State of Israel
Ministry of Education
Type of exam: *Bagrut*
Exam date: Summer 2025
Exam number: 36371
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 that 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 in 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 significant figures, and suitable units of measurement.
(3) Use at least half a page for drawing graphs.
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 $10\ \text{m/s}^2$ for the magnitude of g, free-fall acceleration (near the surface of Earth).
(6) Write your answers in pen. You may use pencil for sketches and graphs only.
(7) If you make a mistake, it is sufficient to cross out the incorrect words or sentences with a double line.

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"ה, 2025
מספר השאלון: 36371
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 שאלות 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 $10\ \text{m/s}^2$ 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.

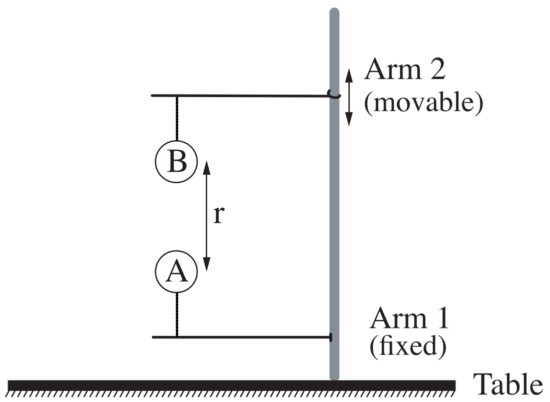
יש לכתוב במחברת הבחינה בלבד. יש לרשום "טיוטה" בראש כל עמוד המשמש טיוטה.
כתיבת טיוטה בדפים שאינם במחברת הבחינה עלולה לגרום לפסילת הבחינה.

בהצלחה!

Questions

Answer three 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 group of students were given an assignment – to conduct a computer-simulated experiment in electrostatics.
In the simulation there are two small balls, A and B. Ball A is charged with a charge q, and Ball B is charged with a charge of equal magnitude and opposite sign, $-q$.
The system in this simulation is in a vacuum.
The system in the simulation contains a lab stand on a table. Two arms are attached to the stand: Arm 1 is fixed in place with Ball A tied to it with a non-conducting string, and Arm 2 can be moved up and down, with Ball B hanging from it by a non-conducting string.
The centers of the balls are positioned on a vertical line (see figure).



The simulation shows measurements of:
– T_B, tension in the string to which Ball B is tied
– r, distance between the centers of Balls A and B
The mass of each ball is m. Assume that the amount of charge q on each ball in the simulation is fixed and uniformly distributed.
Gravitational conditions in the simulation are the same as those on Earth's surface.

א. **(1)** Draw the force diagram acting on Ball B. Label each force with its name and indicate what exerts the force.
(2) Develop an expression for the tension in the string, T_B, as a function of the distance r. Use the parameters m, q, and physical constants, if necessary.
(7 points)

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

/Continued on page 3/

The students changed the distance r between the balls' centers in the simulation several times and recorded the corresponding tension T_B that the simulation produced.
The results of these measurements are shown in the table below:

r (m)	0.16	0.18	0.20	0.22	0.24
$\mathbf{T_B}$ (N)	0.41	0.33	0.28	0.25	0.21

The students sketched a graph of the tension T_B as a function of a new variable selected so that the graph would be linear.

ב. Determine what the new variable is, and what its units of measurement are. Copy the T_B row from the table to your answer booklet, add a new row beneath it, and fill in the values and units of the new variable. (4 points)

ג. **(1)** Draw a scatter diagram (dots on a coordinate system) of the tension T_B as a function of the new variable.

(2) Add the best fitting line (trend line) to the scatter diagram.

(9 points)

ד. Use the graph to calculate the magnitude of the charge $|q|$ and the mass m of each of the balls. (8 points)

This simulation was programmed so that the maximum tension that each string can bear without breaking is T_{max} .
The students slowly brought Ball B towards Ball A until at least one of the strings broke.

