State of Israel
Ministry of Education
Type of exam: *Bagrut*
Exam date: Summer 2024
Exam number: 36371
Attachment: Formula and data sheets for 5-point physics
English translation (3)

Physics
Electricity

Instructions

א. Duration of the exam: Two and one-quarter hours.

ב. Exam structure and breakdown of points:
There are six questions in this exam and you are required to answer only three.
Each question is worth $33\frac{1}{3}$ points; $3\times 33\frac{1}{3} = 100$ points

ג. Material that may be used during the exam:
(1) A non-graphing calculator. You may not use the programming options of a programmable calculator.
(2) Formula and data sheets (attached).
(3) A Hebrew–foreign language / foreign language–Hebrew dictionary.

ד. Special instructions:
(1) Answer three questions only. If you answer more than three questions, only the first three answers in your answer booklet will be graded. Clearly indicate the number of the question and item you chose.
(2) When solving questions that require calculations, you must: Write down the mathematical expression as it appears in the attached formula and data sheets; write down all derivations and change of subject of the formula required by the problem; insert the data in the derived expression; write the results of your calculations in decimal form to a suitable number of decimal places, and note the units of measure.
(3) When drawing graphs, use at least one half of the page, and use a ruler to draw straight lines.
(4) When asked to express a magnitude using data from the question, write a mathematical expression that includes some or all of the data given in the question. If necessary, you may also use basic constants from the table in the formula and data sheets, or the free-fall acceleration g .
(5) In your calculations, use the value $10\ m/s^2$ for the magnitude of g , free-fall acceleration (near the surface of Earth).
(6) Write your answers in pen. You may use a pencil for sketches and graphs only.
(7) If you make a mistake, crossing out the incorrect words or sentences with a double line is sufficient.

Write in the answer booklet only. Write the word "טיוטה" at the top of each draft page. If you write draft material on pages not in the answer booklet your exam may be disqualified.

Good Luck!

מדינת ישראל
משרד החינוך
סוג הבחינה: בגרות
מועד הבחינה: קיץ תשפ"ד, 2024
מספר השאלון: 36371
נספח: דפי נוסחאות ונתונים ל-5 יחידות לימוד
תרגום לאנגלית (3)

פיזיקה
חשמל

הוראות

א. משך הבחינה: שעתיים ורבע.

ב. מבנה השאלון ומפתח ההערכה:
בשאלון זה שש שאלות, ומהן יש לענות על שלוש בלבד.
לכל שאלה — $33\frac{1}{3}$ נקודות; $3\times 33\frac{1}{3} = 100$ נקודות

ג. חומר עזר מותר בשימוש:
(1) מחשבון לא גרפי. אין להשתמש באפשרויות התכנות במחשבון שיש בו אפשרות תכנות.
(2) דפי נוסחאות ונתונים (מצורפים).
(3) מילון עברי–לועזי / לועזי–עברי.

ד. הוראות מיוחדות:
(1) יש לענות על שלוש שאלות בלבד. אם תענו על יותר משלוש שאלות, ייבדקו רק שלוש התשובות הראשונות שבמחברת. יש לציין באופן ברור את מספר השאלה שבחרתם ואת הסעיף.
(2) בשאלות שבפתרון שלהן נדרש חישוב, יש להציג את השלבים האלה: רישום הביטוי המתמטי כפי שהוא כתוב בדפי הנוסחות והנתונים המצורפים, פיתוח מתמטי ושינוי נושא נוסחה בהתאם לבעיה, הצגה מפורשת של הנתונים בביטוי שהתקבל, הצגת תוצאות החישוב באמצעות שבר עשרוני ובו מספר מתאים של ספרות משמעותיות וכן יחידות המידה.
(3) את הגרפים יש לסרטט בגודל של חצי עמוד לפחות. יש להשתמש בסרגל לסרטוט קווים ישרים.
(4) כאשר נדרשים להביע גודל באמצעות נתוני השאלה, יש לרשום ביטוי מתמטי הכולל את נתוני השאלה או את חלקם; במידת הצורך אפשר להשתמש גם בקבועים בסיסיים מתוך הטבלה שבדפי הנוסחאות והנתונים או בגודל תאוצת הנפילה החופשית g .
(5) בחישובים יש להשתמש בערך $10\ m/s^2$ לגודל של g — תאוצת הנפילה החופשית (בסמוך לפני כדור הארץ).
(6) יש לכתוב את התשובות בעט. מותר להשתמש בעיפרון לסרטוטים וגרפים בלבד.
(7) במקרה של טעות, אפשר להסתפק בהעברת קו חוצה כפול על המילים או המשפטים השגויים.

