State of Israel
Ministry of Education
Type of exam: *Bagrut*
Exam date: Summer 2022
Exam number: 036371
Attachment: Formula and data sheets for 5-point physics
English translation (3)

Physics
Electricity

Instructions

א. Duration of the exam: Two 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 show the following steps:
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 reasonable number of decimal places, including the correct units of measurement.
(3) When the answer to the question has to be expressed in words, be concise and on topic.
(4) When drawing graphs, use a ruler to draw straight lines.
(5) 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 .
(6) In your calculations, use the value 10 m/s^2 for the magnitude of free-fall acceleration (near the surface of Earth).
(7) Write your answers in pen. If you write in pencil or erase with White-Out you will not be able to appeal your grade. You may use a pencil for sketches and graphs only.

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"ב, 2022
מספר השאלון: 036371
נספח: דפי נוסחאות ונתונים ל-5 יחידות לימוד
תרגום לאנגלית (3)

פיזיקה
חשמל

הוראות

א. משך הבחינה: שעתיים.

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 והסעיף שבחרתם.
(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 סביר של ספרות משמעותיות ויחידות המדידה המתאימות.
(3) בשאלות שהתשובה עליהן מילולית, יש לענות בקצרה אך ורק בנוגע למה שנשאלתם.
(4) בגרפים, יש לסרטט קווים ישרים באמצעות סרגל.
(5) כאשר אתם 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 .
(6) בחישובים יש להשתמש בערך 10 m/s^2 לגודל תאוצת הנפילה החופשית (בסמוך לפני כדור הארץ).
(7) יש לכתוב את התשובות בעט. אם תכתבו בעיפרון או תמחקו בטיפקס לא תוכלו לערער.
מותר להשתמש בעיפרון לסרטוטים וגרפים בלבד.

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

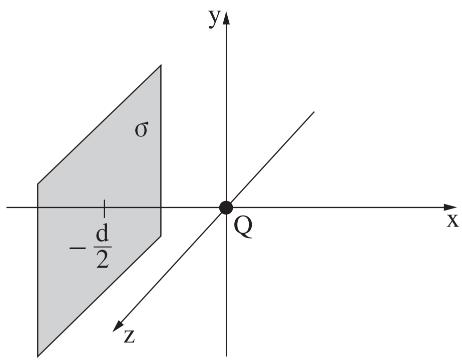
Answer three of the questions 1-6.

(Each question – $33\frac{1}{3}$ points; the point value of each item is given.)

1. Given: a system consisting of a positive point charge whose charge is Q, and a very large plane sheet ("an infinite plate") of positive uniform surface charge density σ.

The point charge is held at rest at the origin, and the plate is located at the point $x=-\frac{d}{2}$, perpendicular to the x-axis (the plate is parallel to the plane yz).

The figure below describes this system.



The system is located in a vacuum. The effect of the point charge on the surface charge density σ is negligible throughout the question.

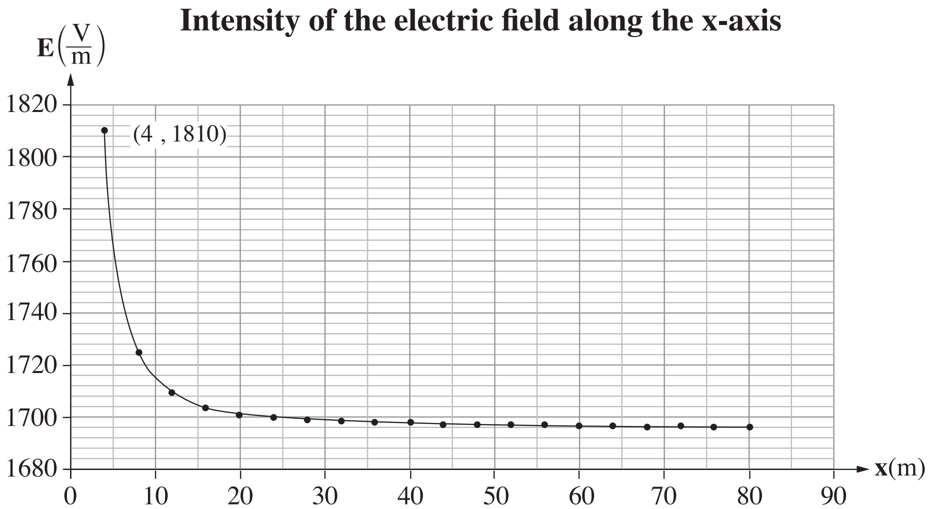
א. Write an expression for the intensity of the electric field $E(x)$ along the x-axis, for $x>0$. Use the parameters σ, Q, and basic constants. (6 points)

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

/Continued on page 3/

The graph below describes the intensity of the electric field E at several points along the x-axis, beginning at the point $x = d$.

