

# ශ්‍රී ලංකා විශාල දෙපාර්තමේන්තුව ඇලංකාප් ප්‍රේසේත් නිශේෂකණය Department of Examinations, Sri Lanka

**Department of Examinations, Sri Lanka**

សាខាភ័ត៌មាន នគរបាល នគរបាល (ក្រសួង សុខភាព) និង ឆ្នាំ ២០២៣(២០២៤)

අධ්‍යාපන රෝග කෘතක රඟු (දෙස පෙළ) එහෙම, 2023(2024) ක්‍රිංචීය මාත්‍රණ කාරාකාර්යාලය (ඉ. පාර්. කා.) සඳහා 2023(2024)

# கலைப் பொதுத் துறைப் பந்து (உயிர் துறை) பாட்டும், 2023 (2024)

## General Certificate of Education (Adv. Level) Examination - 2023 (2024)

# ஸைதிக விடையால் I பொதிகவியல் I Physics I

01 E I

පැය දෙකය  
இரண்டு மணித்தியாலம்  
*Two hours*

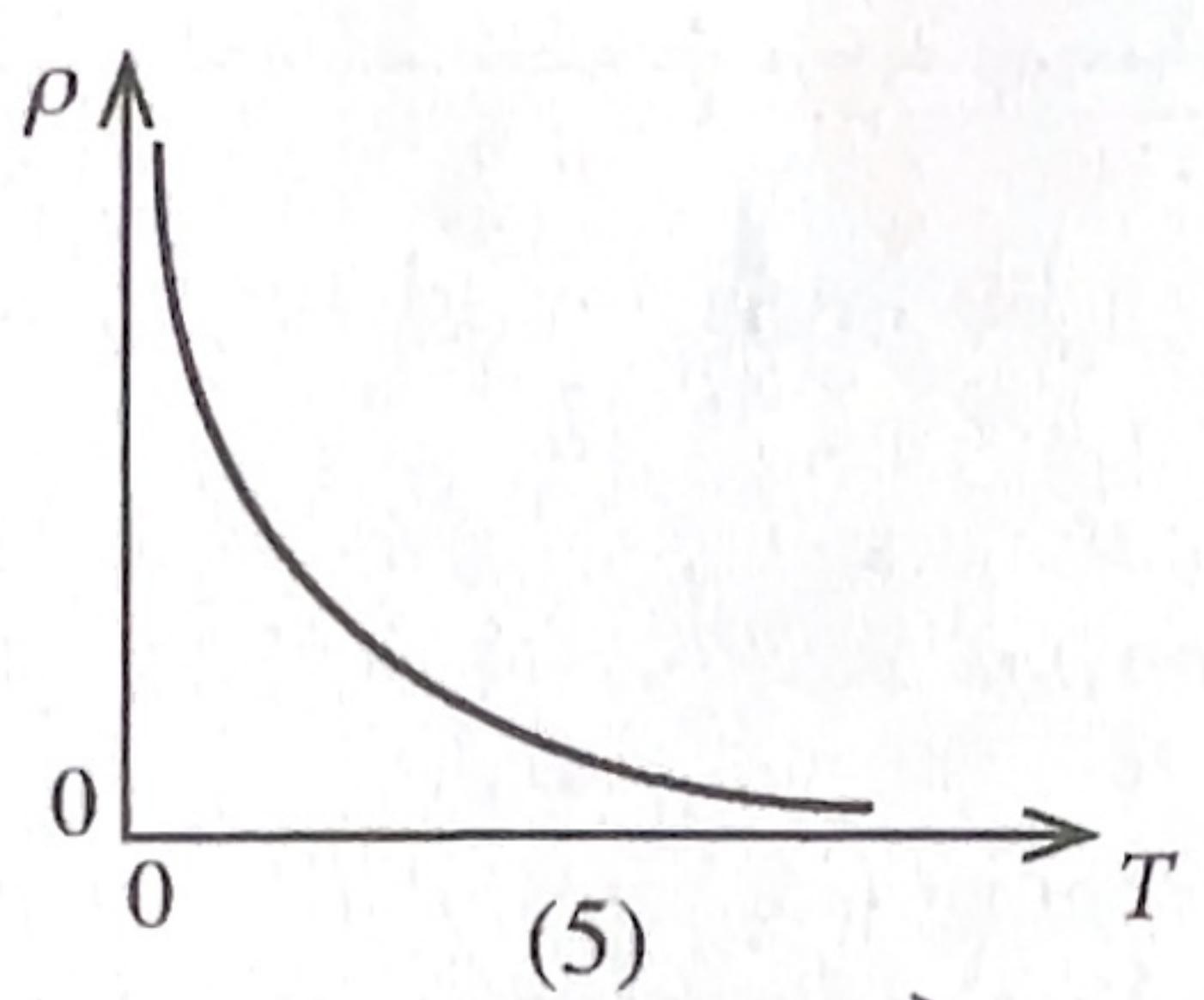