יש לכתוב במחברת הבחינה בלבד. יש לרשום "טיוטה" בראש כל עמוד המשמש טיוטה.
כתיבת טיוטה בדפים שאינם במחברת הבחינה עלולה לגרום לפסילת הבחינה.

בהצלחה!

Questions

Answer <u>three</u> of the questions 1–6.
(Each question – $33\frac{1}{3}$ points; the point value of each item is given at the end of the item.)

1. A physics teacher demonstrated two experiments in electrostatics.
In the first experiment the teacher suspended a plastic ball of mass m at the end of a string connected to the ceiling, and charged it with a charge of q_1 .
In the space around the ball, the teacher applied a uniform horizontal electric field $\vec{E}$ directed to the right. In response to the applied electric field, the ball attached to the string deviated to the right by an angle α relative to the perpendicular, as shown in Figure 1.

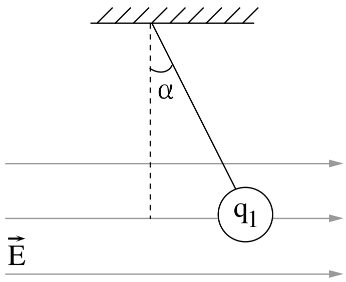


Figure 1

א. **(1)** Develop an expression that relates the angle of deviation α to the intensity of the electric field E .
Use the parameters m , q_1 , and physical constants, as needed.

(2) We know that the mass of the ball is $m = 0.2\text{g}$.
When the intensity of the electric field was $E = 5700\frac{\text{N}}{\text{C}}$, the ball attached to the string deviated by an angle $\alpha = 14^\circ$.
Determine the sign of the electric charge, q_1 , and calculate the magnitude of this charge using the expression you developed. Explain your answer.

(7 points)

In the second experiment the teacher suspended an additional plastic ball of same mass m in the field $\vec{E}$, charged with a <u>positive</u> charge q_2 .
In response to this, the angle of deviation of the first ball (of charge q_1) changed to β . The distance between the centers of the balls is r , as shown in Figure 2.

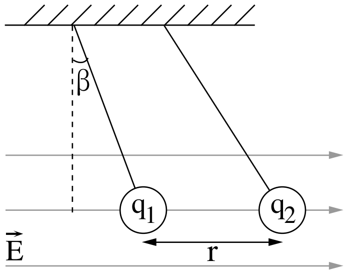


Figure 2

/Continued on page 3/

During the second experiment the teacher changed the distance between the ball centers several times, and each time adjusted the intensity of the electric field E so that the size of β, the deviation angle of the first ball, stayed constant.

Each time the teacher noted the distance r between the ball centers and the corresponding intensity of the electric field E.

For each measurement, the teacher made sure that the height of the ball centers remained constant (by changing the length of the string of the second ball).

ב. Sketch a diagram of the forces acting on the ball of charge q_1 in the second experiment (Figure 2). Write the name of each force next to its vector. For each force, specify the factor that exerts it. (5 points)

ג. Show that the expression that describes the intensity of the established electric field E, as a function of the distance r between the ball centers, is

$$E = k\frac{q_2}{r^2} + \frac{mg}{q_1}\tan\beta \quad .$$

(8 points)

The graph in Figure 3 describes the intensity of the electric field as a function of $\frac{1}{r^2}$.

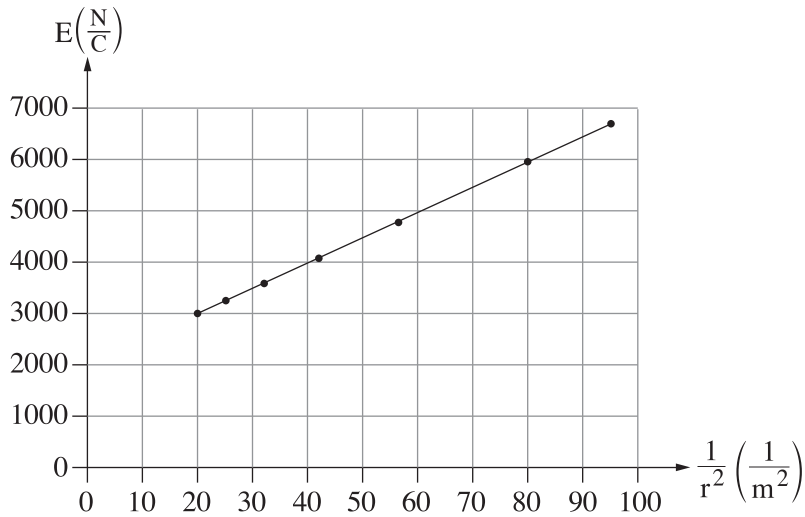


Figure 3

ד. Use the graph to find the magnitude of the charge q_2 and the deviation angle β of the first ball. (8 points)

ה. A student in the class suggested charging the second ball with a different charge q_2 in such a way that both balls would deviate to the right by the same angle relative to the perpendicular. Is this possible?

