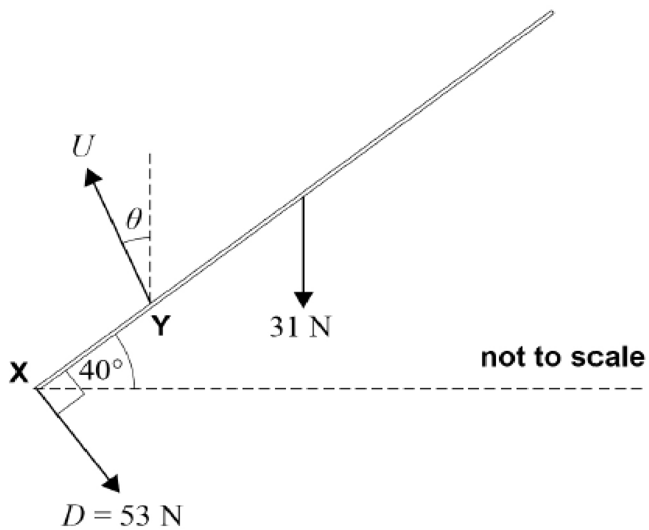
U is applied at point Y at an angle θ to the vertical.

The magnitude of D is 53 N and is applied at 90° to the pole at X.

The uniform pole is in equilibrium. It has a weight of 31 N.

Figure 8 shows the forces acting on the pole.

Figure 8



Q.4(1)

Determine, using a scale diagram, θ and the magnitude of U.

Explanation:

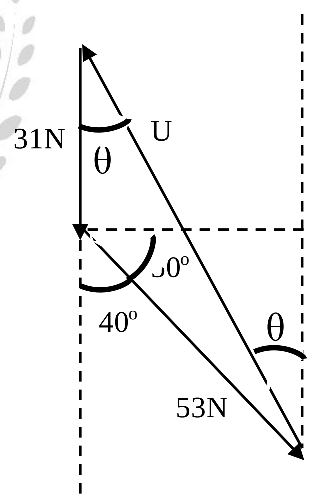
1. Weight of the pole: The weight of the pole is 31 N acting vertically downward.
2. Force D: Force D is applied at point X and has a magnitude of 53 N. It is perpendicular to the pole. Since the pole is at an angle of 40° to the horizontal, the angle between force D and the horizontal is 90° - 40° = 50°.

3. Force U: Force U is applied at point Y and has an unknown magnitude. It is at an angle θ to the vertical. The angle between force U and the vertical is 90° - θ.

To find the magnitude of force U and the angle θ, we'll use the equation $U^2 = a^2 + b^2 - 2ab\cos(\theta)$, where:

- a is the magnitude of force D (53 N).
- b is the magnitude of the weight of the pole (31 N).
- U is the unknown magnitude we're trying to find.
- θ is the angle between forces U and D.

$U^2 = 53^2 + 31^2 + 2 * 53 * 31 * \cos(40°)$



Calculating this equation:

$U^2 \approx 2809 + 961 + 2 * 53 * 31 * 0.7660$

$U^2 \approx 2809 + 961 + 2534.12$

$U^2 \approx 6304.12$

$U \approx \sqrt{6304.12}$

$U \approx 79.4$ N

The magnitude of force U is approximately 79.4 N.

To find the angle θ, we can rearrange the equation:

cos(θ) = (U^2 - 53^2 - 31^2) / (2 * 53 * 31)

cos(θ) = (79.4^2 - 53^2 - 31^2) / (2 * 53 * 31)

cos(θ) = 6327.36 / 3286

cos(θ) ≈ 1.9257

θ ≈ acos(1.9257)

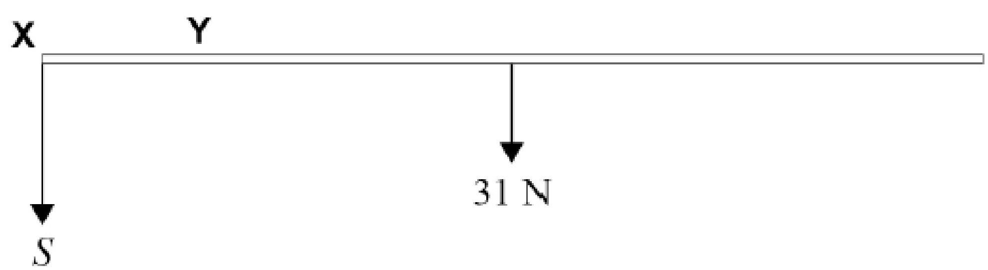
θ ≈ 25.4°

Therefore, the angle θ is approximately 25.4°, and the magnitude of force U is approximately 79.4 N.

