Electromagnetism and Optics: Final Exam

13 May 2026

Name: _____ **Total:** **/155**

Instructions

- There are 18 questions on 12 pages.
- Show your reasoning and calculations and always explain your answers.

Physical constants and useful formulae

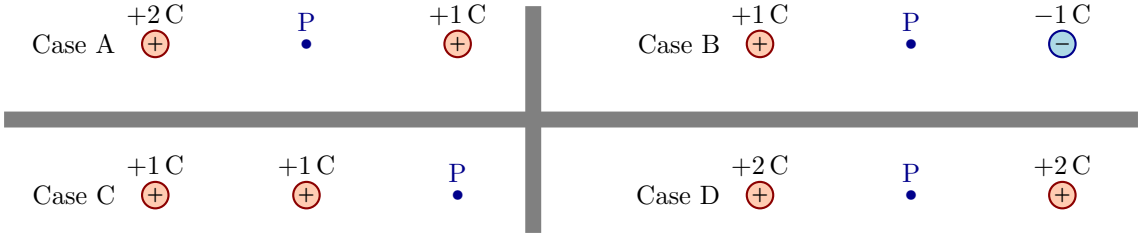
$$e = 1.60 \times 10^{-19}\,\text{C} \qquad q_{\text{electron}} = -e \qquad q_{\text{proton}} = +e \qquad q_{\text{area sphere}} = 4\pi r^2$$

$$m_{\text{electron}} = 9.11 \times 10^{-31}\,\text{kg} \qquad m_{\text{proton}} = 1.67 \times 10^{-27}\,\text{kg} \qquad c = 3.0 \times 10^{8}\,\text{m/s}$$

$$k = 8.99 \times 10^{9}\,\text{Nm}^2/\text{C}^2 \qquad \epsilon_0 = 8.85 \times 10^{-12}\,\text{C}^2/\text{Nm}^2 \qquad \mu_0 = 4\pi \times 10^{-7}\,\text{Tm/A}$$

Question 1

Various arrangements of fixed charges are illustrated.



a) In each arrangement a proton is placed at the location marked P. Rank the *magnitudes* of the net forces on the proton from *smallest to largest* (written left to right).

b) Suppose that the proton is replaced by a Helium nucleus which contains two protons and two neutrons. Will the *ranking of the magnitudes* of the net force on the Helium nucleus be any different to that of the single proton? Explain your answer.

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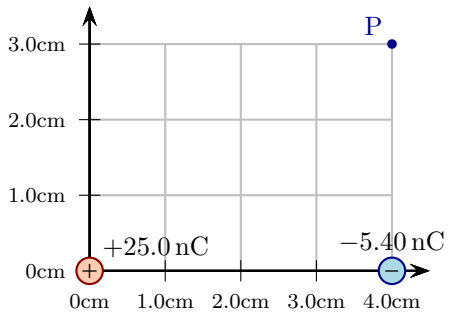
Question 2

Two fixed point charged particles are located as illustrated, where distances are measured in centimeters.



a) Determine the electric field produced (by the two fixed particles) at the location labeled P.

b) A proton is placed at the location labeled P and is released. Determine the acceleration (both magnitude and direction) of the proton at the moment of release.

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Question 3

A proton is fired with speed 2.50×10^5 m/s directly towards a carbon nucleus that is held fixed and is initially infinitely far from the proton. The carbon nucleus has six protons and six neutrons and can be approximated as a point charge. Determine the closest point that the proton approaches the center of the nucleus.