Below are five answers 1–5. Determine which answer is correct, and explain why it is correct.

1. Yes. In this case $q_2 > q_1$.
2. Yes. In this case $q_2 = q_1$.
3. Yes. In this case $q_2 < q_1$.
4. Yes. Equal angles will occur for any value of q_2.
5. No. Not possible.

($5\frac{1}{3}$ points)

/Continued on page 4/

2. Figure 1 describes a coordinate system and two <u>positive</u> point charges, q and Q.
The charges are placed along the vertical axis (y-axis), each at a distance d from the origin, O.
We know that $Q > q$.
Assume throughout this question that the effect of the gravitational force is negligible.

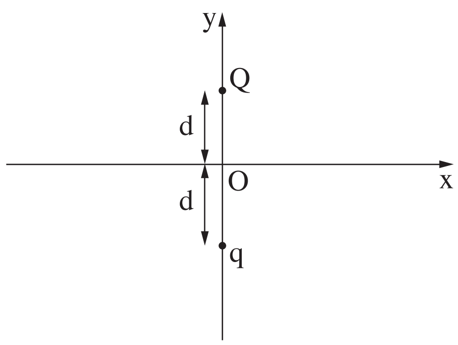


Figure 1

א. Express the <u>magnitude</u> of the electric field created at the origin, O, in terms of the parameters d, Q, q, and physical constants, as needed. Specify the <u>direction</u> of the field. (6 points)

Potential at infinity is set at zero.

ב. Is there any point in space (except at infinity) where the electric potential equals zero?
If yes – express the location of this point. If no – explain why. (6 points)

(Note: This question continues on the next page.)

/Continued on page 5/

Figure 2 shows several lines which describe equipotential surfaces of the charges system. In the figure, the value of the potential of each line is labelled with an arrow.

In the coordinate system in the figure, the distance between adjacent marks on the axes is $2cm$.

Charge Q is located at the point $(0, 6\text{ cm})$, and Charge q at the point $(0, -6\text{ cm})$, as shown in Figure 2. We know that $Q = 6 \cdot 10^{-10}C$.

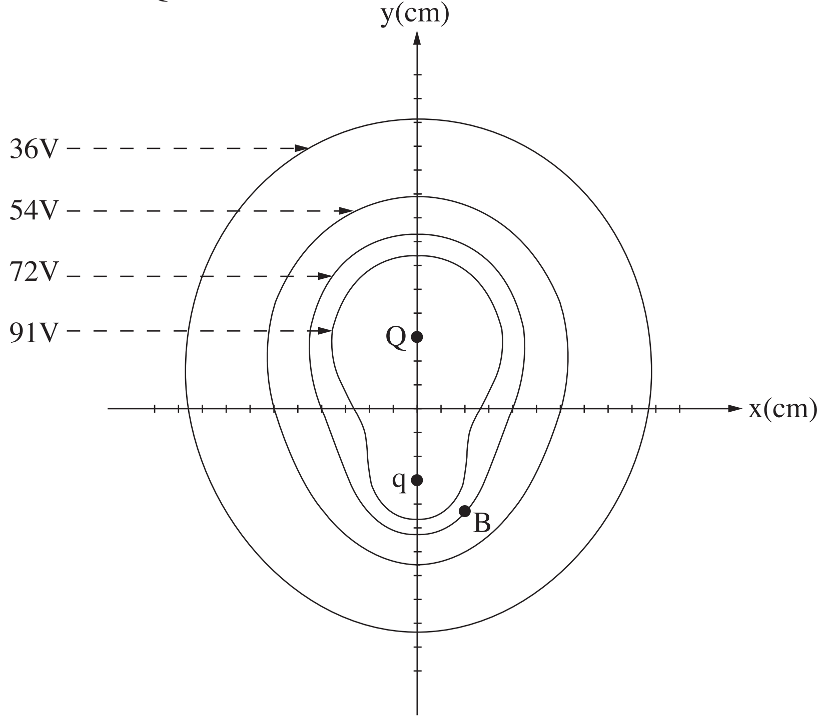
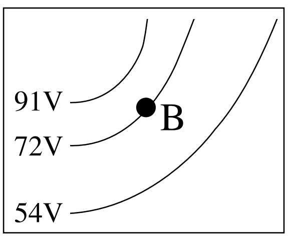


Figure 2

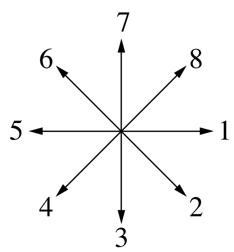
ג. Using Figure 2 as an aid, calculate the magnitude of Charge q . Provide detailed calculations. (8 points)