Q.4(2)

Figure 9

not to scale



The athlete now moves the pole to a horizontal position. The pole is held stationary in this position.

The athlete's right hand applies a force *S* vertically downwards at **X** as shown in **Figure 9**. The athlete's left hand applies a force *V* at **Y**.

Discuss the differences between the magnitudes and directions of force *U* in **Figure 7** and force *V* applied at **Y** in **Figure 9**.

Explanation:

Differences Between Force U in Figure 7 and Force V in Figure 9:

1. **Magnitude Difference:**
    - In Figure 7, force U is generally greater than the weight of the pole to counterbalance the moment created by the weight.
    - In Figure 9, force V can be smaller as it only needs to balance the weight of the pole.
2. **Direction Difference:**
    - Force U in Figure 7 is applied at an angle, not parallel to the weight of the pole.
    - Force V in Figure 9 is applied vertically downwards, parallel to the weight of the pole.

Justification for Increasing Force V:

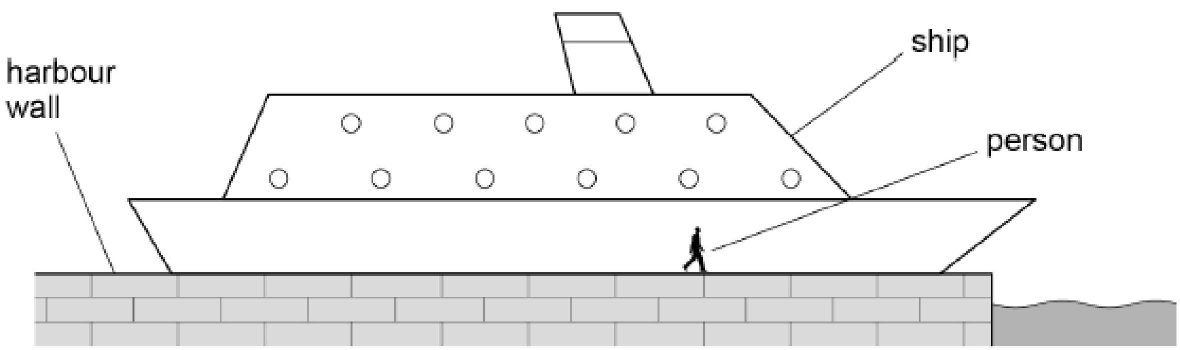
- When the weight of the pole is perpendicular to the pole itself, the moment arm is maximized.
- By increasing force V, the moment created by V (V multiplied by the moment arm) can counterbalance the greater moment created by the weight of the pole.
- Increasing the magnitude of force V allows it to effectively balance the moment due to the weight of the pole and maintain stability.

By considering these differences and justifications, the athlete can ensure equilibrium and maintain the pole in a horizontal position.

Q.5(1)

Figure 10 shows a ship leaving a harbour at a constant velocity.
The ship moves at the same velocity as a person walking on the harbour wall alongside the ship.

Figure 10



The momentum of the ship is approximately 1 × 107 N s.
Estimate the mass of the ship.

Explanation:

Given that the momentum of the ship is approximately 1×10^7 N s and the mass of the ship is unknown, we can use the formula for momentum:

Momentum = mass × velocity

Rearranging the formula to solve for velocity, we have:

velocity = Momentum / mass

Since the person and the ship are moving at the same velocity, we can assume that the velocity of the person is also 1 m/s.

