State of Israel
Ministry of Education
Type of exam: *Bagrut*
Exam date: Summer 2023
Exam number: 36361
Attachment: Formula and data sheets for 5-point Physics
English translation (3)

מדינת ישראל
משרד החינוך
סוג הבחינה: בגרות
מועד הבחינה: קיץ תשפ"ג, 2023
מספר השאלון: 36361
נספח: דפי נוסחאות ונתונים בפיזיקה ל-5 יח"ל
תרגום לאנגלית (3)

Physics
Mechanics

פיזיקה
מכניקה

Instructions

א. Duration of the exam: Two hours

ב. Exam structure and breakdown of points:
This exam has six questions. Answer three questions only.

Each question – $33\frac{1}{3}$ 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 question and item number 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 formula and data sheets; write down all derivations and change in subject of the formula required by the problem; insert the data in your derived expression; write the results of your calculations in decimal form using a suitable number of significant figures and the 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 m/s^2 for the magnitude of g, free-fall acceleration (near the surface of Earth).
(6) Write your answers in pen. Use pencil for sketches and graphs only.
(7) If you make a mistake, it is sufficient to cross out the incorrect text with a double line.

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

Good Luck!

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 והסעיף שבחרתם.
(2) בשאלות שבפתרון שלהן נדרש חישוב, יש להציג את השלבים האלה: רישום הביטוי המתמטי כפי שהוא כתוב בדפי הנוסחאות 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 המדידה.
(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 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. An experimenter runs two experiments using a small object and a smooth inclined plane.

The bottom of the inclined plane is labeled K as shown in Figure 1 below.

In the first experiment, the object is held at rest at Point A on the inclined plane. At a certain time, the object is given an initial speed of v_1 up the slope (see Figure 1–First experiment).

In the second experiment, the object is held at rest at Point B on the inclined plane. At a certain time, the object is given an initial speed of v_2 down the slope (see Figure 1–Second experiment).

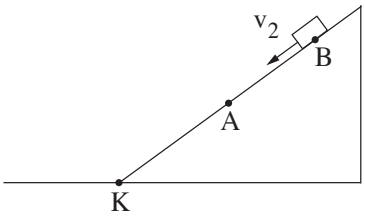


Figure 1–Second experiment

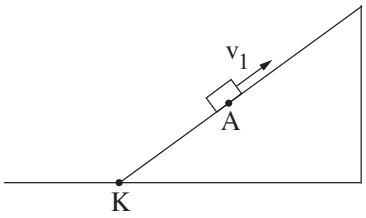


Figure 1–First experiment

Graphs א–ב in Figure 2 below describe the velocity of the object in each of the experiments during the first half-second of movement. In both experiments, $t = 0$ is the moment the object started moving.

Object velocity as a function of time in both experiments

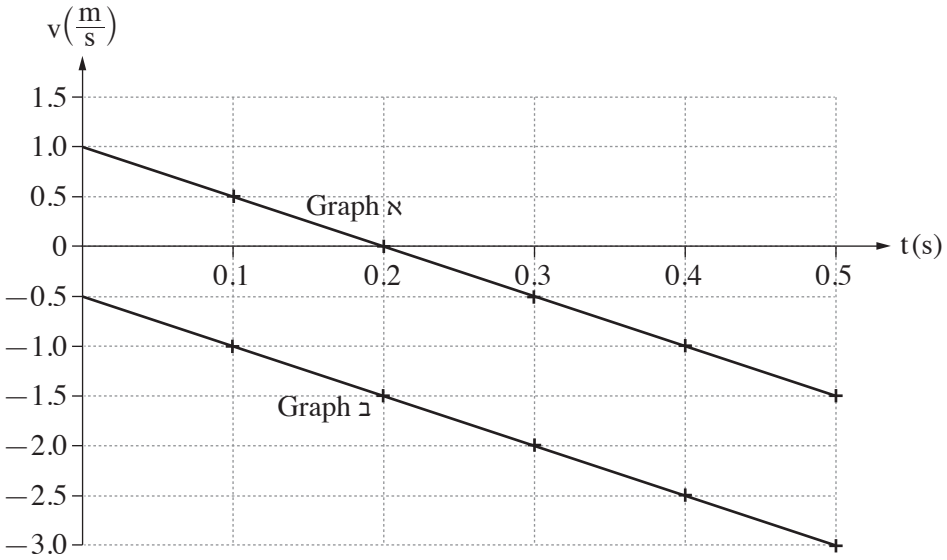


Figure 2

א. Determine whether the positive direction of the velocity is set to up or down the inclined plane. Explain your answer. (6 points)