Given: $d = 4m$, $E(4) = 1810\frac{V}{m}$.



ב. **(1)** Use the graph to calculate the surface charge density σ .

(2) Calculate the magnitude of the point charge Q .

(9 points)

A particle with a positive charge is released from rest at a point that is located on the positive side of the x-axis. The particle moves along the x-axis in the positive direction.

ג. Determine which of the following statements 1-4 is correct, and explain your answer. (6 points)

1. When a particle is located at a great distance from the system, its motion is approximately uniformly accelerated.
2. When a particle is located at a great distance from the system, its motion is approximately uniform.
3. When a particle is located at a great distance from the system, its velocity becomes zero.
4. We cannot know what type of motion it is without knowing the mass of the particle.

ד. Calculate $V_{d\,,\,2d}$, the potential difference between the point $x = d$ and the point $x = 2d$ (both theses points are located on the x-axis). (7 points)

ה. If the charged plate were located at the point $x = \frac{d}{2}$, would the potential difference between the point $x = d$ and the point $x = 2d$ increase, decrease, or remain unchanged? Explain your answer. ($5\frac{1}{3}$ points)

/Continued on page 4/

2. Figure 1 shows an electrical circuit that consists of a battery whose emf [כא"מ] is ε and internal resistance is r, a resistor with a constant resistance of $R_1 = 4\Omega$, a variable resistor MN whose sliding contact is P, and ideal wires.

Given: The resistance of the variable resistor per unit of length is $\lambda = 0.8\frac{\Omega}{cm}$ and its total length is $\ell = 30$ cm.

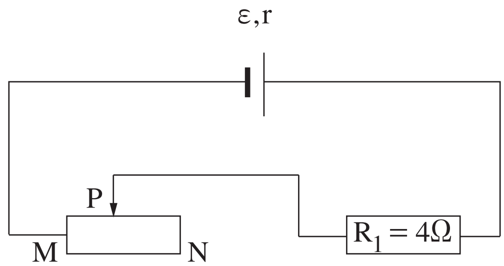


Figure 1

א. Below are five statements, 1-5. Copy only the correct statements into your answer booklet. (6 points)

1. The terminal voltage value is dependent on the internal resistance of the battery.
2. The terminal voltage value decreases as the external resistance of the circuit increases.
3. The greater the intensity of the current in the circuit, the greater the terminal voltage.
4. The emf value is not dependent on the current.
5. $\frac{J}{C}$ is a unit of emf.

Given:

When the intensity of the current in the circuit is $I = 1.5A$, the terminal voltage is $V = 18V$.

When the intensity of the current in the circuit is $I = 2.5A$, the terminal voltage is $V = 16V$.

ב. Calculate the emf of the battery, ε, and its internal resistance r. (8 points)

ג. Calculate the distance of the sliding contact P from the end N of the variable resistor, when the current in the circuit is $I = 1.5A$. (7 points)

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

/Continued on page 5/

The circuit shown in Figure 1 was dismantled and the same parts were used to assemble another circuit, shown in Figure 2. The sliding contact P is located at the position you calculated for Item ג.

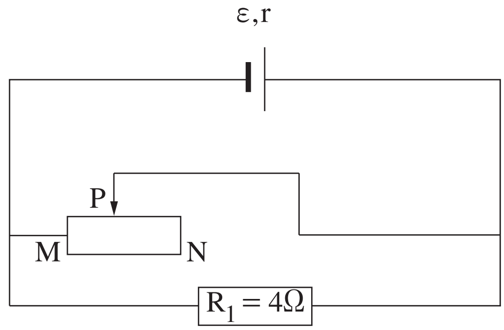


Figure 2

Answer Items ד and ה for the circuit shown in Figure 2.

ד. Is the terminal voltage equal to, greater than, or less than 18V ? Explain your answer.