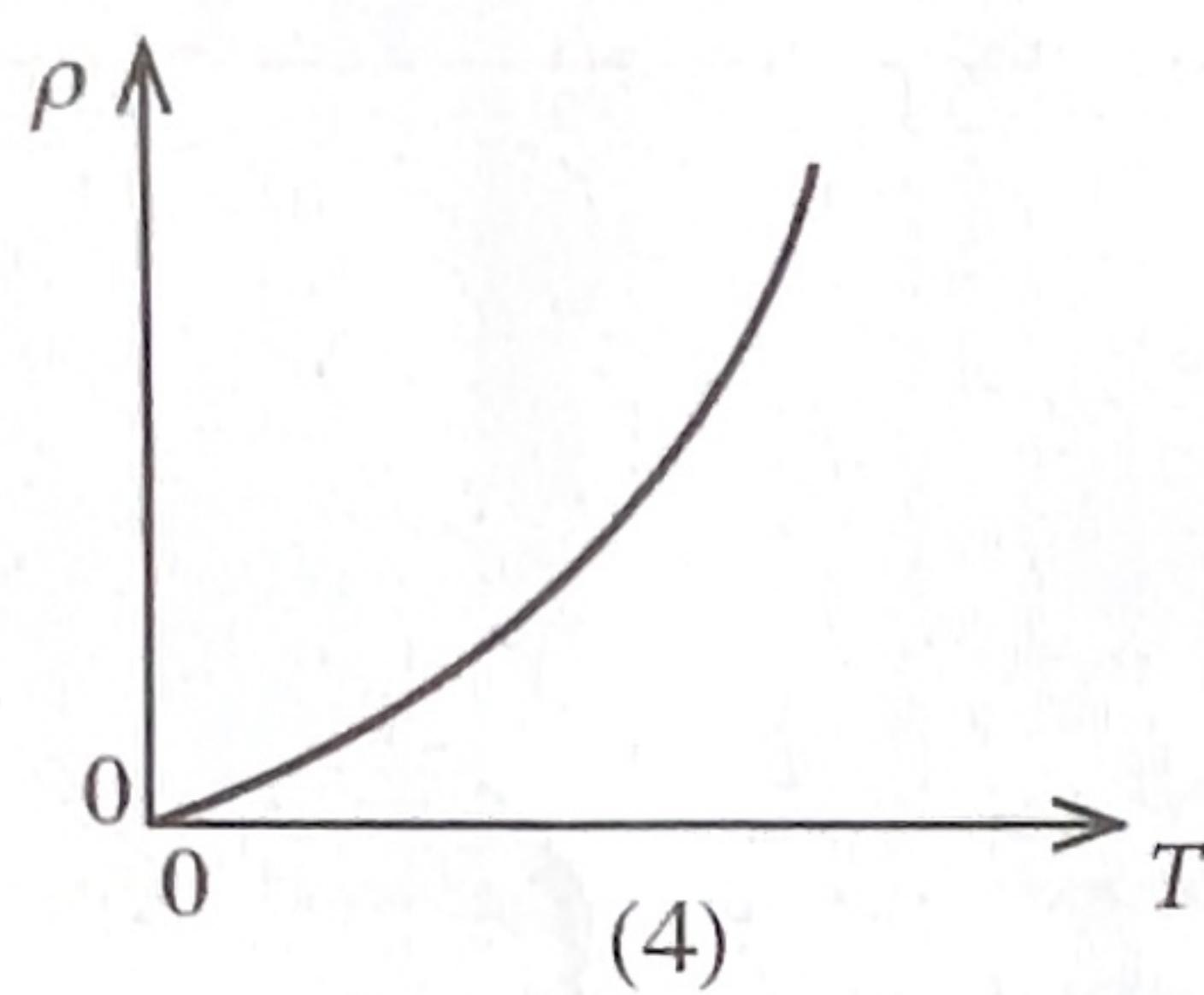
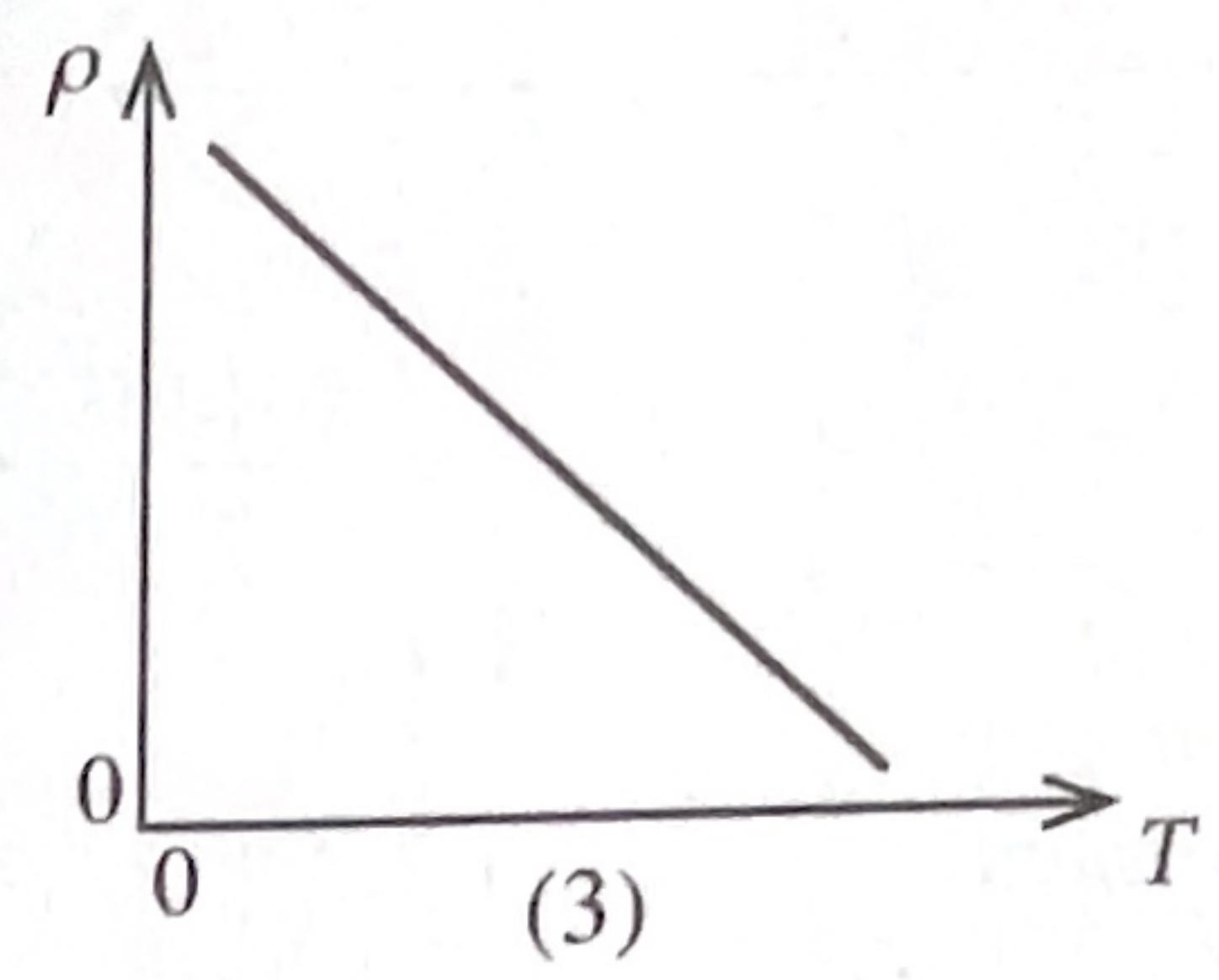
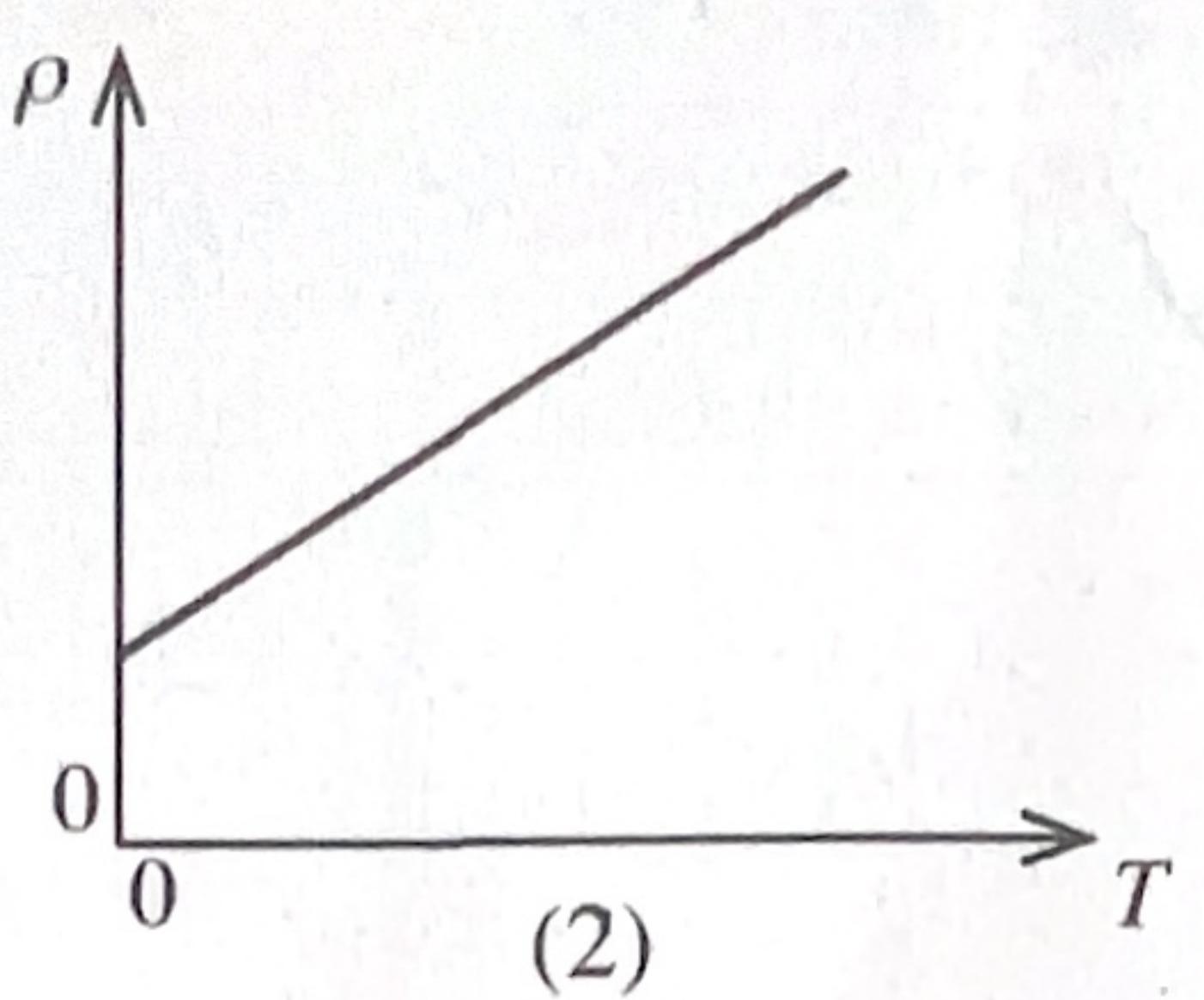
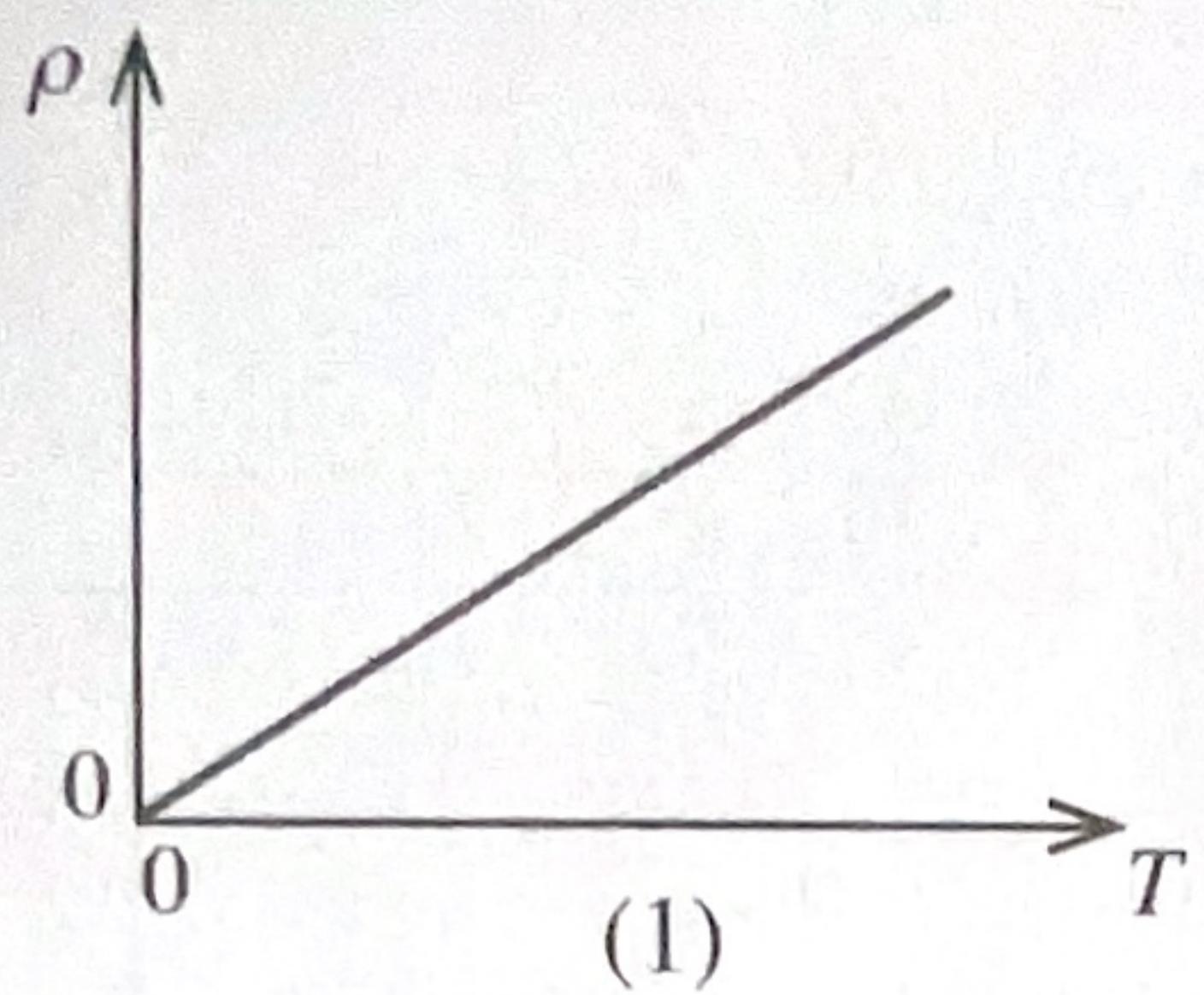
### **Instructions:**