ד. We assign a velocity of $v_O = 5.2 \cdot 10^6 \frac{m}{s}$ to a positively charged particle (positron, labelled e^+) located at the origin O .
We know that the mass of a positron is $m_{e^+} = 9.11 \cdot 10^{-31}kg$, and its charge is $q_{e^+} = +1.6 \cdot 10^{-19}C$.
The positron moves on a trajectory that is influenced by the electric forces exerted on it by Charges q and Q , and as it moves it passes through Point B which is located on one of the equipotential lines, as shown in Figure 2.
Calculate the velocity of the positron, v_B , as it passes through Point B. (8 points)

ה. Figure 3א shows a compass rose with eight labelled directions (1–8).
Use Figure 3ב and determine which of the directions 1–8 approximately corresponds to the description of the direction of the positron's acceleration as it passes through Point B .
Explain your answer. ($5\frac{1}{3}$ points)



3ב: Magnification of the space around Point B



3א: Compass rose

Figure 3

/Continued on page 6/

3. A student assembled the electric circuit shown in Figure 1 using the following components:

- a battery with an emf of $\varepsilon = 12V$ and negligible internal resistance
- a resistor R with fixed resistance
- two identical conducting rods, each with resistance R_x, and fixed resistance per unit length, λ
- ideal measuring instruments: ammeter A, voltmeter V_1, voltmeter V_2
- a sliding contact P connecting voltmeter V_2 to the top conducting rod R_x
- wires with negligible resistance

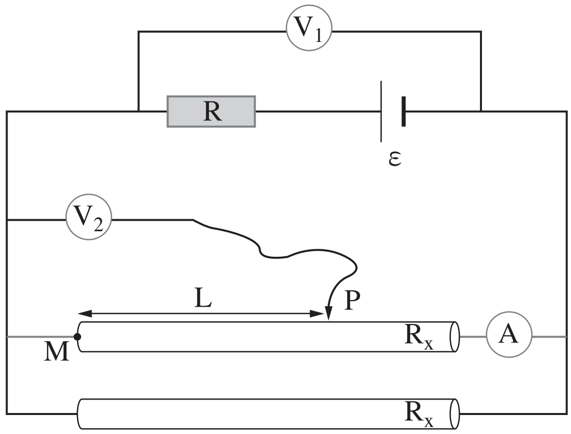


Figure 1

We know that the reading on the ammeter in the circuit (see Figure 1) is $I = 1.25A$, and the reading on voltmeter V_1 is $V_1 = 8V$.

א. Calculate the resistance R_x of each of the rods. List the steps of your solution. (6 points)

ב. Calculate the resistance of resistor R. List the steps of your solution. (7 points)

Point M in the figure is the left end of the top R_x rod.
When sliding contact P is at a distance of $L = 40\,cm$ to the right of Point M, the reading on voltmeter V_2 is $V_2 = 6V$.

ג. Calculate λ (resistance per unit length of conducting rod). List the steps of your solution. (7 points)

(Note: This question continues on the next page.)

/Continued on page 7/

Next, the student added several conducting rods, identical and parallel to the two existing conducting rods in the circuit (see Figure 2).
At this stage the circuit has a total of n identical conducting rods, each of resistance R_x .