Plugging in the values, we get:

1 m/s = (1 × 10^7 N s) / mass

Simplifying the equation, we find:

mass = (1 × 10^7 N s) / 1 m/s

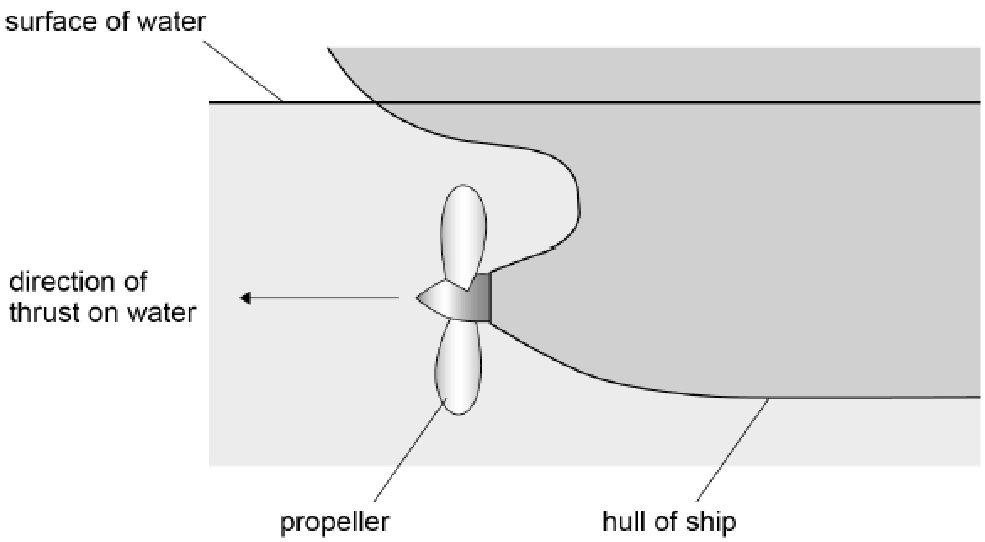
mass = 1 × 10^7 kg

Therefore, the estimated mass of the ship is approximately 1 × 10^7 kg, and we can assume that the velocity of the person walking on the harbour wall alongside the ship is 1 m/s.

Q5(2)

Figure 11 shows the direction of the thrust exerted by the ship's propeller as the propeller rotates. The ship's engine makes the propeller rotate. When more water is accelerated, more work is done by the engine.

Figure 11



Explain, using Newton's laws of motion, how the thrust of the propeller on the water enables the ship to maintain a constant momentum.

Explanation:

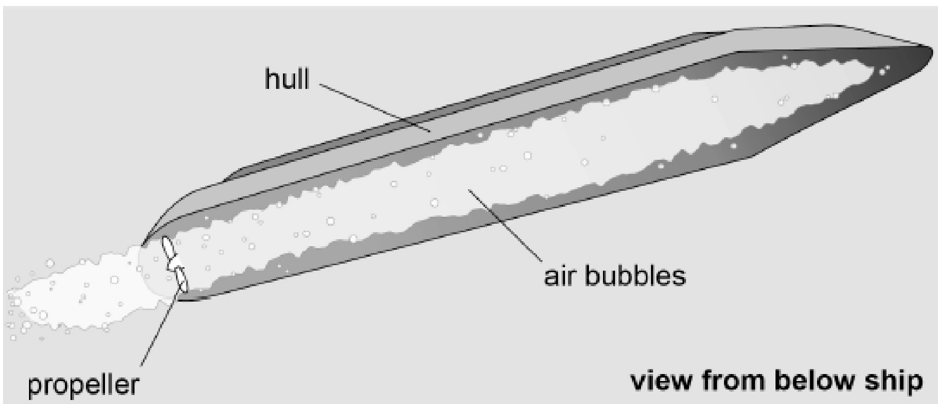
- Newton's First Law of Motion (Law of Inertia): An object at rest tends to stay at rest, and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an external force.

- Newton's Second Law of Motion: The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass (F = ma).
- When the ship's engine rotates the propeller, the propeller blades push against the water, exerting a force known as thrust.
- According to Newton's second law, the thrust of the propeller causes the water to accelerate in the opposite direction.
- Newton's Third Law of Motion: For every action, there is an equal and opposite reaction.
- As the propeller exerts a force on the water, the water exerts an equal and opposite force on the propeller, known as the reaction force or thrust.
- The reaction force or thrust pushes the ship forward in the direction opposite to the accelerated water.
- By continuously exerting a force on the water, the propeller enables the ship to maintain a constant momentum in the forward direction.
- The conservation of momentum applies, keeping the momentum of the ship and the accelerated water system constant unless acted upon by external forces.
- The thrust generated by the propeller compensates for external forces (e.g., friction, air resistance, water resistance), allowing the ship to maintain its momentum and move forward at a constant speed.