ה. Determine what happened: the string tied to Ball A broke first, the string tied to Ball B broke first, or both strings broke simultaneously. Explain your answer. ($5\frac{1}{3}$ points)

/Continued on page 4/

2. A group of students conducted experiments with an electric circuit. The components available to them were:

– a voltage source of emf $\varepsilon = 20V$ and internal resistance $r = 2\Omega$
– a resistor of resistance R_1
– two ideal voltmeters
– conductive wires of negligible resistance
– a variable resistor MN with a sliding contact P

The students connected the resistor R_1 to the voltage source. They measured the terminal voltage of the voltage source using one of the voltmeters. The voltmeter reading was $16V$.

א. **(1)** Draw a diagram of the circuit that the students assembled.

(2) Calculate the resistance R_1 .

(7 points)

In another experiment, the students assembled the circuit shown in Figure 1.

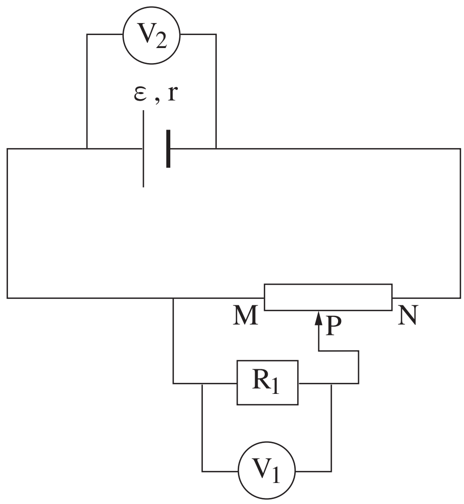


Figure 1

ב. The students positioned the sliding contact P exactly in the middle of variable resistor MN and observed the readings on voltmeters V_1 and V_2 .

Determine whether V_1 is greater than, less than, or equal to $\frac{V_2}{2}$. Explain your answer.

(7 points)

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

/Continued on page 5/

The students positioned the sliding contact P at a new point.
At this new point, the reading on voltmeter V_1 was $V_1 = 12V$, and the reading on voltmeter V_2 was $V_2 = 15V$.

ג. Calculate the resistance of segment MP in the variable resistor, R_{MP} . (9 points)

ד. Calculate the resistance of the entire variable resistor, R_{MN} . (5 points)

The students decided to connect switch S instead of resistor R_1 to the circuit shown in Figure 1.
The new circuit they assembled is shown in Figure 2.
The students slowly moved the sliding contact P towards point N , in such a way that the sliding contact remained connected to the variable resistor throughout the process, while observing the readings on voltmeters V_1 and V_2 .

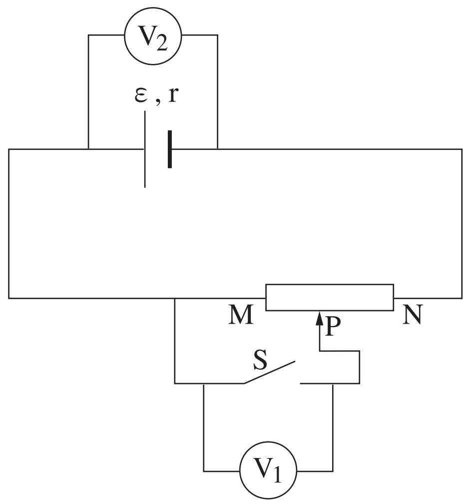


Figure 2

ה. For each of the voltmeters V_1 and V_2 , determine whether the value it reads will decrease, increase, or remain unchanged during this process in each of the two states (1) and (2) below. Explain your answers.

(1) Switch S is open.

(2) Switch S is closed.

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

/Continued on page 6/

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

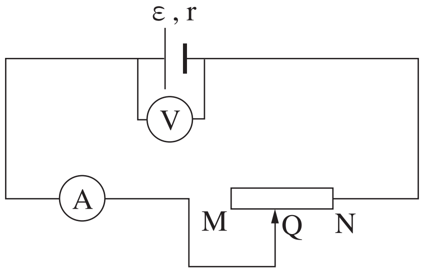


Figure 1

The students changed the position of sliding contact Q on the variable resistor R_{MN}, each time recording the reading on voltmeter V and the reading on ammeter A. The students sketched a graph of the terminal voltage V as a function of the current I (see Figure 2).