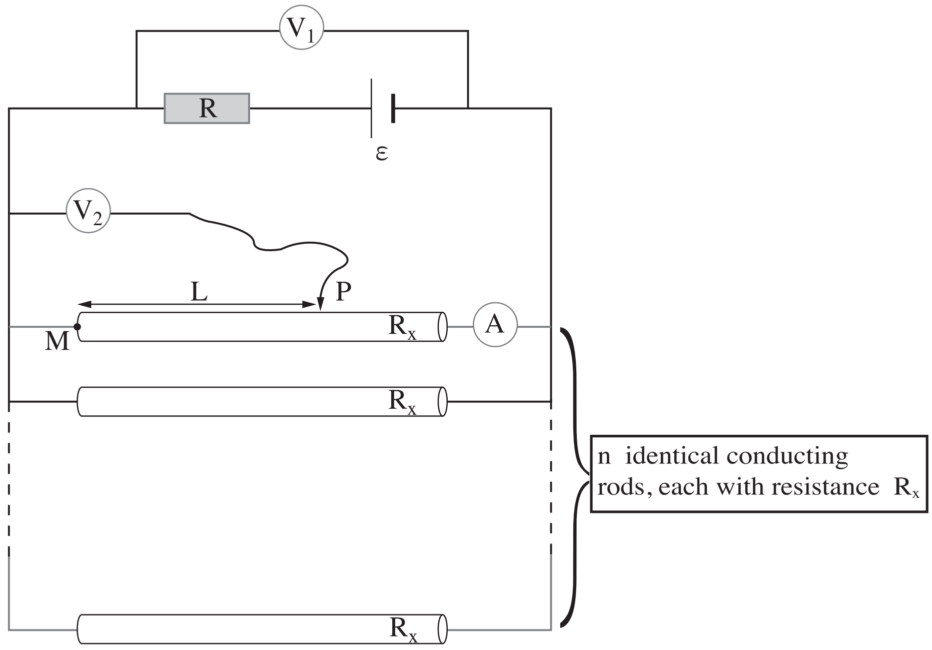


Figure 2

ד. Develop a parametric expression for the current reading shown on <u>ammeter A</u> (<u>in the circuit in Figure 2</u>) as a function of ε , R_x , R , n , as needed.
(8 points)

ה. Below are statements 1–4 regarding the changes in readings of the voltmeters as the number of conducting rods increases (as n is increased).
Determine which statement is correct, and explain your answer.
1. The readings of both voltmeters decrease.
2. The readings of both voltmeters increase.
3. The reading of voltmeter V_1 increases and the reading of voltmeter V_2 decreases.
4. The reading of voltmeter V_1 decreases and the reading of voltmeter V_2 increases.

($5\frac{1}{3}$ points)

/Continued on page 8/

4. A group of students assembled the electric circuit shown in Figure 1 from the following components: a battery with emf ε and internal resistance r, a variable resistor with resistance R_{LK} and whose sliding contact point is S, wires of negligible resistance, and ideal measuring instruments – voltmeter V and ammeter A.

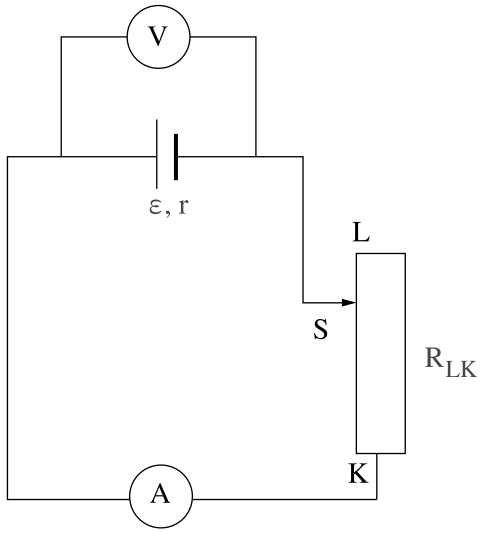


Figure 1

א. The students moved the sliding contact S of the variable resistor R_{LK} toward the edge L. Determine whether the reading of voltmeter V increased, decreased, or remained unchanged. Explain your answer. (5 points)

The students changed the position of the sliding contact S five times (two of the positions were at edges K and L).
Each time they noted the reading on ammeter A and voltmeter V, and calculated the power P that developed in the variable resistor R_{LK} at each of the five measurement points $M_1 – M_5$.
The students sketched a graph of the power P as a function of the current I (see Figure 2).

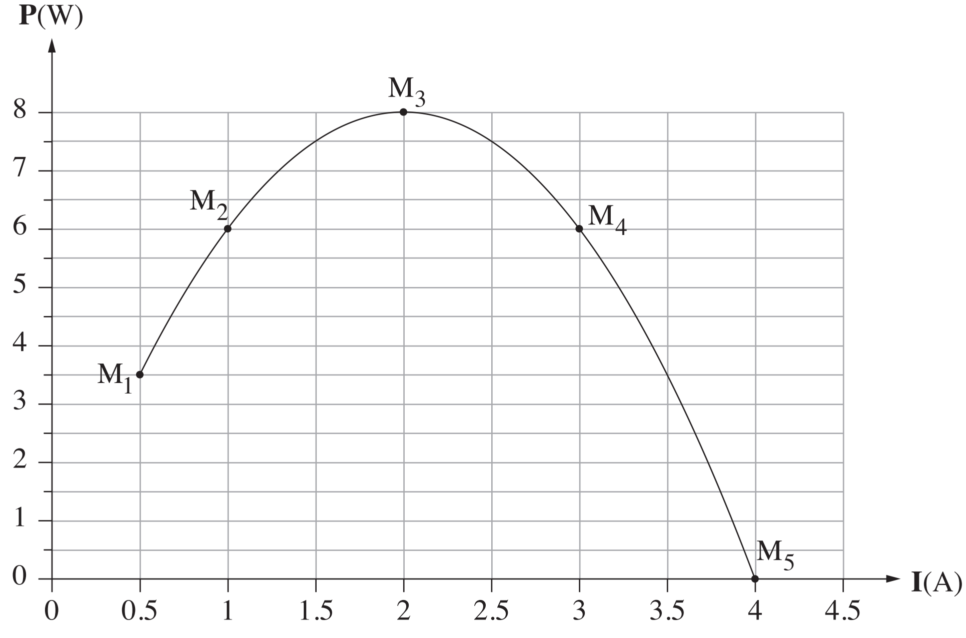


Figure 2

/Continued on page 9/

ב. Choose the appropriate point on the graph in Figure 2 for calculating the maximum resistance of variable resistor R_{LK} .
Calculate the maximum resistance of variable resistor R_{LK} .
List your considerations in choosing the appropriate point. Write the steps of your solution.
(7 points)