- \* This question paper consists of 50 questions in 10 pages.
  - \* Answer all the questions.
  - \* Write your Index Number in the space provided in the answer sheet.
  - \* Read the instructions given on the back of the answer sheet carefully.
  - \* In each of the questions 1 to 50, pick one of the alternatives from (1), (2), (3), (4), (5) which is correct or most appropriate and mark your response on the answer sheet with a cross (x) in accordance with the instructions given on the back of the answer sheet.

*Use of calculators is not allowed.*

( $g = 10 \text{ m s}^{-2}$ )

9. If the pressure of a given mass of an ideal gas is kept constant, the variation of its density  $\rho$  with the absolute temperature  $T$  is best represented by



10. Three thermodynamic processes are given below.

- (A) an isothermal process ✓  
(B) a constant volume process ~~ΔW ≠ 0~~ X  
(C) a constant pressure process X : none ≠ 0

All the heat energy supplied to an ideal gas is converted to work done by the gas

- (1) only by (A). (2) only by (B). (3) only by (C).  
~~(4) only by (A) and (C).~~ (5) by all (A), (B) and (C).

11. Electric potential of two conducting parallel plates are  $-10\text{ V}$  and  $30\text{ V}$  respectively. If the separation between the plates is  $2\text{ cm}$  what is the electric field intensity between the plates?

- (1)  $1000 \text{ V m}^{-1}$     (2)  $1500 \text{ V m}^{-1}$     (3)  $2000 \text{ V m}^{-1}$     (4)  $3000 \text{ V m}^{-1}$     (5)  $4000 \text{ V m}^{-1}$

12. Which of following is not true about the electric field lines?

- (1) Field lines start from positive charges and end at negative charges.
  - (2) If a single positive charge exists field lines end at infinity. ✓
  - (3) Two field lines can never cross each other. ✓
  - (4) Electrostatic field lines form closed loops. ✗ (Ans)
  - (5) Field lines are imaginary lines which are used to represent the pattern of electric field.

13. A sound source of intensity  $I_1$  produces a sound intensity level of 90 dB at a certain point. Another sound source of intensity  $I_2$  produces a sound intensity level of 40 dB at the same point. The distance

from both the sources to the point is same. What is the ratio of  $\frac{I_1}{I_2}$ ?



14. The photoelectric threshold frequency of a metal is  $f_0$ . When light of frequency  $4f_0$  is incident on the metal, what is the maximum kinetic energy of the ejected photoelectrons?

- (1)  $hf_0$       (2)  $2hf_0$       (3)  $3hf_0$       (4)  $4hf_0$       (5)  $5hf_0$

15. A convex lens of focal length 20 cm and a concave lens of focal length 5 cm are kept along the same axis with a distance  $d$  between them. If a parallel monochromatic beam of light incident on the convex lens leaves the concave lens as a parallel beam what is the distance  $d$ ?