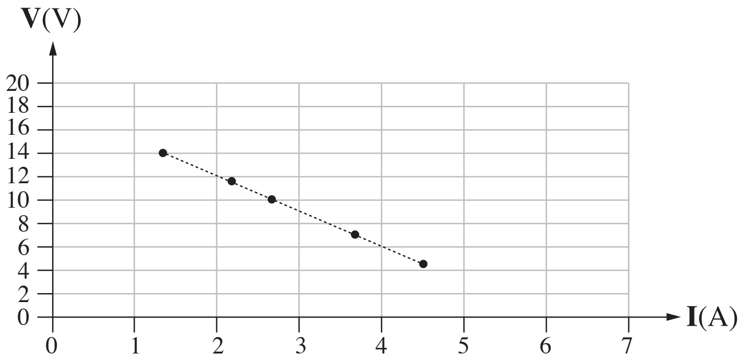


Figure 2

א. Use the graph in Figure 2 to find the emf of voltage source ε, and its internal resistance r. (7 points)

The students calculated the dissipated power for each of the measurements and sketched a graph of dissipated power P as a function of <u>terminal voltage</u> V (see Figure 3 on the next page).

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

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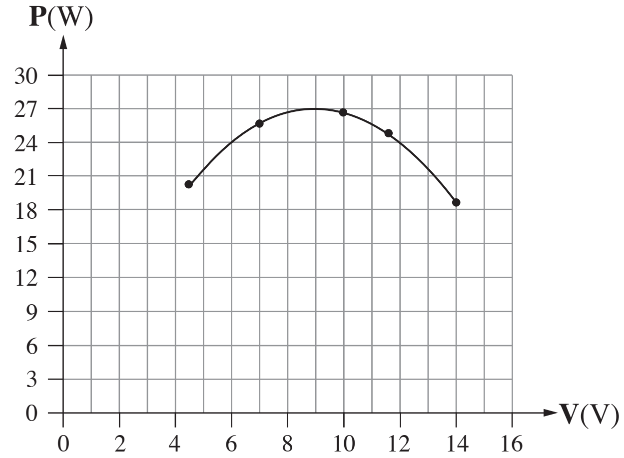


Figure 3

ב. Show that the general expression for the dissipated power P as a function of terminal voltage V is:

$$P = -\frac{V^2}{r} + \frac{\varepsilon V}{r}$$

(8 points)

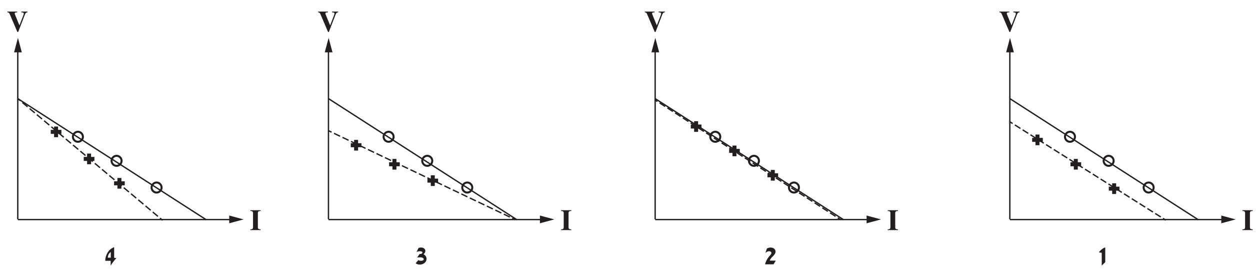
The students wanted to use resistor R_{MN} in this circuit as a heating element for heating water. They positioned sliding contact Q on variable resistor R_{MN} so that the water would heat up as fast as possible.