ג. Calculate the emf ε and internal resistance r of the battery (you may choose two points from the graph or any other method to aid you). List the steps of your solution. (9 points)

At two points, M_2 and M_4 , the power utilized by the variable resistor R_{LK} was identical.

ד. Was the battery's wasted power at these two points also the same? If yes – explain your answer; if no – determine at which point the wasted power was greater, and calculate how many times greater. (7 points)

The students switched the locations of ammeter A and voltmeter V in the circuit (see Figure 3).

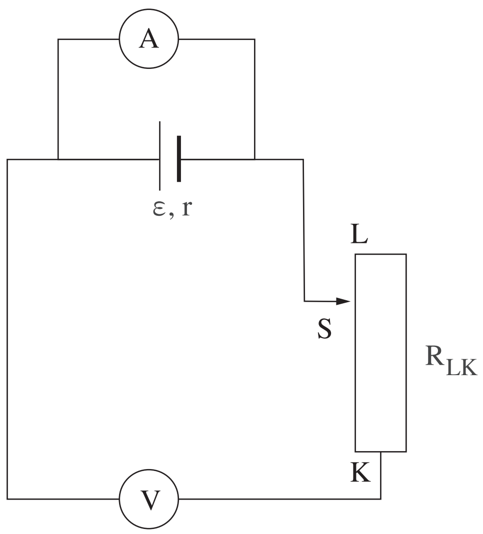


Figure 3

ה. Below are four statements 1–4 about the circuit in Figure 3.
Determine which statement is correct, and explain your answer.

1. The reading on the ammeter is 0 and the reading on the voltmeter is also 0 .
2. As the position of sliding contact S on variable resistor R_{LK} is not specified, we cannot know the readings on the measuring instruments.
3. The readings on the measuring instruments (in the circuit in Figure 3) are identical to the readings on the measuring instruments for point M_5 in the graph in Figure 2.
4. The reading on the ammeter is 0 and the reading on the voltmeter is ε .

($5\frac{1}{3}$ points)

/Continued on page 10 /

5. A particle of mass m and positive charge q enters a rectangular area AKCD in which there is a uniform magnetic field $\vec{B}_1$ directed perpendicular to the page.
The particle enters the magnetic field at Point M perpendicular to Side AK, and exits it at Point N perpendicular to Side KC, as shown in Figure 1.
Assume throughout this question that the effect of the gravitational force is negligible.

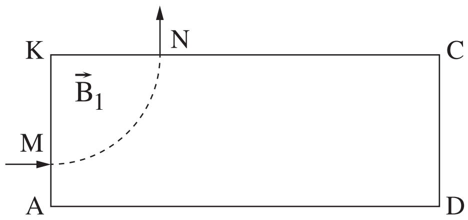


Figure 1

Given: velocity of entry of the particle into the magnetic field: $v_0 = 2 \cdot 10^6 \frac{m}{s}$;
charge on the particle: $q = 1.6 \cdot 10^{-19} C$; magnitude of the magnetic field: $B_1 = 0.05T$;
time that the particle spent in the magnetic field: $t_1 = 3.279 \cdot 10^{-7} s$

א. Find the direction of the magnetic field $\vec{B}_1$; list your considerations. (5 points)

ב. Calculate the mass of the particle m . (8 points)

We create another magnetic field, $\vec{B}_2$, also uniform and perpendicular to the page, in a rectangular area KJFC located above the first rectangular area, as shown in Figure 2. We give the particle the same initial velocity v_0 , and it travels along the path described in Figure 2.
It exits the rectangle KJFC at Point P in a direction perpendicular to Side KC .

We know that the distance KP is 62.6 cm .

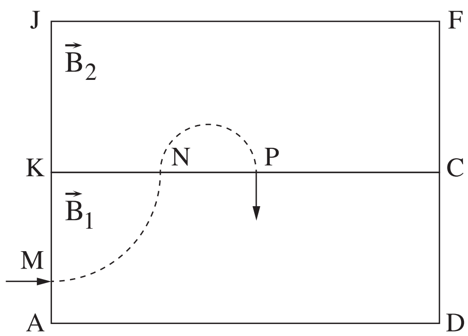


Figure 2

ג. Calculate the magnetic field $\vec{B}_2$ (magnitude and direction) (9 points)

/Continued on page 11/

Two charged plates with a uniform electric field $\vec{E}$ between them (a velocity selector) were added to the rectangle AKCD .