- (1) 25 cm      (2) 20 cm      (3) 15 cm      (4) 10 cm      (5) 5 cm

16. Trolley  $X$  of mass  $m$  and trolley  $Y$  of mass  $M$  are moving in the same direction along a straight line on a smooth horizontal surface. The speed of trolley  $X$  is twice that of trolley  $Y$ . When the two trolleys collide both move together with a common velocity. Due to the collision if the speed of the trolley  $Y$  is increased by 20%, what will be the ratio of  $\frac{M}{m}$ ?

(1) 5      (2) 4      (3) 3      (4) 2      (5) 1

17. A ball is projected upwards at an angle of  $60^\circ$  with the horizontal. If the initial kinetic energy of projection is  $K$  what will be the kinetic energy of the ball at its maximum height? (Neglect air resistance)

(1)  $K$       (2)  $\frac{K}{2}$       (3)  $\frac{K}{3}$       (4)  $\frac{K}{4}$       (5) 0

18. An immersion heater made of a wire of length  $L$  and diameter  $d$  takes 4 minutes to raise the temperature of a given mass of water by  $40^\circ\text{C}$ . How much time is taken for heating a same amount of water by  $40^\circ\text{C}$  using another immersion heater made of a wire with the same material, but having length  $2L$  and diameter  $2d$ ? (Neglect heat loss to the surroundings)

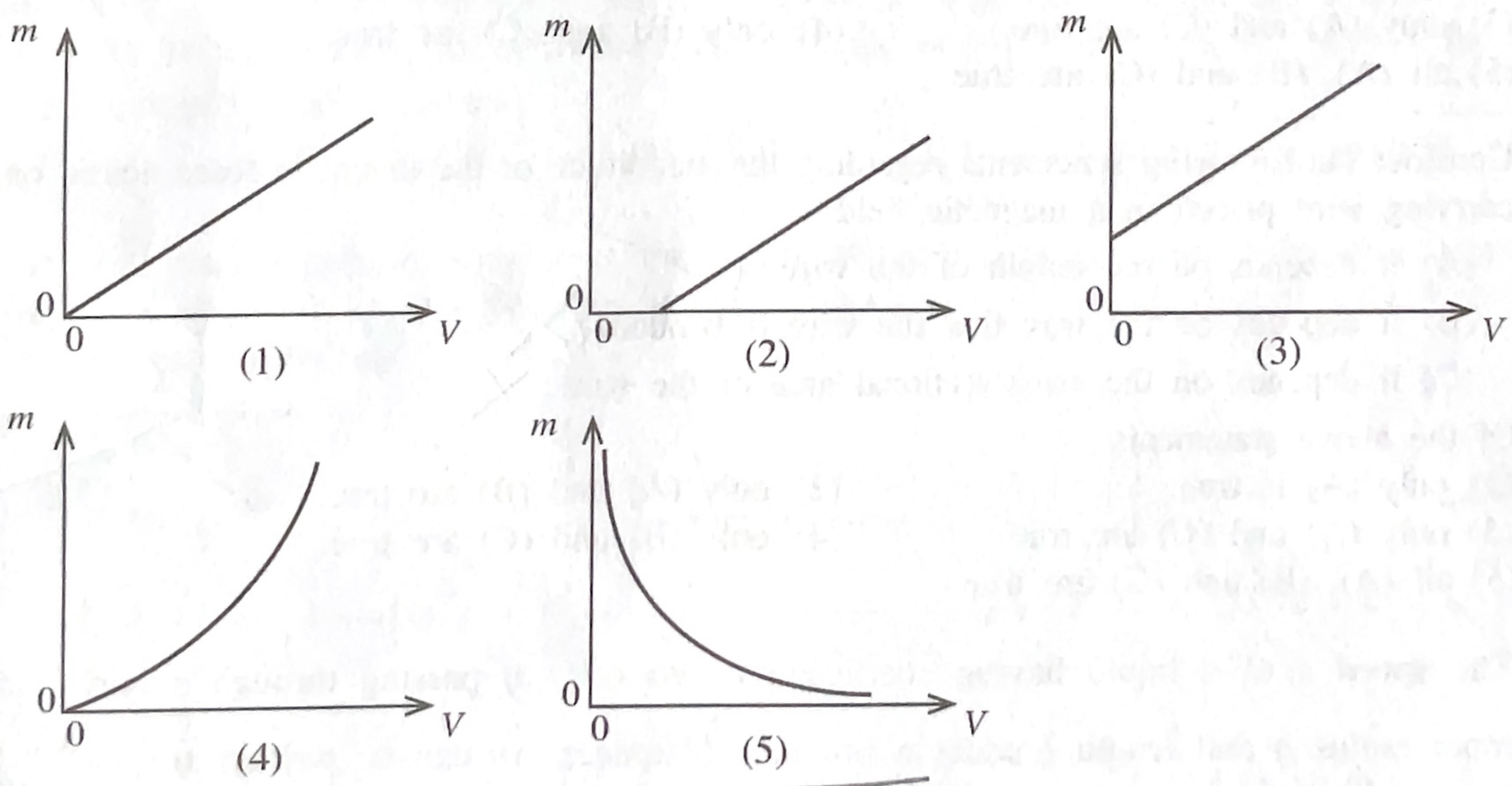
(1) 0.5 min      (2) 1 min      (3) 1.5 min      (4) 2 min      (5) 8 min

19. Assume that the earth revolves around Sun in a circular path of radius  $r_1$  with a speed of  $v_1$ , and Mars revolves around Sun in a circular path of radius  $r_2$  with a speed of  $v_2$ .