Q.5(3)

Figure 12 shows the bottom of the hull with a drag reduction system in operation.
Air bubbles are introduced into the water below the hull. This reduces the work done per second against the drag on the hull at any given speed.
However, when the air bubbles reach the propeller they decrease the mass of water being accelerated by the propeller every second. This decreases the thrust produced by the propeller at a given speed of rotation.

Figure 12



The system enables the ship to save fuel while maintaining the same momentum.
Explain why the system delivers this fuel saving.
In your answer, consider the effects of the introduction of the system on
• the thrust
• the drag on the hull.

Explanation:

Effects of the drag reduction system:

Thrust:

- Introduction of air bubbles reduces the mass of water being accelerated by the propeller every second.
- Decreased mass of water being accelerated leads to a reduction in the thrust produced by the propeller at a given speed of rotation.

Hull Drag:

- Air bubbles create a layer of air between the hull and the surrounding water.
- This air layer acts as a lubricant, reducing frictional forces between the hull and the water.
- Reduction in frictional forces decreases the drag on the hull as the ship moves through the water.
- The introduction of air bubbles helps in lowering the overall drag experienced by the hull.

Fuel Saving:

- The reduction in hull drag outweighs the decrease in propeller thrust caused by the air bubbles.

1. Less power is required to maintain the ship's speed through the water due to reduced drag.
2. The reduction in power needed translates into fuel savings.
3. The system enables the ship to save fuel while maintaining the same momentum.

   By combining these effects, the drag reduction system helps in reducing the drag on the hull while minimizing the impact on propeller thrust, resulting in fuel savings for the ship.

Q.6

A battery has an emf of 5.30 V and negligible internal resistance.

Q.6(1)

State what is meant by an emf of 5.30 V for this battery.

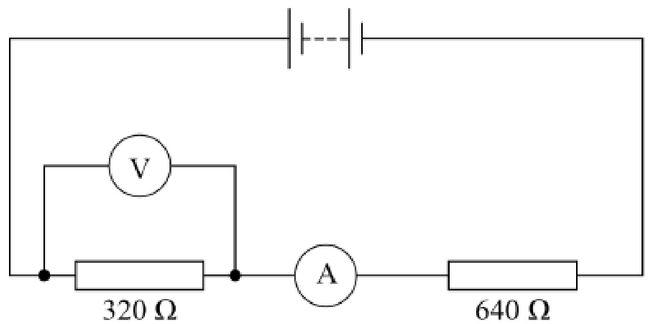
Explanation:

- **Battery emf**: The electromotive force (emf) of the battery is 5.30 V.
- Energy per unit charge: For each coulomb of charge passing through the battery, 5.30 joules of energy are supplied.
- **Total energy transfer**: The emf represents the total energy available to be transferred to the charge passing through the battery.
- Negligible internal resistance: The battery has a negligible internal resistance, meaning that almost all of the emf's energy is available for external use.
- **Usage potential**: The energy supplied by the battery can be utilized to power external devices or perform electrical work.
- **Charge movement**: As the charge moves through the battery, it gains 5.30 joules of energy per coulomb.

Q.6(2)

Figure 13 shows the battery connected into a circuit.

Figure 13



The ammeter is ideal.
The voltmeter is non-ideal and has a resistance *R*.
The reading on the voltmeter is 1.05 V when it is connected across the 320 Ω resistor.
Show that the reading on the ammeter is approximately 7 mA.

Explanation:

1. Given Information:
   - Total EMF across the battery: 5.30 V
   - Reading on the voltmeter (across 320 Ω resistor): 1.05 V
2. Calculation of EMF across 640 Ω resistor:

- EMF across 640 Ω resistor = Total EMF - Reading on voltmeter
- EMF across 640 Ω resistor = 5.30 V - 1.05 V
- EMF across 640 Ω resistor = 4.25 V

3. Calculation of Current across 640 Ω resistor:
    - Current across 640 Ω resistor = EMF across 640 Ω resistor / Resistance of 640 Ω resistor
    - Current across 640 Ω resistor = 4.25 V / 640 Ω
    - Current across 640 Ω resistor ≈ 0.006640625 A
    - Current across 640 Ω resistor ≈ 6.64 mA

Therefore:

The reading on the ammeter (which measures the total current) will be approximately 7 mA

Q.6(3)

Show that the resistance *R* of the voltmeter is approximately 300Ω.