ג. Calculate the resistance R_{QN} in this setup. Provide detailed calculations. (6 points)

ד. Below are two statements. Determine whether each statement is true or false.
Explain your answers.
(1) We position the sliding contact Q so that the water will heat up as fast as possible. In this setup the efficiency of the voltage source is maximum.
(2) It is possible to measure power in units of $\frac{eV}{s}$ (electron-volts per second).
(7 points)

The students conducted the experiment one more time with an ammeter of non-negligible resistance. The contact points of the sliding contact Q on the variable resistor were identical in both experiments.
The figure below shows four scatter graphs 1–4 describing the measurements of both experiments, as follows:

– Measurements from the first experiment (ideal ammeter) are labelled with a "○" and the trend line is a continuous line.
– Measurements from the second experiment (ammeter of non-negligible resistance) are labelled with a "+" and the trend line is a dashed line.



ה. Determine which graph best describes the results of the measurements. Explain your answer.
($5\frac{1}{3}$ points)

/Continued on page 8/

4. A tangent galvanometer-like device is being designed for use in a school laboratory.
A compass is placed in the center of a horizontal board. Two sets of circular coils (with the compass at their common center) are perpendicular to the board. The two sets are parallel to each other and their planes are oriented north-south (See Figure 1).
Data for the coil sets in this device:
Coil set 1 – radius $R_1 = 0.15\text{m}$, number of coils $N_1 = 10$, current i_1 whose magnitude and direction can be changed.
The electric circuit controlling the current in Coil set 1 is shown in Figure 1.
Coil set 2 – radius $R_2 = 0.10\text{m}$, number of coils $N_2 = 10$. In this set, the current i_2 is of constant magnitude and direction.

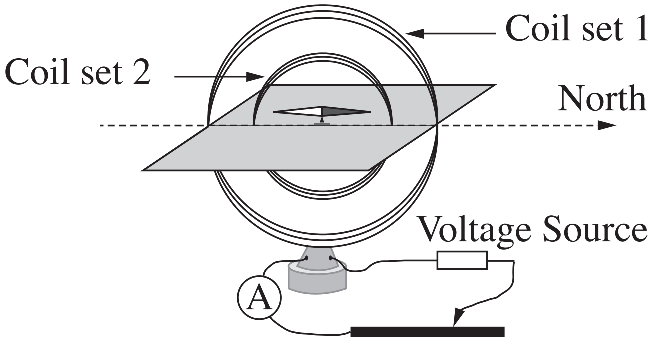


Figure 1

We set the positive direction for both currents to be the direction of current i_2 .
The direction of current i_2 in Coil set 2 is labelled in Figure 2.

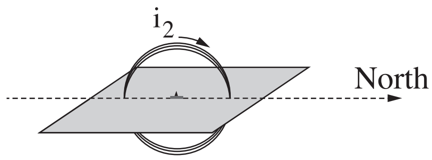
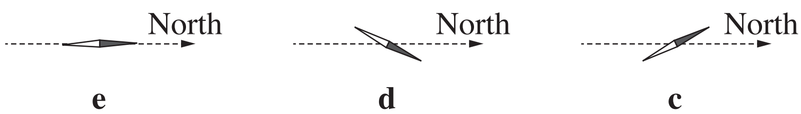


Figure 2

א. **(1)** In one case, there is no current flow in Coil set 1, while in Coil set 2 a current i_2 flows in the direction described in Figure 2.
Determine which of the illustrations (b or a) shows a top view of the direction of the deviation of the compass positioned in the center of the coils.

(2) In another case, in addition to the current flowing in Coil set 2, a current $i_1 = -i_2$ (a current whose magnitude is equal to i_2 in the opposite direction) flows in Coil set 1.
Determine which of the illustrations (e , d , c) shows a top view of the direction deviation of the compass in this case. Explain your answer.

(6 points)



(Note: This question continues on the next page.) /Continued on page 9/

A group of students conducted an experiment with the device described in Figure 1. They altered the current i_1 (the current in Coil set 1) several times, each time measuring the compass's deviation angle from the north, θ .