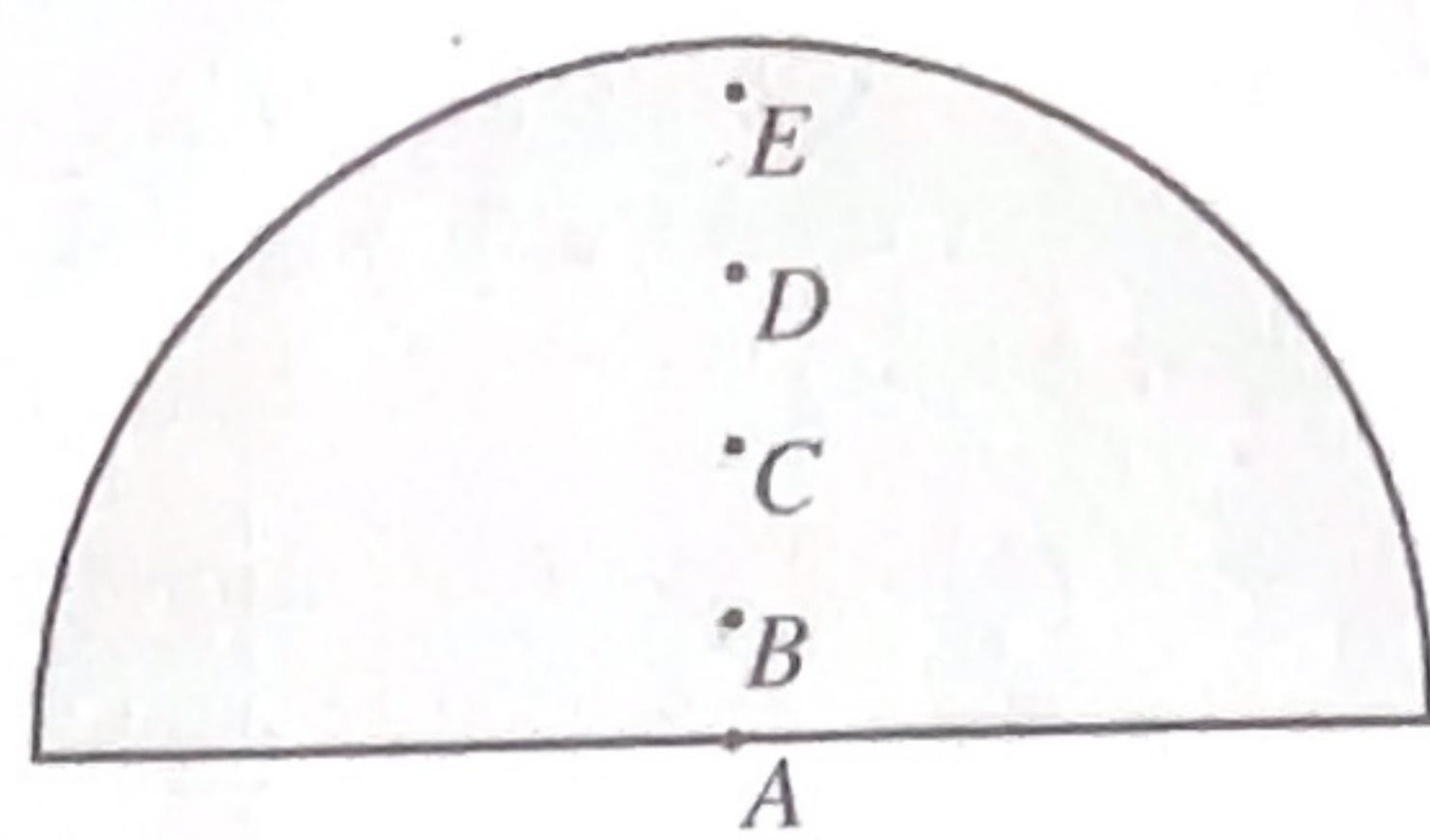
What is the ratio of  $\frac{v_1}{v_2}$ ?