Explanation:

Calculation of Equivalent Resistance in a Parallel Circuit

1. Given Information:
   - Total resistance of the parallel circuit: 1.59 Ω
   - Resistance of the 320 Ω resistor
   - Resistance of the voltmeter (R)
2. Calculation of Equivalent Resistance:
   - Apply the formula for resistors in parallel:
     - 1/Equivalent Resistance = 1/Resistance1 + 1/Resistance2 + 1/Resistance3 + ...
   - In this case, we have two resistors connected in parallel (320 Ω resistor and R of the voltmeter):
     - 1/Equivalent Resistance = 1/320 Ω + 1/R
   - Substitute the total resistance (1.59 Ω) into the equation:
     - 1/1.59 Ω = 1/320 Ω + 1/R
   - Find a common denominator and simplify the equation:
     - 320 Ω * R * (1/1.59) = R + 1.59
   - Isolate the term with R on one side:
     - 320 Ω * R * (1/1.59) - R = 1.59
   - Simplify the left side of the equation:
     - (320 Ω - 1.59) * R = 1.59
   - Solve for R:
     - R = 1.59 / (320 Ω - 1.59)
   - Calculate the value of R:
     - R ≈ 300 Ω

Q.6(4)

The voltmeter is now connected across the battery terminals.
Calculate the power dissipated in the voltmeter.

Explanation:

Given that the internal resistance of the voltmeter is 300 Ω and the voltage across the voltmeter is 5.0 V, we can calculate the power dissipated using the formula:

Power = (Voltage)^2 / Resistance

Substituting the values:

Power = (5.0 V)^2 / 300 Ω
= 25.0 V^2 / 300 Ω
= 0.0833 V^2/Ω

To express the answer in watts, we need to convert V^2/Ω to watts by dividing by the resistance (1 Ω):

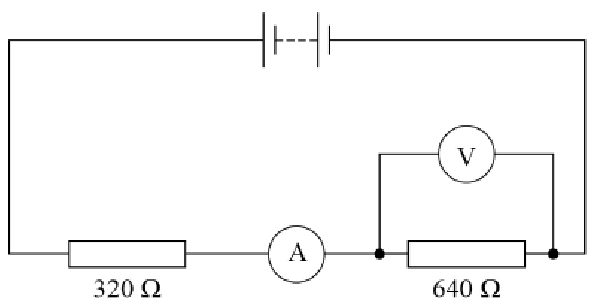
Power = 0.0833 V^2/Ω / 1 Ω
= 0.0833 W

Therefore, the power dissipated in the voltmeter is approximately 0.0833 watts.

Q.6(5)

The voltmeter is now connected across the 640 Ω resistor as shown in **Figure 14**

Figure 14



The reading on the voltmeter is 2.10 V.

When the voltmeter was connected across the 320 Ω resistor, as shown in Figure 13, the reading on the voltmeter was 1.05 V.

Explain why the sum of these voltmeter readings does not equal the emf of the battery.

Explanation:

- The position of the voltmeter in a circuit affects the current because the voltmeter's internal resistance alters the total resistance in the branch it connects to.
- The change in resistance leads to a change in current, as per Ohm's Law.
- Therefore, when measuring voltage with a voltmeter, it is essential to recognize and consider the impact on current due to the voltmeter's internal resistance.

Q.7 Optical fibres are used to carry pulses of light.

Q.7(1)

Explain what is meant by modal dispersion in an optical fibre.

Explanation:

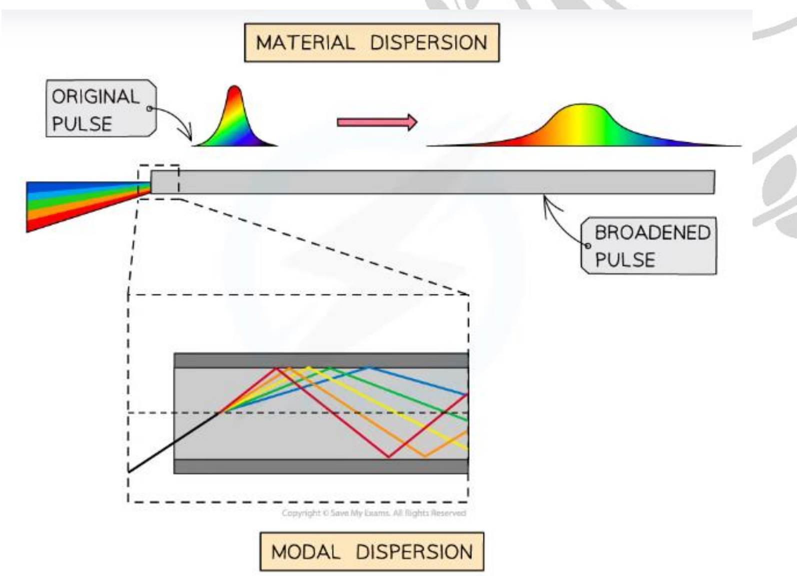
Modal Dispersion:

1. Definition: Modal dispersion refers to the spreading out or broadening of pulses of light in an optical fiber. Or (light pulses in an optical fibre spread out due to varying angles of incidence in the original pulse, this is known as modal dispersion.)

2. Cause: It occurs due to the presence of multiple modes or paths that light can take within the fiber.(When light pulses in an optical fibre spread out due to varying angles of incidence in the original pulse, this is known as modal dispersion.)

3. This is more noticeable in larger cores because light travelling down the core's axis travels a shorter distance than light experiencing total internal reflection at the core-cladding boundaries.
4. Effect: Different modes have different path lengths, causing components of the pulse to experience varying travel times.
5. Consequences: Modal dispersion leads to pulse broadening, distortion, and limitations in data transmission rate and quality.
6. Solutions: Graded-index multimode fibers or single-mode fibers are used to minimize or eliminate modal dispersion.

Graded-index fiber is an optical fiber with a varying refractive index profile across its core, designed to reduce modal dispersion by equalizing the travel times of different modes.



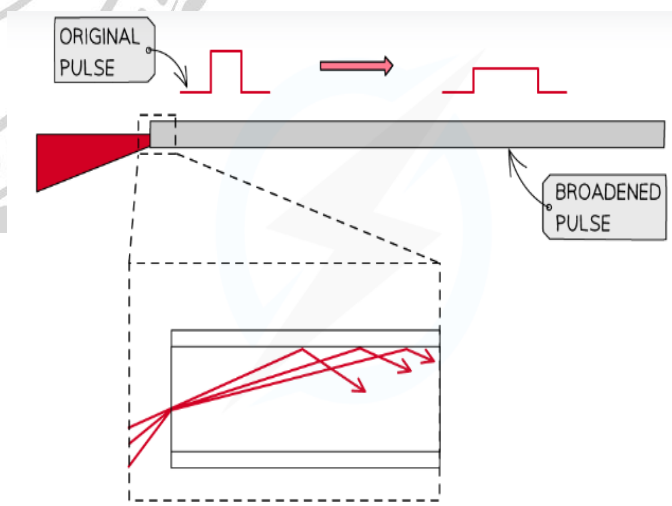
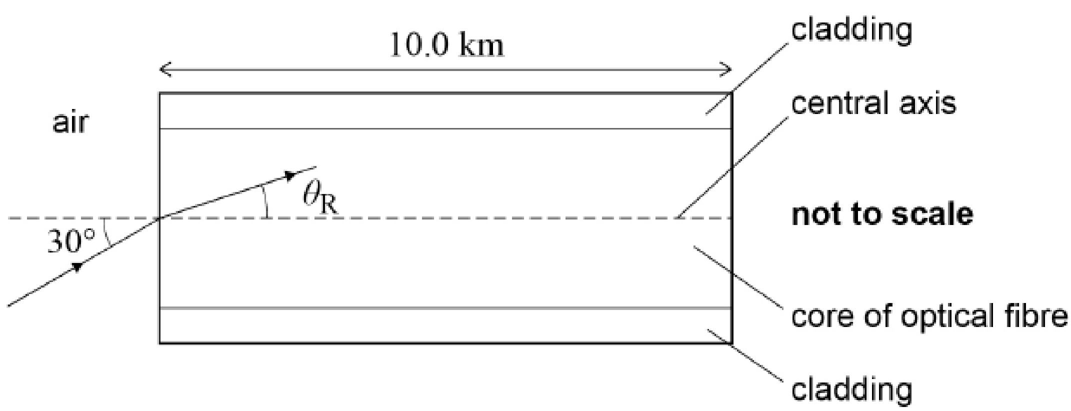


Figure 15 shows a ray of light incident on the central axis of an optical fibre at an angle of incidence of 30°. The optical fibre is straight and horizontal and has a length of 10.0 km.