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

/Continued on page 3/

In the first experiment, the object reached Point K (the lowest point on the inclined plane) at the time $t = 0.5s$.

ב. Calculate the distance between the highest point that the object reached in the first experiment and Point K . (7 points)

ג. Calculate the distance AK . (7 points)

In the second experiment the object reached Point K at the time $t = 0.62s$.

ד. Calculate AB (the distance between the object's position at the moment it started moving in the first experiment and its position at the moment it started moving in the second experiment). (8 points)

The two experiments are repeated in a system similar to the one described in Figure 1, but this time there is friction between the object and the inclined plane.

One of the following diagrams א–ד correctly describes the velocity of the object in both experiments during some of the time it was in motion, as a function of time.

ה. Determine which of the diagrams א–ד correctly describes the movement of the object when friction is exerted on it in the two additional experiments. Explain your answer. ($5\frac{1}{3}$ points)

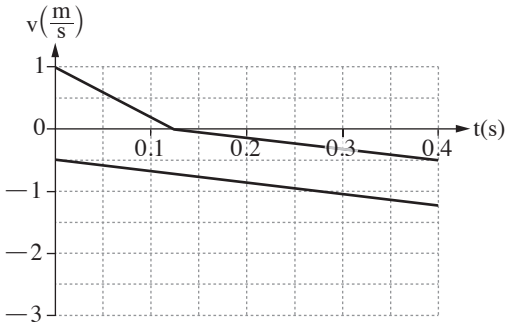


Diagram ב

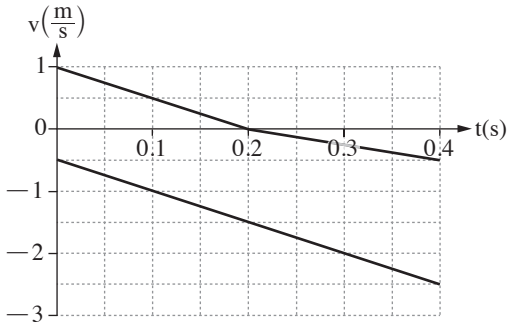


Diagram א

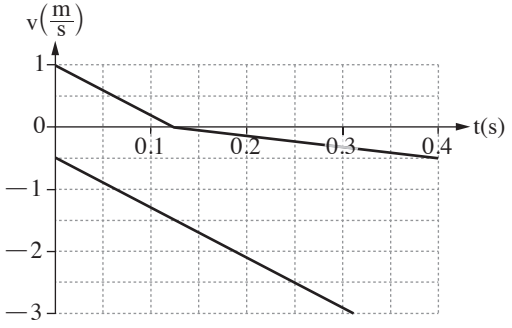


Diagram ד

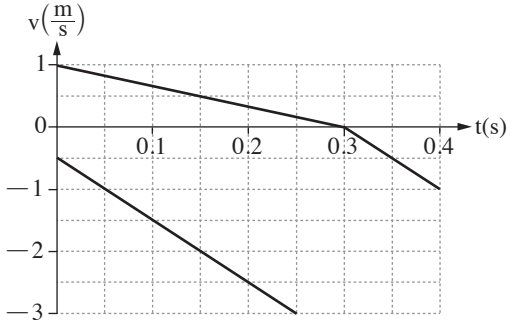


Diagram ג

/Continued on page 4/

2. Two objects, A and B, of masses m_A and m_B, respectively, are tied to each other with a string, as shown in Figure 1 below.

Object A is pulled up vertically by an external force F_1 whose magnitude can vary.