(7 points)

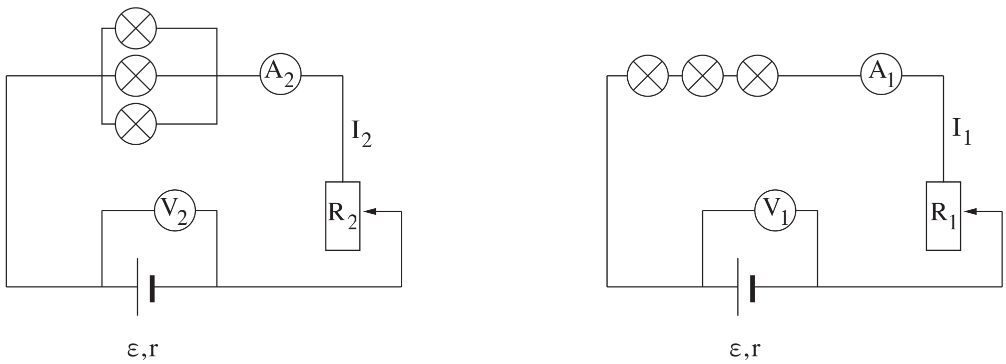
ה. **(1)** In this circuit, is it possible to measure a terminal voltage whose value is $V = \varepsilon$? If it is possible, explain how; if not, explain your answer.

(2) In this circuit, is it possible to measure a terminal voltage whose value is $V = 0$? If it is possible, explain how; if not, explain your answer.

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

/Continued on page 6/

3. The diagrams below describe two different electric circuits, Circuit 1 and Circuit 2, which are composed of identical components: a voltage source with an emf of ε and internal resistance r, three lamps each marked $3V$ and $2W$, a variable resistor, wires, and ideal measuring instruments.



Circuit 2 **Circuit 1**

In each of the two circuits the sliding contact of the variable resistor is moved until all the lamps glow with maximum brightness, according to the values marked on them. This state remains unchanged for all the items of this question.

א. Calculate I_1, the ammeter [מד־זרם] reading in Circuit 1, and I_2, the ammeter reading in Circuit 2. (7 points)

Given: The voltmeter [המד־מתח] reading in Circuit 1 is $V_1 = 9\frac{1}{3}V$, and the voltmeter reading in Circuit 2 is $V_2 = 4V$.

ב. Calculate R_1, the resistance of the variable resistor in Circuit 1, and R_2, the resistance of the variable resistor in Circuit 2. (7 points)

ג. Determine in which of the two circuits, Circuit 1 or Circuit 2, the power delivered [ההספק המושקע] by the voltage source is greater, and calculate by what factor [פי כמה] the delivered power is greater. (6 points)

ד. Determine in which of the two circuits, Circuit 1 or Circuit 2, the power dissipated [ההספק המבוזבז] in the voltage source is greater, and calculate by what factor [פי כמה] the dissipated power is greater. (5 points)

The efficiency [נצילות] of a circuit is defined as the ratio between the power consumed by the entire circuit (lamps and variable resistor) and the power delivered by the voltage source.

A student claims that the total power of the lamps in Circuit 1 is the same as the total power of the lamps in Circuit 2, and therefore the circuit with the greater variable resistor power is the circuit with the greater efficiency.

ה. Determine whether this claim is correct or incorrect. Explain your answer. (4 points)

ו. Determine in which of the two circuits, Circuit 1 or Circuit 2, the efficiency is greater. Explain your answer. ($4\frac{1}{3}$ points)

/Continued on page 7/

4. Figure 1 below describes a system for accelerating charged particles called a cyclotron. The system is composed of two semicircles, M and N , that are separated by a rectangular area C . In each of the semicircles, the particles move under the influence of a magnetic field $\vec{B}$ whose magnitude is constant. The magnetic field is directed into the page, and it is perpendicular to the particles' trajectory. The rectangular area C has no magnetic field, but it does have an electric field $\vec{E}$ whose magnitude is constant. The direction of the electric field is parallel to the particles' direction of motion inside the rectangular area C , and it reverses its direction each time the particles complete half a revolution [חֲצִי הַקָּפָה]. In this way, the electric field accelerates the particles whenever they cross between the two semicircles M and N . Figure 1 describes a particle and a part of its trajectory.