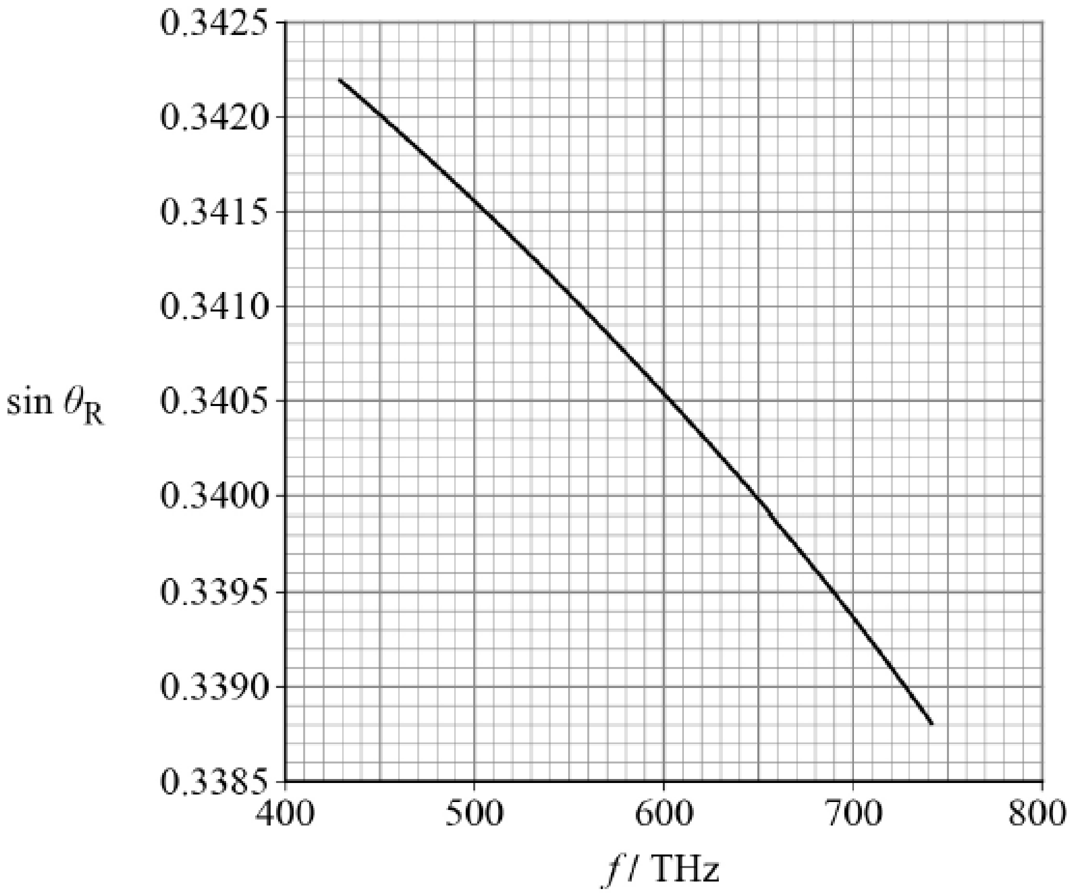
Figure 15



For light incident on the core at a given angle of incidence, the angle of refraction θR varies with the frequency f of the light.

Figure 16 shows how sin θR varies with f when the angle of incidence is 30°.

Figure 16



The transit time is the time between a pulse of light entering and leaving the optical fibre.
A single pulse of blue light is incident on the air−core boundary at an angle of incidence of 30°.
The transit time of this pulse along the 10 km length of the optical fibre is 5.225 × 10−5 s.

Q.7(2)

Show that the horizontal component of the velocity of the pulse is approximately 1.9 × 108 m s−1.

Explanation:

Determine the horizontal component of the velocity of the pulse:

1. Given information:
   - Angle of incidence: 30°
   - Length of the optical fiber: 10.0 km (or 10,000 m)
   - Transit time of the pulse: 5.225 × 10^(-5) s
2. Use the formula for velocity: velocity = distance / time
3. Substitute the values into the formula: velocity = 10,000 m / (5.225 × 10^(-5) s)
4. Perform the calculation: velocity ≈ 1.913 × 10^8 m/s
5. Round the result to three significant figures: velocity ≈ 1.9 × 10^8 m/s

Therefore, the horizontal component of the velocity of the pulse is approximately 1.9 × 10^8 m/s.