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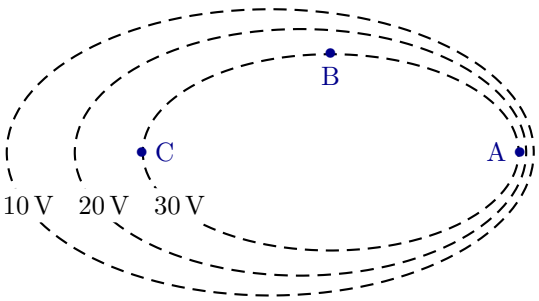
Question 4

Hidden source charges produce the illustrated equipotential lines. Which of the following (choose one) ranks the magnitudes of the electric fields at the indicated points, A, B and C?



i) $E_A = E_B = E_C$

ii) $E_A > E_B > E_C$

iii) $E_A > E_C > E_B$

iv) $E_A < E_B < E_C$

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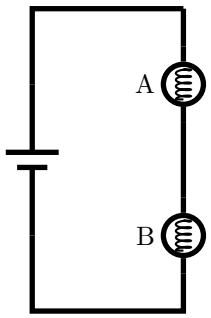
Question 5

A battery and bulbs are connected in the illustrated circuit. Assume that the bulbs obey Ohm's law and the resistance of A is three times the resistance of B. Which of the following (choose one) is true regarding the power delivered by each bulb?



i) $P_A = \frac{1}{9} P_B$

ii) $P_A = \frac{1}{3} P_B$

iii) $P_A = P_B$

iv) $P_A = 3P_B$

v) $P_A = 9P_B$

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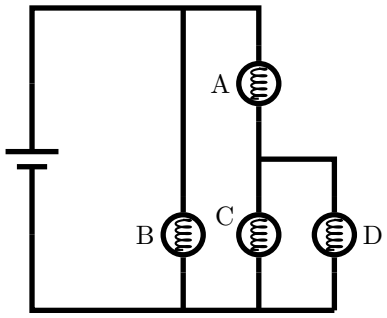
Question 6

A battery and identical bulbs are connected in the illustrated circuit. If bulb D is removed would the current in bulb A stay the same, increase or decrease (compared to when bulb D was present)? Explain your answer.



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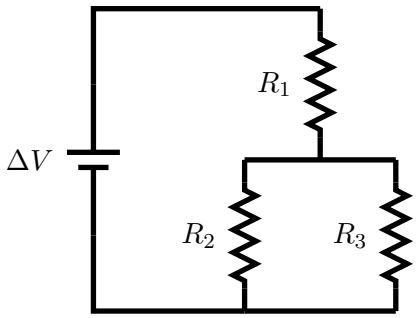
Question 7

Three resistors are connected as illustrated. The battery provides a potential difference of $\Delta V = 12.0\,\text{V}$ and the resistances are: $R_1 = 60.0\,\Omega$ and $R_2 = R_3 = 120\,\Omega$.



a) Determine the current that flows through each resistor.

b) Rank the voltages across each resistor in order from smallest to largest. Indicate equality when that appears. Explain your ranking.

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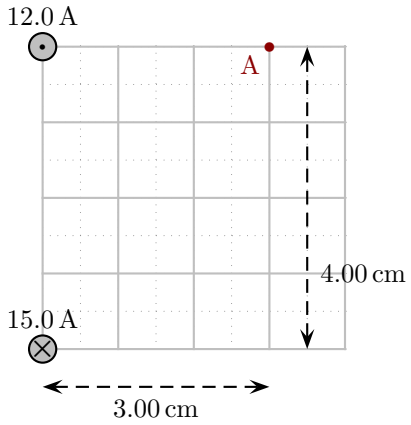
Question 8

Two infinitely long wires point perpendicular to the page.



a) Determine the net magnetic field at point A.

b) A proton passes point A moving with velocity 8.00×10^5 m/s out of the page. Determine the *magnitude of the net force* exerted by the fields on the proton.