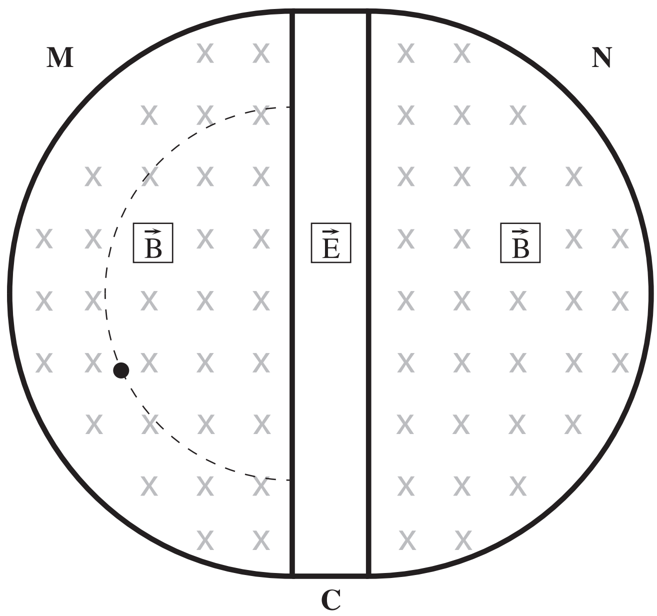


Figure 1

א. **(1)** Explain why the motion of the particles in the two semicircles is approximately circular, and why the radius of this circular motion continuously increases.

(2) Determine whether the proton moving in the magnetic field described above is moving in a clockwise or counterclockwise direction.

(8 points)

ב. Prove that the time a proton is in motion in Semicircle M is equal to the time it is in motion in Semicircle N . (6 points)

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

/Continued on page 8/

In an experiment conducted in the particle acceleration system described above, researchers measured the speed of a proton as a function of time, from the moment it entered Semicircle M and then crossed the electric field C, until it exited Semicircle N.
The researchers recorded their measurements in a graph, shown in Figure 2, describing the speed of the proton as a function of time (note the units marked on the two axes).

Proton speed as a function of time

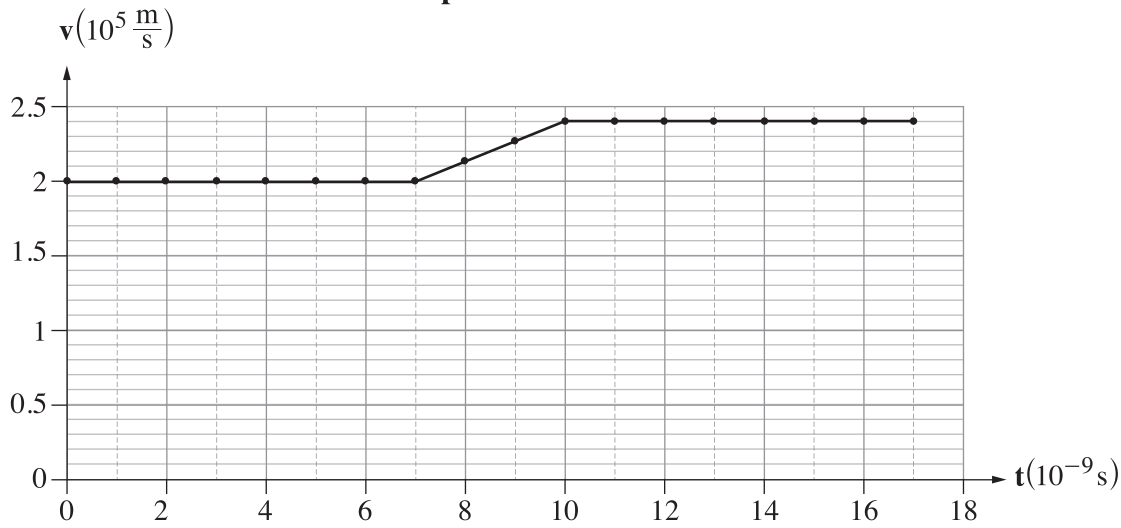


Figure 2

Given: The mass of a proton is $m_p = 1.67 \cdot 10^{-27}$ kg.