Q.7(3)

The frequency of the blue light in the pulse is 720 THz.
Calculate the speed of the blue light in the core of the optical fibre

Explanation:

Determine the speed of the blue light in the core of the optical fiber:

1. Given information:
   - Frequency of the blue light = 720 THz
   - Angle of incidence (theta1) = 30°
   - Sine of angle of refraction = 0.3390
   - Refractive index of incident medium (n_1) = 1
   -

2. Use Snell's law to relate the angles of incidence and refraction:

$$n1 * \sin(\theta_1) = n2 * \sin(\theta_2)$$

3. Substitute the given values into Snell's law:
   1 * sin(30°) = n2 * 0.3390
4. Solve for n2 (refractive index of the core):
   n2 ≈ 0.5 / 0.3390 n2 ≈ 1.475
5. Use the refractive index formula to calculate the speed of light in the core:
   v = c / n
6. Substitute the values into the formula:
   v ≈ (3 × 10^8 m/s) / 1.475
7. Perform the calculation: v ≈ 2.034 × 10^8 m/s

Therefore, the speed of the blue light in the core of the optical fiber is approximately 2.034 × 10^8 m/s.

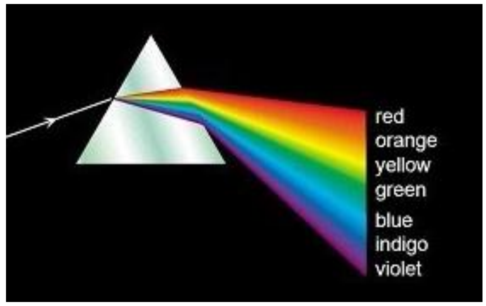
Q.7(4)

Two pulses of monochromatic light are incident normally on the air−core boundary. They then travel along the central axis of the core.
One pulse consists of blue light; the other consists of red light.
Explain, with reference to refractive index, why the pulse of red light has a shorter transit time than the pulse of blue light.

Explanation:

1. Refractive index: It measures how much the speed of light is reduced when passing through a medium compared to its speed in a vacuum.
2. Higher refractive index of the core: The core of the optical fiber has a higher refractive index than air.
3. Refraction: When light transitions from air to the core, it bends towards the normal and slows down due to the higher refractive index.
4. Blue light: Blue light has higher energy and frequency compared to red light.
5. Greater reduction in speed: The higher energy of blue light causes a larger reduction in speed when entering the higher refractive index core.
6. Longer transit time: The slowed-down blue light pulse takes more time to traverse the fiber's length.
7. Red light: Red light, with lower energy, is less affected by the higher refractive index of the core.
8. Shorter transit time: The red light pulse experiences less slowing down and, therefore, has a shorter transit time.

In summary, the higher refractive index of the core causes more significant slowing down of the blue light pulse, resulting in a longer transit time. The red light pulse, with its lower energy and less affected by the refractive index, travels faster and has a shorter transit time.



Q.7(5)

Another two pulses, identical to the pulses in Question **07.4**, are incident on the central axis of the optical fibre and travel along its length.
However, the pulse of red light and pulse of blue light are now incident on the air−core boundary at an angle of incidence of 30°.
Suggest **one** reason why the difference in their transit times may **not** be the same as in Question **07.4**.

Another two pulses, identical to the pulses in Question **07.4**, are incident on the central axis of the optical fibre and travel along its length.

However, the pulse of red light and pulse of blue light are now incident on the air−core boundary at an angle of incidence of 30°.

Suggest **one** reason why the difference in their transit times may **not** be the same as in Question **07.4**.

Explanation:

- One reason why the difference in transit times between the pulse of red light and the pulse of blue light may not be the same when they are incident at an angle of 30° is due to the phenomenon of chromatic dispersion.
- Chromatic dispersion is the phenomenon where different wavelengths (colors) of light travel at different speeds through a medium. In an optical

fiber, this dispersion arises from the material properties of the fiber and can lead to a difference in the propagation velocities of different colors of light.

- Since red light and blue light have different wavelengths, they can experience different levels of chromatic dispersion in the optical fiber. This means that their respective transit times can be affected differently by the dispersion effects.