A force sensor is attached to the string connecting the two objects and measures the tension in the string.

Assume throughout this question that the mass of the string, the mass of the sensor, and the forces of friction exerted on the objects are negligible.

We set the positive direction of the vertical axis to be upward.

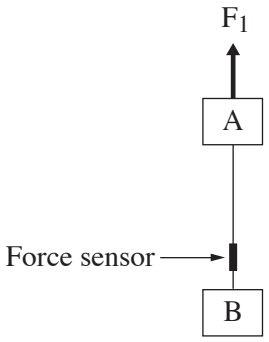


Figure 1

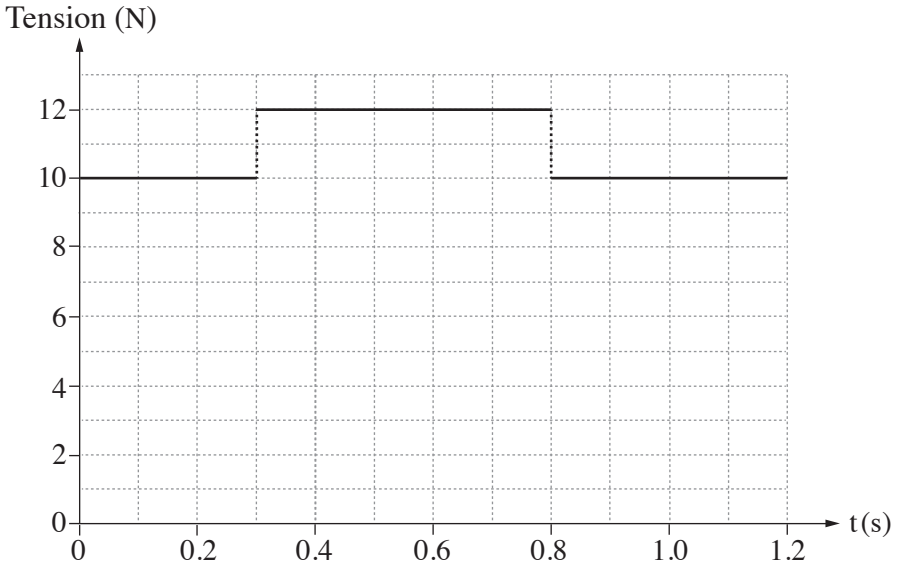
א. Sketch a free-body diagram [תרשים כוחות] of the forces acting on Object A and a free-body diagram of the forces exerted on Object B.

In both diagrams, label each force with its name and specify what exerts it (for the force F_1, write "external force" [כוח חיצוני]). (4 points)

ב. Write the force equation for each of the two objects, and use these equations to develop an expression for the system's acceleration in terms of the parameters F_1, m_A, m_B, and known physical constants. (6 points)

The following graph describes the tension measured by the sensor as a function of time, from time $t = 0$ until $t = 1.2s$. Remember that the magnitude of F_1 is not necessarily constant over time.

Tension as a function of time



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

/Continued on page 5/

We know that up to the time $t = 0.3s$ the system was at rest. The mass of Object A is $m_A = 3\,kg$.

ג. Use the graph to calculate m_B, the mass of Object B. (5 points)

ד. Use the graph to calculate the magnitude of the external force F_1 in each of the three time intervals described in the graph: $0 < t < 0.3s$, $0.3s < t < 0.8s$, $0.8s < t < 1.2s$. (8 points)

ה. For each of the intervals $0.3s < t < 0.8s$ and $0.8s < t < 1.2s$, determine the type of motion (rest/uniform motion/accelerated motion). Explain your answers. (6 points)

After these measurements were made, the system was used to conduct two experiments:
In the first experiment, a certain force F_1 was applied to the system, and the system's acceleration was found to be $a_1 \neq 0$ upward (see Figure 2א).
In the second experiment, Object B and the force sensor were detached from the string, and a force F_2 was applied vertically downward to the underside of Object A, in addition to the force F_1, which was identical to F_1 in the first experiment (see Figure 2ב).
Measurement showed that the acceleration was a_1 (upward) in the second experiment too.