ג. Use the graph to calculate the magnitude of the magnetic field $\vec{B}$. (6 points)

ד. Use the graph to calculate the magnitude of the electric field $\vec{E}$. (7 points)

ה. F_1 is the magnitude of the radial force exerted on the proton at the moment of its entry into Semicircle M.
F_2 is the magnitude of the radial force exerted on the proton at the moment of its next entry into Semicircle M.
Determine whether F_1 is greater than, smaller than or equal to F_2.
Explain your answer. ($6\frac{1}{3}$ points)

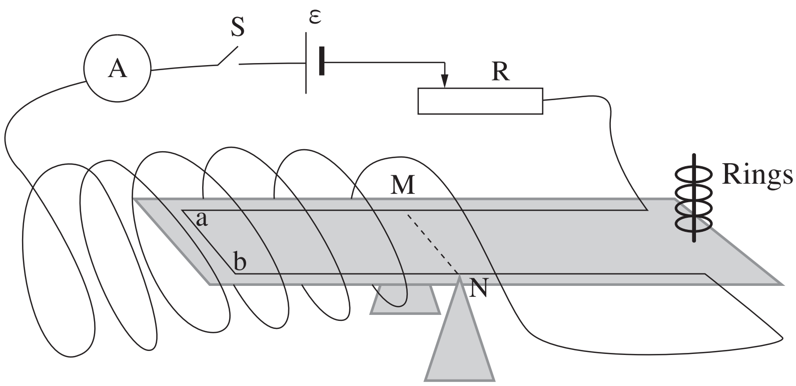
/Continued on page 9/

5. Given: a system for measuring the mass of small objects (a current balance). The system is composed of a solenoid [סילונית] with N loops and a length of L, an insulated rectangular plate with conductive wire attached along three of its sides, an ideal voltage source ε, a variable resistor R, a switch S, an ideal ammeter [מד־זרם], ideal conductive wires, and several identical rings made of insulating material. We want to measure the mass of a ring, m_0, using this system.

We insert part of the plate that has conductive wire attached to its edges into the horizontal, balanced solenoid.

The ends of the wire attached to the plate are connected in series to the solenoid.

The plate is free to move on the axis MN, which passes through the center of the plate, as shown in the figure.



In the starting position, Switch S is open, no current is flowing through the system, and the plate is horizontally balanced.

We then close the switch, and a force F_B is exerted on the section of length ℓ_{ab} of the conductive wire lying across the plate (see figure), causing the plate to move out of its balanced horizontal position. We place one ring on the end of the plate that is outside the solenoid, and change the intensity of the current in the circuit using the variable resistor, until the magnetic force balances the force that the ring exerts on the plate, and the plate returns to its balanced horizontal position.

א. Determine whether the direction of the magnetic field produced in the solenoid after the switch is closed is from left to right or from right to left. (4 points)

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

/Continued on page 10 /

We repeat the measurements several times, each time placing an additional ring on the plate, changing the intensity of the current until the plate returns to a horizontal position, and noting down the intensity of the current and square of the current intensity.
The experimental results are shown in the table below.

Number of rings K	**I** (A)	$\mathbf{I^2}$ (A^2)
1	4.0	16.0
2	5.0	25.0
3	6.5	42.3
4	7.5	56.3
5	8.5	72.3

ב. Express the magnitude of the magnetic force F_B exerted on the section of the wire ab as a function of current intensity I (use the parameters μ_0 , ℓ_{ab} , L , N , I). (6 points)

ג. Express the square of the current intensity (I^2) as a function of the number of rings (K) placed on the plate. (6 points)

ד. Based on the results shown in the table:

(1) Draw a scatter diagram (points on a coordinate system) of the square of current intensity (I^2) as a function of the number of rings (K).

(2) Add the most appropriate line (trendline) to the scatter diagram.

(7 points)

Given: $\ell_{ab} = 2.8$ cm , $L = 25$ cm , $N = 2500$.

ה. Based on the value of the graph's slope, calculate the mass of a ring, m_0 . (5 points)

We then reverse the poles of the voltage source.

ו. Can we still use this system to measure the mass of small objects? Explain your answer. ($5\frac{1}{3}$ points)

/Continued on page 11/

Induction

6. Given: a conductive wire KLM shaped to form an isosceles right triangle, as described in Figure 1. The wire is located in a rectangular area, EFGH, in which a uniform magnetic field exists. The intensity of the magnetic field varies over time, and its direction is perpendicular to the plane of Triangle KLM.

Given: The wire's resistance is $R = 1.2\Omega$. The area of the triangle formed by the wire is $S_{KLM} = 100 cm^2$.