After the particle passes through Point P and reenters the area of the rectangle AKCD , it travels in a straight path between the plates and exits the rectangle at Point Z , as shown in Figure 3.

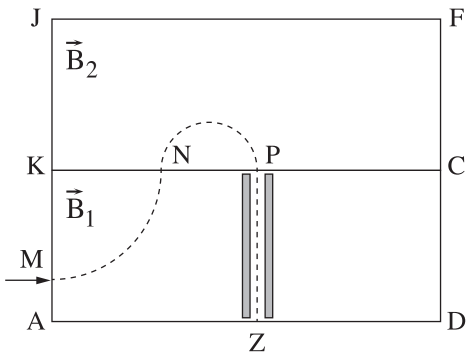


Figure 3

ד. Calculate the electric field $\vec{E}$ (magnitude and direction). List the steps of your solution. (6 points)

We give this particle (m , q) the same initial velocity, $v_0 = 2 \cdot 10^6 \frac{m}{s}$.

This time the particle enters at Point Z, perpendicular to Side AD (see Figure 3), travels in the opposite direction along the path $Z \rightarrow P \rightarrow N \rightarrow M$ and exits at Point M, perpendicular to Side AK .

ה. Determine whether the direction of one (or more) of the fields $\vec{B}_1$, $\vec{B}_2$, $\vec{E}$ was reversed, in this experiment.

Explain your answer. ($5\frac{1}{3}$ points)

/Continued on page 12/

6. Some students built an experimental setup consisting of a conducting rod suspended from a horizontal wooden beam by means of two conducting wires.
The rod and wires are part of an electric circuit in which it is possible to change the intensity of the current i (Figure 1).
The conducting rod passes between the poles Q , P of a horseshoe magnet placed on a surface.
The direction of the conducting rod is perpendicular to the direction of the uniform magnetic field $\vec{B}$ of the magnet, and the rod does not touch the surface or the magnet.
The mass of the conducting rod is m .
The length of the segment of the conducting rod that is inside the magnetic field is $L = 10\,\text{cm}$.
A force sensor measures the tension in one of the wires. The tension in both wires is identical.
Assume throughout this question that the effect of the earth's magnetic field, the mass of the wires, and the mass of the force sensor are negligible.

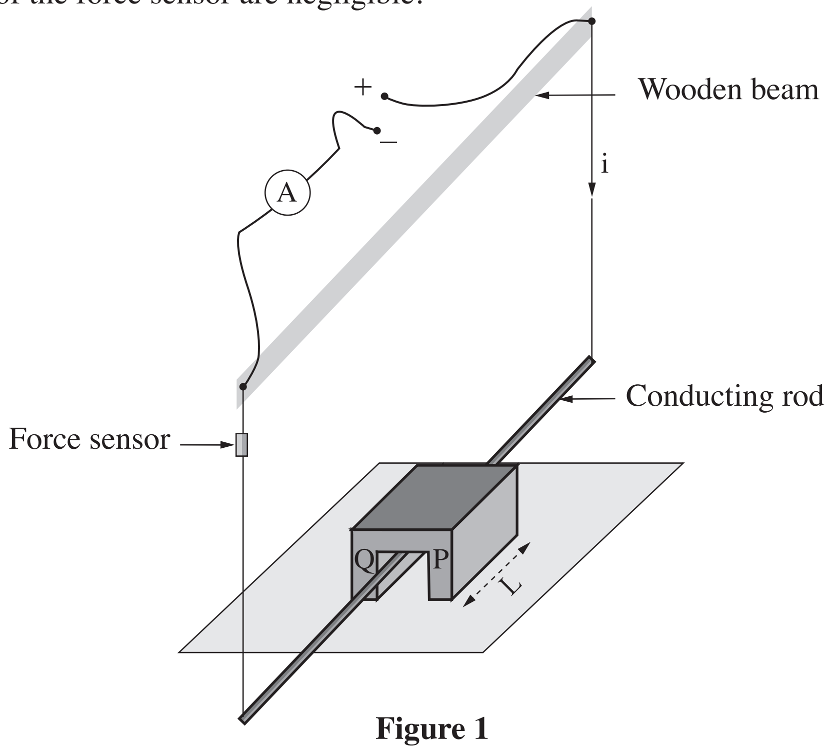


Figure 1

The students changed the current intensity i several times, and each time noted the tension T measured by the force sensor. The results are shown in the table below.

i(A)	1.0	3.0	5.0	7.0	9.0
T(N)	0.090	0.075	0.045	0.035	0.010

א. Determine the direction of the magnetic field in the horseshoe magnet (from P to Q or from Q to P). Base your answer on Figure 1 and on the measurement results shown in the table.
Explain your answer. (6 points)

ב. Develop an expression for the tension in the wire as a function of the current intensity i .
Use parameters m , B , L , and physical constants, as needed. Assume that outside of the magnet the intensity of the magnetic field is negligible, and that inside the magnet it is uniform.
(6 points)

/Continued on page 13/

ג. **(1)** In your answer booklet, sketch a scatter diagram (dots on a coordinate system) of the tension in the wire as a function of the current flowing in the rod.