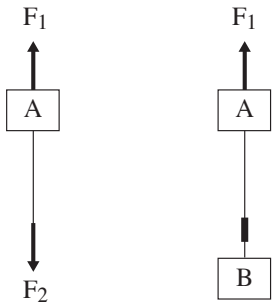


Figure 2ב

Figure 2א

ו. Which of the following statements 1–4 is correct? Explain your answer. ($4\frac{1}{3}$ points)

1. $F_2 < m_B g$

2. $F_2 = m_B g$

3. $F_2 > m_B g$

4. The relationship between F_2 and $m_B g$ cannot be determined based on the data.

/Continued on page 6/

3. A toy drone can release small balls while it is in flight.

The drone flew horizontally over level ground at an elevation of 6 meters, at a speed of $3\frac{m}{s}$, and released three balls, one after the other.

The time between releasing one ball and the next was 0.5 s .

Throughout this question, neglect air resistance to the balls' movement.

א. Calculate how much time passed from the moment a ball was released until it hit the ground. (7 points)

ב. Calculate the ball's velocity as it hit the ground (magnitude and direction). (9 points)

ג. When two balls are released one after another they hit the ground at two points. Find the distance between the two points and explain your considerations. (7 points)

ד. Determine which one of the figures 1–4 below best describes the locations of the drone and balls after the third ball was released. Explain your answer. (5 points)

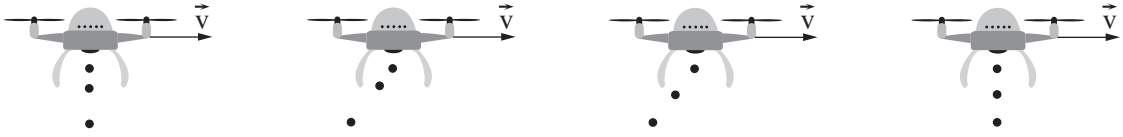
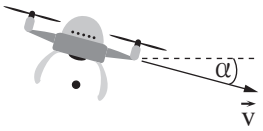


Figure 4 **Figure 3** **Figure 2** **Figure 1**

In a second case, the drone moves at the same speed as in the first case, but this time it flies at an angle α below the horizon, not horizontally (see figure below). Here, too, the drone releases a ball from an elevation of 6 meters above the ground.



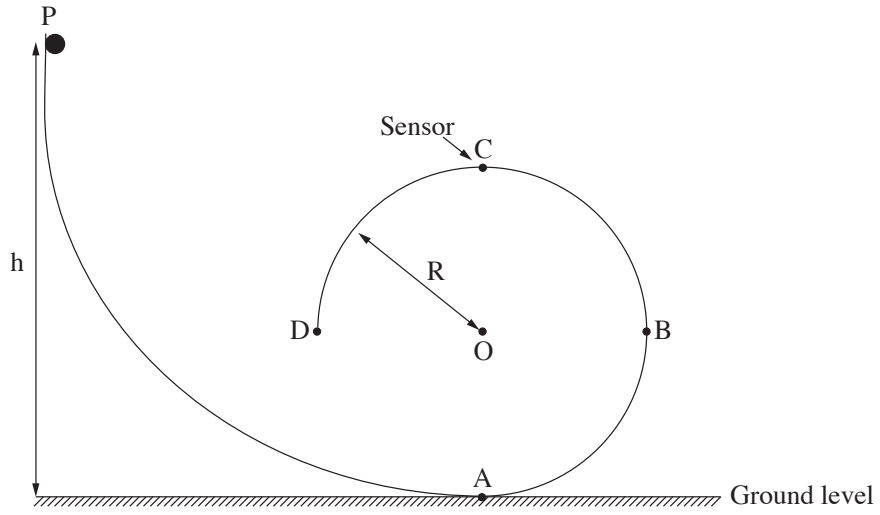
Yosef says that when the ball hit the ground in the second case it was moving at a greater speed than in the first case, but Dana argues that in both cases the ball hit the ground at the same speed.