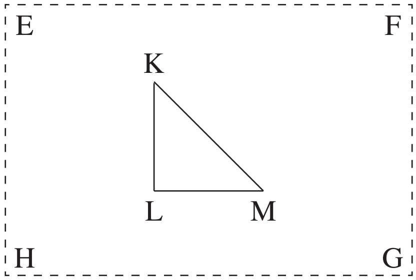


Figure 1

The graph in Figure 2 describes the magnetic field as a function of time (note the units of measurement).

Magnetic field as a function of time

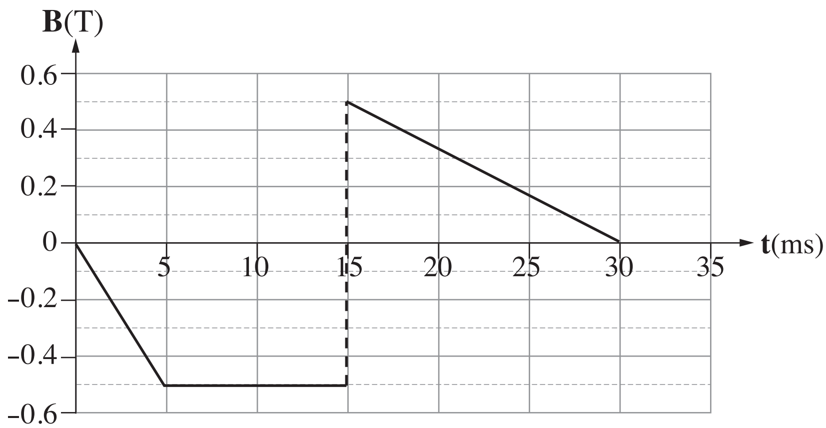


Figure 2

Given: During the time interval $0 < t < 5ms$, an induced electric current flows through the wire from L to M.

א. What is the direction of the magnetic field <u>induced</u> inside the triangle during this time interval – into the plane of the page or out of the plane of the page? (4 points)

ב. What is the direction of the uniform magnetic field during this time interval? Explain your answer. (6 points)

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

/Continued on page 12/

ג. Calculate the induced current in the wire in <u>each</u> of the three time intervals specified in the sub-items (1)-(3) below.
The positive direction of the current is from L to M. (8 points)

(1) the time interval $0 < t < 5ms$

(2) the time interval $5ms < t < 15ms$

(3) the time interval $15ms < t < 30ms$

ד. Calculate the electric power in the wire at the moment $t = 20ms$. (6 points)

In another case, in the same system, the magnetic field is uniform and <u>constant over time</u>, and is directed out of, and perpendicular to, the plane of the triangle. The wire moves to the right at a constant speed, and moves out of the region in which the magnetic field is acting.

ה. Determine whether the intensity of the induced current is constant or variable in the interval between the moment the wire begins to move out of the field until it has moved out completely. Explain your answer. (5 points)

Another system is composed of a circular region with a uniform magnetic field that varies as a function of time. On one occasion the field was surrounded by a loop of conductive wire shaped to form a square (Figure 3א). On another occasion, a conductive wire was looped around the field forming a shape whose area was greater than that of the square (Figure 3ב).

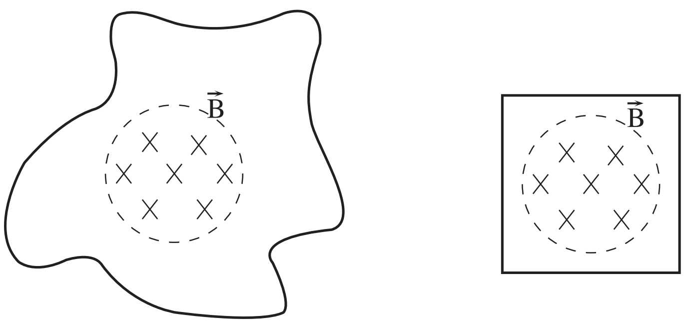


Figure ב **Figure א**

Figure 3

ו. Consider the following statement: The emf induced in the wire in Figure 3ב is greater than the emf induced in the wire in Figure 3א, because the region that the wire encloses is larger.
Determine whether this statement is correct or incorrect. Explain your answer.

($4\frac{1}{3}$ points)

Good Luck!

בהצלחה!