(2) Add the best-fitting line (regression line) to your scatter diagram.

(8 points)

ד. Calculate the mass m of the conducting rod and the intensity of the magnetic field $\vec{B}$ in the horseshoe magnet. Base your calculation on the expression you developed and the graph you sketched. (8 points)

The students removed the horseshoe magnet, and placed the conducting rod along the axis of a solenoid in which a constant current flows (the direction of the current in the solenoid is indicated in Figure 2).

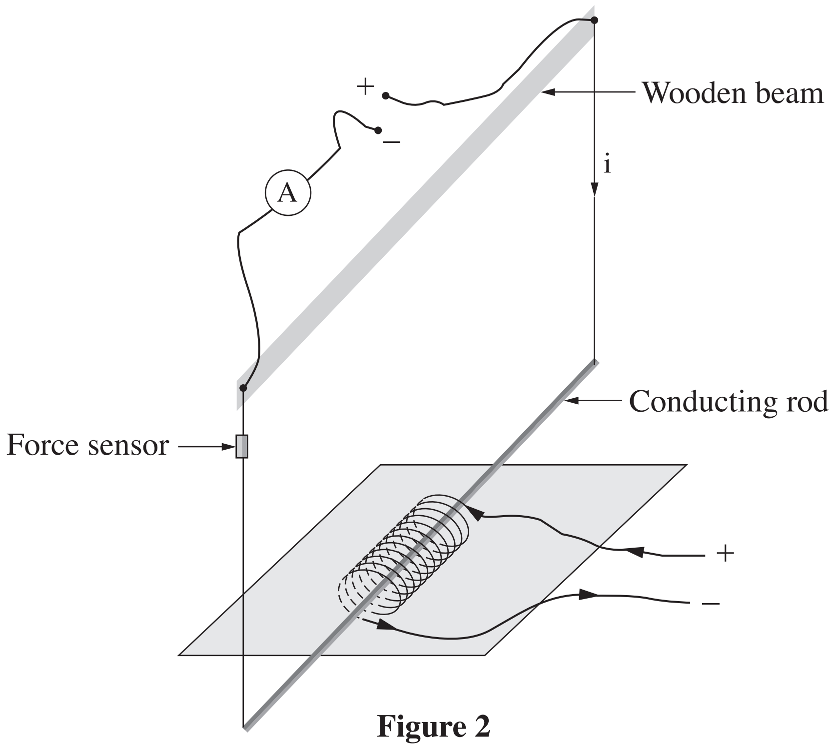


Figure 2

ה. Figure 3 below shows graphs 1–4.

Determine which graph correctly describes the reading of the force sensor as a function of the intensity of the current flowing in the rod.

Explain your answer. ($5\frac{1}{3}$ points)

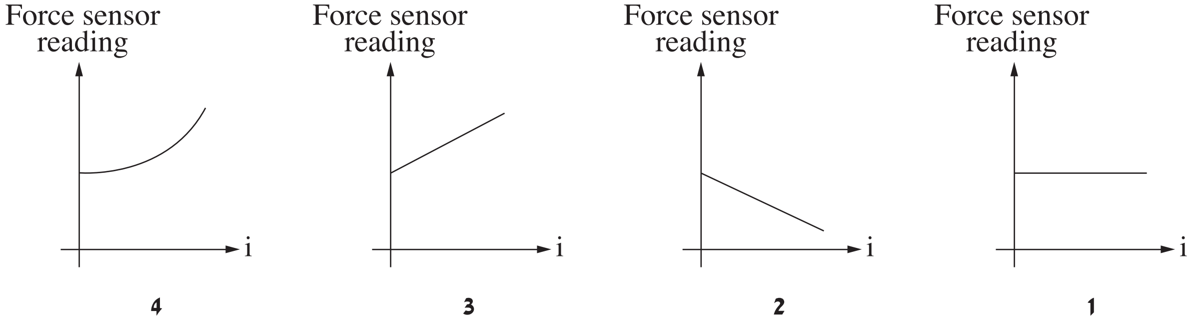


Figure 3

Good Luck!

בהצלחה!