The students sketched a graph of $\tan\theta$ as a function of current i_1 . The trend line for this graph is shown in Figure 3.

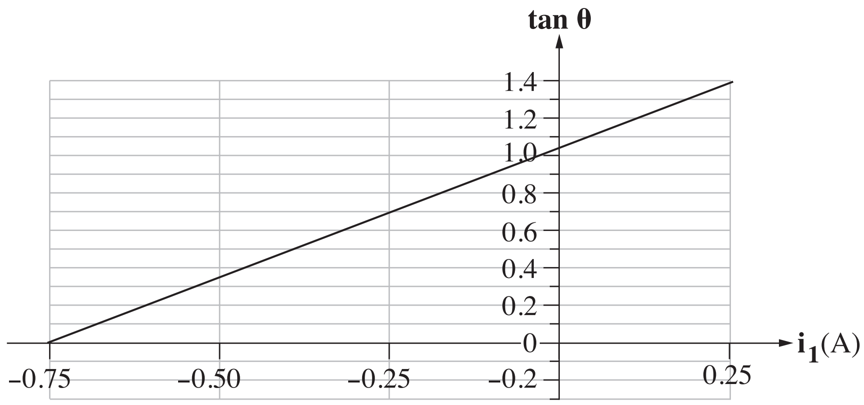


Figure 3

ב. **(1)** Show that for the intersection point of the trend line with the horizontal axis, the following relationship is satisfied: $\frac{|i_1|}{i_2} = \frac{R_1}{R_2}$.

(2) Calculate the magnitude of current i_2 .

(6 points)

ג. Use the graph in Figure 3 to calculate the magnitude of the horizontal component of the magnetic field of Earth, $B_{E\parallel}$, in the area where this experiment was conducted.

(8 points)

We rotate Coil set 2 shown in Figure 1 by 90^o , so that the magnetic field created by the current is in the northern direction.

Coil set 1 remained unchanged, so that the two sets are perpendicular to each other.

ד. Sketch a diagram of the magnetic fields acting on the compass needle in this setup, and mark in your diagram the deviation angle of the compass needle from north. ($5\frac{1}{3}$ points)

ה. Current i_1 was changed so that the tangent of the deviation angle of the needle is equal to 1.4 . Calculate the magnitude of current i_1 in this setup. (8 points)

/Continued on page 10 /

Capacitance

5. A parallel-plate capacitor of capacitance C_1 consists of two identical thin horizontal conductive plates, whose spacing is $d = 15\text{mm}$.
There is a vacuum between the plates $(\varepsilon_r = 1)$.
In a first experiment, the capacitor is connected to a voltage source V. In this setup the charge on the bottom plate is $Q = -1.3\text{nC}$.
Two points N and M are located in the space between the plates, as shown in Figure 1. The vertical distance between the points is 6 mm.
We know that the absolute value of the potential difference between the points is 88V.

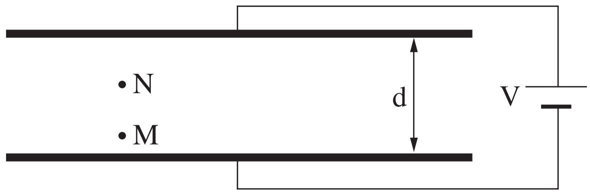


Figure 1

א. **(1)** Calculate the capacitance C_1.
(2) Calculate the area of each of the plates.
(6 points)

A charged particle is located near the bottom plate. The particle is given a vertical velocity v_0, and it moves towards the top plate.
Given: The charge of the particle is $q = +3.2 \cdot 10^{-19}\text{C}$, the mass of the particle is $m = 6.64 \cdot 10^{-27}\text{kg}$.