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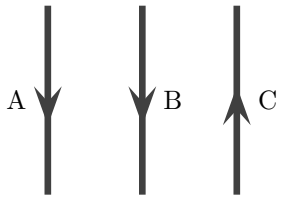
Question 9

Three wires each carry currents of identical magnitudes in the illustrated directions. The distance between adjacent wires are equal. The wires are all the same length and are close together compared to their lengths. Rank the wires in order of the magnitudes of the net magnetic force on each. *Explain your answer.*



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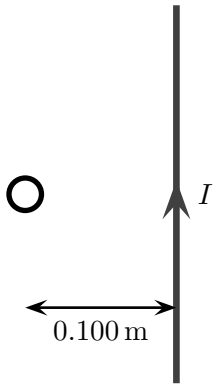
Question 10

A small loop of radius 0.00200 m is placed alongside an infinitely long current carrying wire. The current in the wire points up and increases at a constant rate from an initial value of 2.00 A to a final value of 8.00 A during time 3.00×10^{-5} s. The distance from the wire to the center of the loop is 0.100 m.

a) Determine the magnetic field at the center of the loop initially and finally.



b) Using the approximation that the field is uniform throughout the loop, determine the magnitude and direction of the induced EMF in the loop while the field increases.

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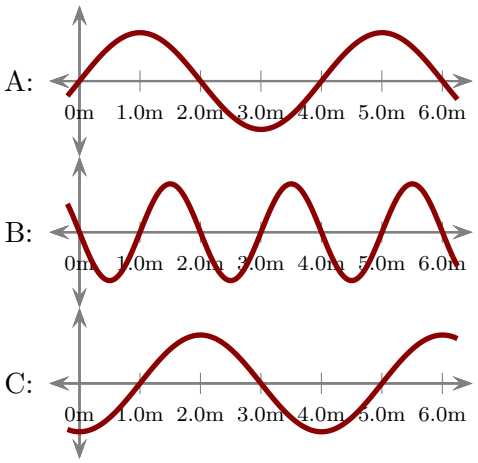
Question 11

Snapshots of waves on different strings are as illustrated. The frequency for A is 1.0 Hz, the frequency for B is 2.0 Hz and the frequency for C is 2.0 Hz. The units of the axes are meters. Let v_A be the speed of case A, v_B be the speed of case B, etc,.... Which of the following (choose one) is true?



i) $v_A = v_C < v_B$
ii) $v_A = v_C > v_B$
iii) $v_A = v_B > v_C$
iv) $v_A = v_B < v_C$
v) $v_A < v_B = v_C$
vi) $v_A > v_B = v_C$

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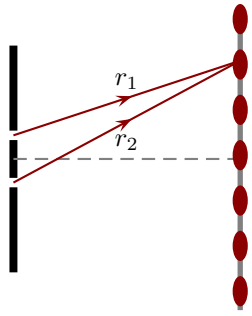
Question 12

Light with wavelength 650 nm is incident on a double slit; the spacing between the slits is 5000 nm. The pattern is projected onto a screen 0.80 m from the slit. Let r_1 be the distance from the upper slit to the second bright fringe. Let r_2 be the distance from the lower slit to the second bright fringe away from the central maximum. Which of the following (choose one) is true about $\Delta r = r_2 - r_1$?



i) $\Delta r = 650$ nm.
ii) $\Delta r = 1300$ nm.
iii) $\Delta r = 5000$ nm.
iv) $\Delta r = 0.80$ m.

Explain your answer.

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Question 13

A string has two fixed ends and is stretched so that the wave speed on the string is 450 m/s. The standing wave with three antinodes oscillates with frequency 225 Hz.

a) Sketch the standing wave with three antinodes.

b) Determine the length of the string that produces such standing waves.

c) Is there a standing wave on this string (with the same speed) with frequency 400 Hz? Explain your answer.

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Question 14

A diffraction grating has slits that are 3.33×10^{-6} m apart. Violet light with wavelength 4.80×10^{-7} m is incident on the diffraction grating.

a) Determine the number of bright spots that appear beyond the grating.

b) Red light with wavelength 6.70×10^{-7} m is incident on the grating. Which of the following (choose one) is true?

i) There are infinite bright spots both with red and violet light.

ii) There are finite bright spots with both; the number is the same for each.

iii) There are finite bright spots with both; there are more for violet than red.

iv) There are finite of bright spots with both; there are fewer for violet than red.