ה. Determine who is right and explain your answer. You may use energy considerations to help you decide. ($5\frac{1}{3}$ points)

/Continued on page 7/

4. The following figure describes a system composed of a smooth track PABCD . The section ABCD of the track is part of a vertical circle of radius R . At Point C , the highest point on the track, there is a sensor; the moment that the force on the sensor is $N_{C,min}$ or higher, an electric circuit closes and lights up a lamp.

Neglect the air resistance in this question.



A small ball of mass m is held at rest on the track at elevation h above the ground, and then released. The ball moves along the track and the moment it reaches Point C , the sensor displays the value of the force N_C exerted on the sensor.

א. **(1)** Draw a free-body diagram [תרשים כוחות] of the forces acting on the ball as it passes Point C . Label each force in your diagram with its name and the name of the object exerting it.

(2) Express the magnitude of the force N_C exerted on the sensor as a function of the height h . Use the parameters m , R , and g .

(9 points)

The ball is released from rest several times, each time from a different height h , and the force readings on the sensor, N_C , are recorded.

The measurements are shown in the table below.

h(m)	0.6	0.8	1.0	1.2	1.4
N_C(N)	0.20	0.55	0.75	0.95	1.20

ב. **(1)** Draw a scatter diagram for the force N_C as a function of the height h .

(2) Add a trend line to the scatter diagram you drew.

(8 points)

ג. Use the graph to calculate the radius R of the circle and the mass m of the ball. (8 points)

We know that, for the lamp to light up, the force on the sensor must be at least $N_{C,min} = 0.6N$.

ד. Determine or calculate the minimum height h_{min} from which the ball must be released for the lamp to light up. (4 points)

Let h_1 be the x-coordinate of the point at which the trend line and the horizontal axis intersect.

ה. If we release the ball from the height h_1 , will the speed of the ball at Point C be zero? If the speed is zero, explain your answer; if not, calculate the speed of the ball at Point C .

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

/Continued on page 8/

5. Figure 1 below describes a system composed of an inclined plane and a rough horizontal surface. An object at rest is released from some point on the inclined plane. The object moves down the slope and stops on the horizontal surface.
Neglect air resistance in this question.

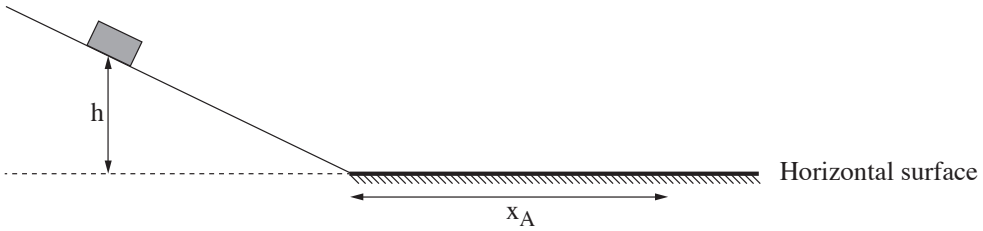


Figure 1

א. **(1)** Determine whether the object's mechanical energy is conserved on each of the two sections of travel (the inclined plane and the horizontal surface).
Explain your answers.

(2) Determine whether the object's momentum is conserved on each of the two sections of travel (the inclined plane and the horizontal surface).
Explain your answers.

(6 points)

Consider two objects: Object A of mass $m_A = 0.4kg$ and Object B of mass $m_B = 1.2kg$.
We know that the coefficient of friction between each object and the horizontal surface is the same.
Object A is released from height $h = 0.6m$. The object stops on the horizontal surface after it has traveled a distance of $x_A = 1.5m$ across the surface.

ב. Calculate the coefficient of friction between the horizontal surface and Object A. (8 points)

ג. If we release Object B from the same height, will the distance it travels over the horizontal surface be greater than, equal to, or smaller than x_A? Explain your answer. (6 points)

Object A is left on the horizontal surface and Object B is released from some point on the inclined plane. Object B collides with Object A in a perfectly elastic collision. The speed of Object B the moment before the collision is $4\frac{m}{s}$.
Assume that the collision's duration is very short, and that the positive direction is to the right.