ב. Calculate the minimum velocity v_0 needed for the particle to reach the top plate.
(6 points)

ג. Determine whether the minimum velocity you calculated in Item ב will increase, decrease, or remain unchanged in each of the cases (1) and (2) below. Explain your answers.
(1) The capacitor plates are brought closer together while the capacitor is connected to the voltage source.
(2) The capacitor is disconnected from the voltage source and then the capacitor plates are brought closer together.
(8 points)

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

/Continued on page 11/

In a second experiment, the same capacitor was connected to an additional capacitor C_2, whose spacing between its plates was also d. However, the area of its plates was 2 times smaller than the area of the plates in capacitor C_1. There is a vacuum between the plates of capacitor C_2 as well.

– The first time, the capacitors were connected in series (see Figure 2a).
– The second time, the capacitors were connected in parallel (see Figure 2b).

Each time the uncharged capacitors were connected to the same voltage source V as in the first experiment.

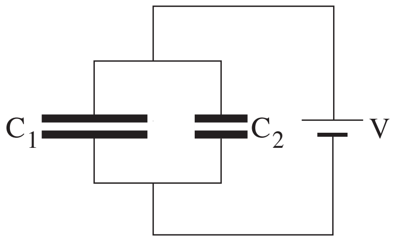


Figure 2b

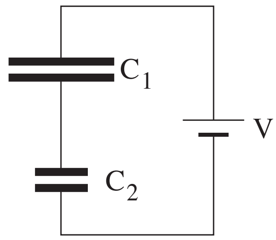


Figure 2a

ד. Find the magnitude of the charge on capacitor C_1 in each of the configurations.
(8 points)

In the parallel capacitors configuration (Figure 2b), we disconnect the voltage source (see Figure 3).

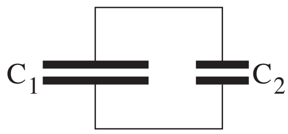


Figure 3

ה. Determine whether the magnitude of charge Q on capacitor C_1 increases, decreases, or remains unchanged. Explain your answer.
($5\frac{1}{3}$ points)

/Continued on page 12/

Induction

6. A group of physics students assembled an electric circuit containing a voltage source, long solenoid, resistor, ideal ammeter A_1 , and ideal wires.
The radius of the solenoid is r , its length is L , and the number of loops in it is N . The students placed a conducting ring of radius R around the solenoid $(R > r)$. The ring is positioned at the middle of the solenoid, so that the axis of the solenoid is perpendicular to the plane of the ring and passes through its center (see Figure 1). The resistance of the conducting ring is negligible.
The students connected an ideal ammeter A_2 and lamp K of fixed resistance to the conducting ring.

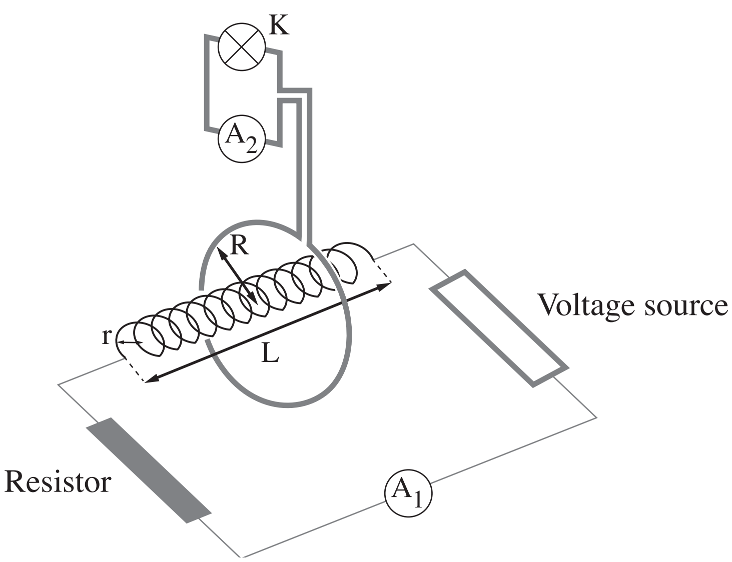


Figure 1

Figure 2 below qualitatively describes the magnitude of current I_1 in the solenoid as a function of time.
The positive direction of the current is defined as clockwise.