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Question 15

The indices of refraction for various materials are listed in the table. Which of the following (choose one) is true regarding the critical angles, θ_c?

Air	1.00
Water	1.33
Glass	1.55

i) θ_c for air/glass is smaller than θ_c for air/water.

ii) θ_c for air/glass is the same as θ_c for air/water.

iii) θ_c for air/glass is larger than θ_c for air/water.

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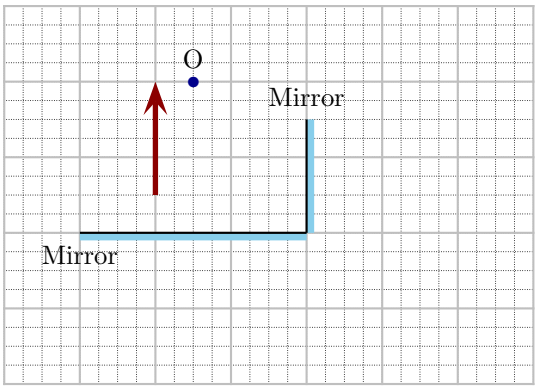
Question 16

Two flat mirrors are at right angles and an arrow is placed as illustrated.



a) Using the diagram, indicate as accurately as possible all the images of the arrow produced by both mirrors.

b) An tiny observer is located at O. Indicate which portions of *each* of the images can be seen by the observer. Explain your answer with diagrams.

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Question 17

A concave (diverging) lens is used to form an image of an upright object, which is left of the lens. Which of the following (choose one) is true?

i) The image is always left of the lens.

ii) The image is always right of the lens.

iii) The image is left of the lens is the object is between the focal point and the lens. The image is right of the lens if the object is left of the focal point.

iv) The image is right of the lens is the object is between the focal point and the lens. The image is left of the lens if the object is left of the focal point.

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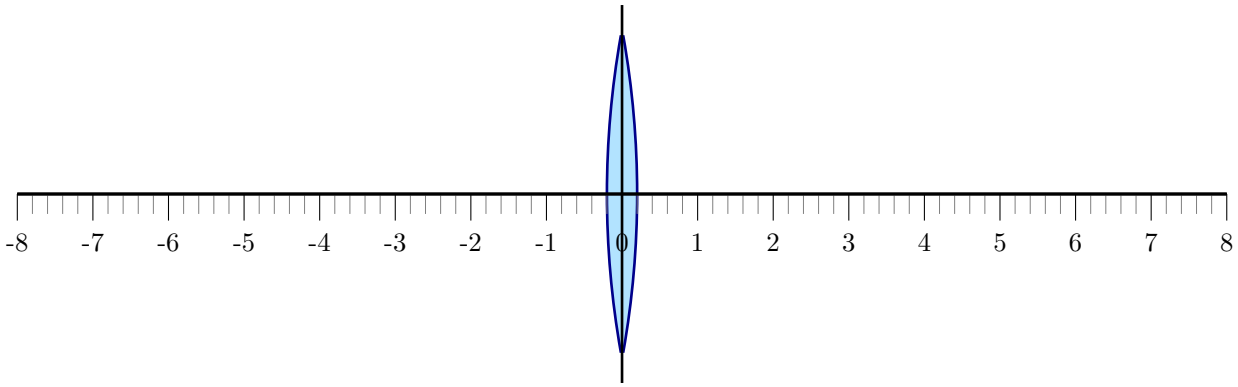
Question 18

A convex lens has focal length f. An arrow is placed a distance $\frac{f}{2}$ left of the lens.



a) Determine an expression for the location of the image in terms of f.

b) Determine an expression for the magnification of the image in terms of f.

c) Determine the (approximate) location of the image produced by the lens using accurate ray tracing for the case where the focal length of the lens is 4.00 cm.

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