ד. What was the impulse (magnitude and direction) acting on Object B in this collision?
(8 points)

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

/Continued on page 9/

In another experiment, Object A is released twice:

First, Object A is released from rest at a certain height H near the top of the inclined plane, which now slopes at an angle α (see Figure 2א).

The second time, the slope of the inclined plane is increased to an angle β, and Object A is released from rest from the same height H as the first time (see Figure 2ב).

Both times, the object moves along without colliding with other objects.

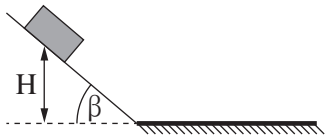


Figure 2ב

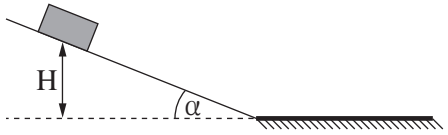


Figure 2א

Let J_1 be the magnitude of the impulse acting on the object from the moment it started moving until it reached the bottom of the slope the first time.

Let J_2 be the magnitude of the impulse acting on the object from the moment it started moving until it reached the bottom of the slope the second time.

ה. Consider the expressions 1–4 below, and choose the correct one. Explain your answer. ($5\frac{1}{3}$ points)

1. $J_1 > J_2$

2. $J_1 = J_2$

3. $J_1 < J_2$

4. We cannot know which impulse is greater without knowing the numerical values of the angles.

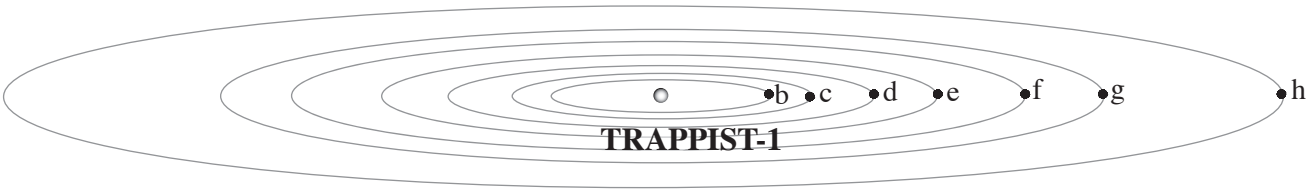
/Continued on page 10/

6. During 2016 and 2017 astronomers discovered seven planets—all similar in size to Planet Earth—in orbit around a dwarf star called TRAPPIST-1.

Let us name these planets b , c , d , e , f , g , h . Planet b is the planet closest to the dwarf star TRAPPIST-1 and Planet h is the furthest away.

For the calculations you make in this question, assume that the planets' orbits are circular, and that the effect of the seven planets on each other is negligible.

The TRAPPIST-1 system



The following table shows some data about the orbital radius and the orbital period of the three planets closest to the star TRAPPIST-1.

Planet	**r orbital radius** (10^9 m)	**T orbital period** (days)
b	1.73	1.51
c	2.36	
d		4.05

א. Calculate the missing values in the table. (7 points)

Eitan, who is studying physics in high school, argues that the further a planet is from the dwarf star TRAPPIST-1, the faster it moves.

ב. Is Eitan right? Explain your answer. (6 points)

ג. **(1)** Express g_b , the acceleration of Planet b caused by TRAPPIST-1.
Use the parameters T , r , and basic constants.

(2) Consider an object of mass m located on Planet b . Is the weight of this object mg_b ?
Explain your answer.

(8 points)

ד. Calculate the mass of the star TRAPPIST-1. (7 points)

Consider two spacecraft of equal mass, m_s . Spacecraft I orbits our sun and Spacecraft II orbits the star TRAPPIST-1. Both orbits are circular, and both have the same radius.

The additional energy that Spacecraft I needs to escape our sun's gravity is ΔE_I , and the additional energy Spacecraft II needs to escape TRAPPIST-1's gravity is ΔE_{II} .

ה. Calculate the ratio $\frac{\Delta E_I}{\Delta E_{II}}$. ($5\frac{1}{3}$ points)

Good Luck!

בהצלחה!