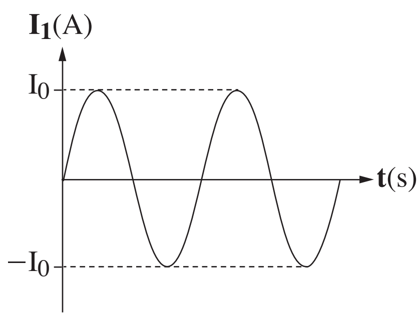


Figure 2

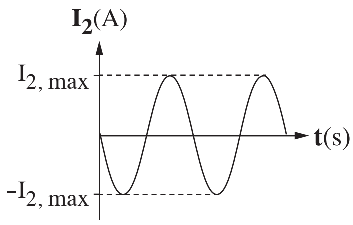
$I_1(t) = I_0 \sin(\omega t)$ is the algebraic expression describing the magnitude of current I_1 as a function of time.

א. Consider the argument: "The lamp does not light up, because the conducting ring is not within the magnetic field created in the solenoid."
Determine whether the argument is correct or incorrect. Explain your answer. (5 points)

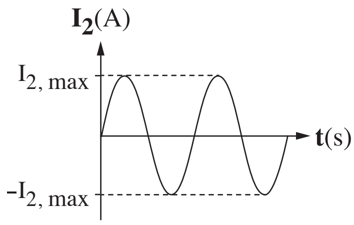
(Note: This question continues on the next page.)

/Continued on page 13/

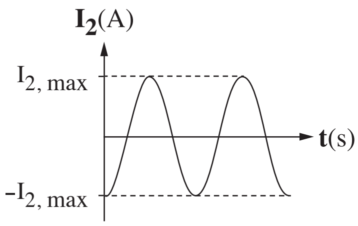
ב. Below are four graphs 1–4 describing the magnitude of a current as a function of time.
Determine which of the graphs best describes the magnitude of current I_2 in the conducting ring as a function of time.
Explain your answer using Faraday-Lenz's law. (6 points)



2



1



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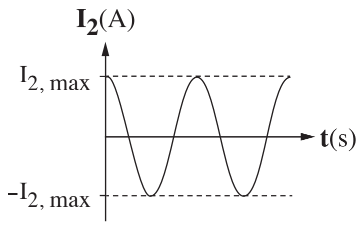

3

ג. Show that the expression describing $\varepsilon_{2,\,max}$, the maximum induced emf in the conducting ring, is:

$$\varepsilon_{2,max} = \frac{\mu_0 N I_0 \pi r^2 \omega}{L}$$ (9 points)

<u>Given</u>: $I_0 = 2.42\ A$, $\omega = 314\ s^{-1}$;
the solenoid radius is $r = 10\ cm$, the density of loops in it is $\frac{N}{L} = 4000\ m^{-1}$;
the radius of the conducting ring is $R = 12\ cm$;
the voltage rating printed on lamp K is 3V.

The students want the maximum voltage $\varepsilon_{2,\,max}$ on the lamp to match its printed voltage rating. They found that the voltage $\varepsilon_{2,\,max}$ is <u>too small</u>, when using the equipment available to them. The students proposed two different ways for increasing the maximum voltage so that it would match the printed voltage rating on the lamp.

ד. The first suggestion was to <u>increase the number of coils in the conducting ring</u>, N_{ring}, without making any other changes.
Find the number of coils N_{ring} necessary in order to meet their goal. (8 points)

ה. The second suggestion was to replace the solenoid with another long solenoid with the same density of loops $\frac{N}{L}$ but with a <u>radius r larger than the radius of the ring R</u> (the ring would be entirely inside the solenoid), without making any other changes. The students argued that with a large enough solenoid radius, the voltage on the lamp would match its printed voltage rating.
Explain why this argument is <u>not</u> correct. ($5\frac{1}{3}$ points)

Good Luck!

בהצלחה!