(1)  $\frac{r_1}{r_2}$       (2)  $\frac{r_2}{r_1}$       (3)  $\sqrt{\frac{r_2}{r_1}}$       (4)  $\sqrt{\frac{r_1}{r_2}}$       (5)  $\frac{r^2}{r_2}$

20. The variation of linear magnification ( $m$ ) of real images formed by a convex lens with the image distance ( $V$ ) is best represented by



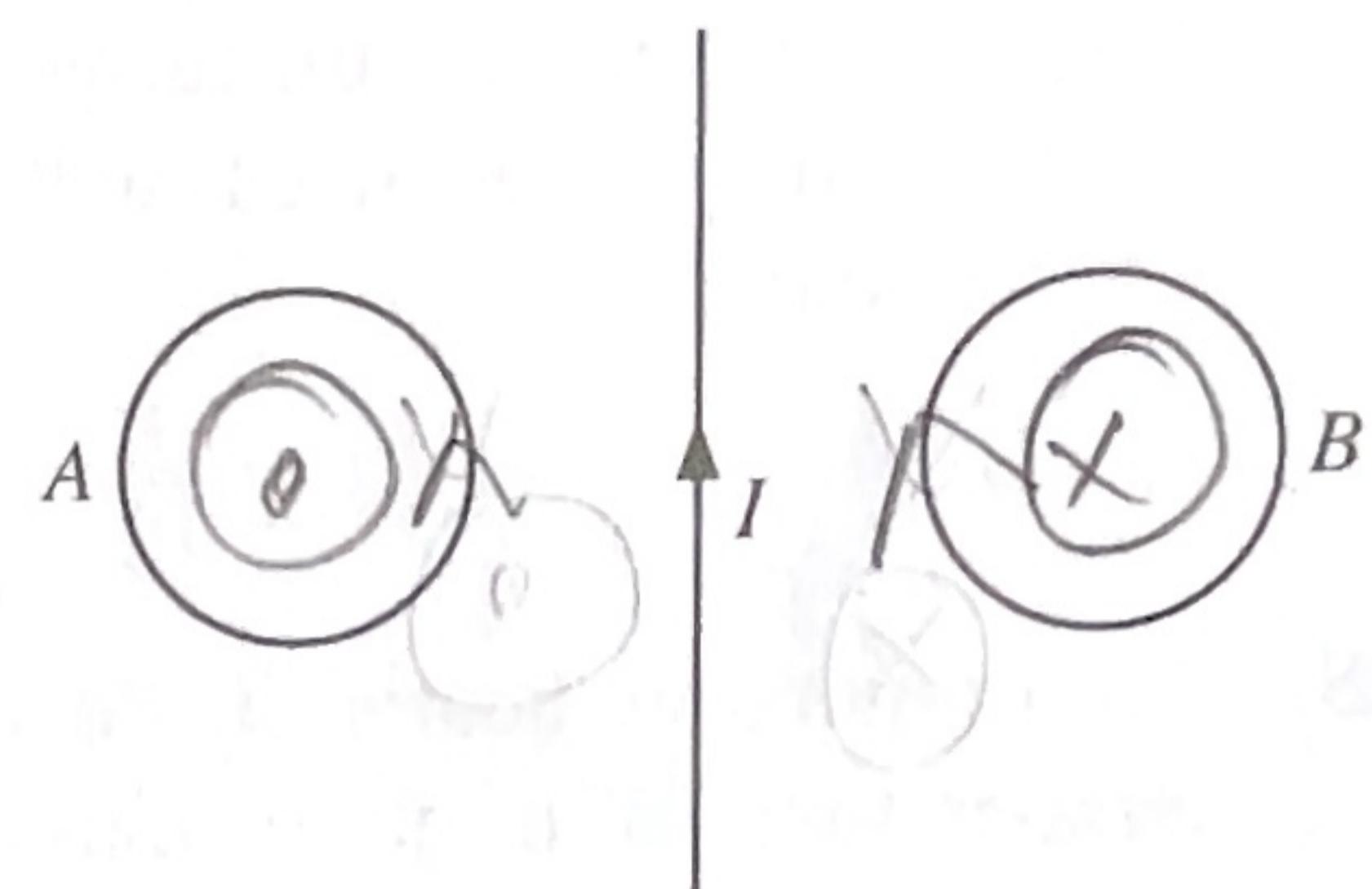
21. If a proton is projected with a velocity  $v$  along the axis of a current carrying long solenoid,
- the proton will be accelerated along the axis.
  - the proton will be decelerated along the axis.
  - the path of the proton will be circular about the axis.  $\times$
  - the path of the proton will be helical about the axis.  $\times$
  - the proton will continue to move with velocity  $v$  along the axis.  $\checkmark$



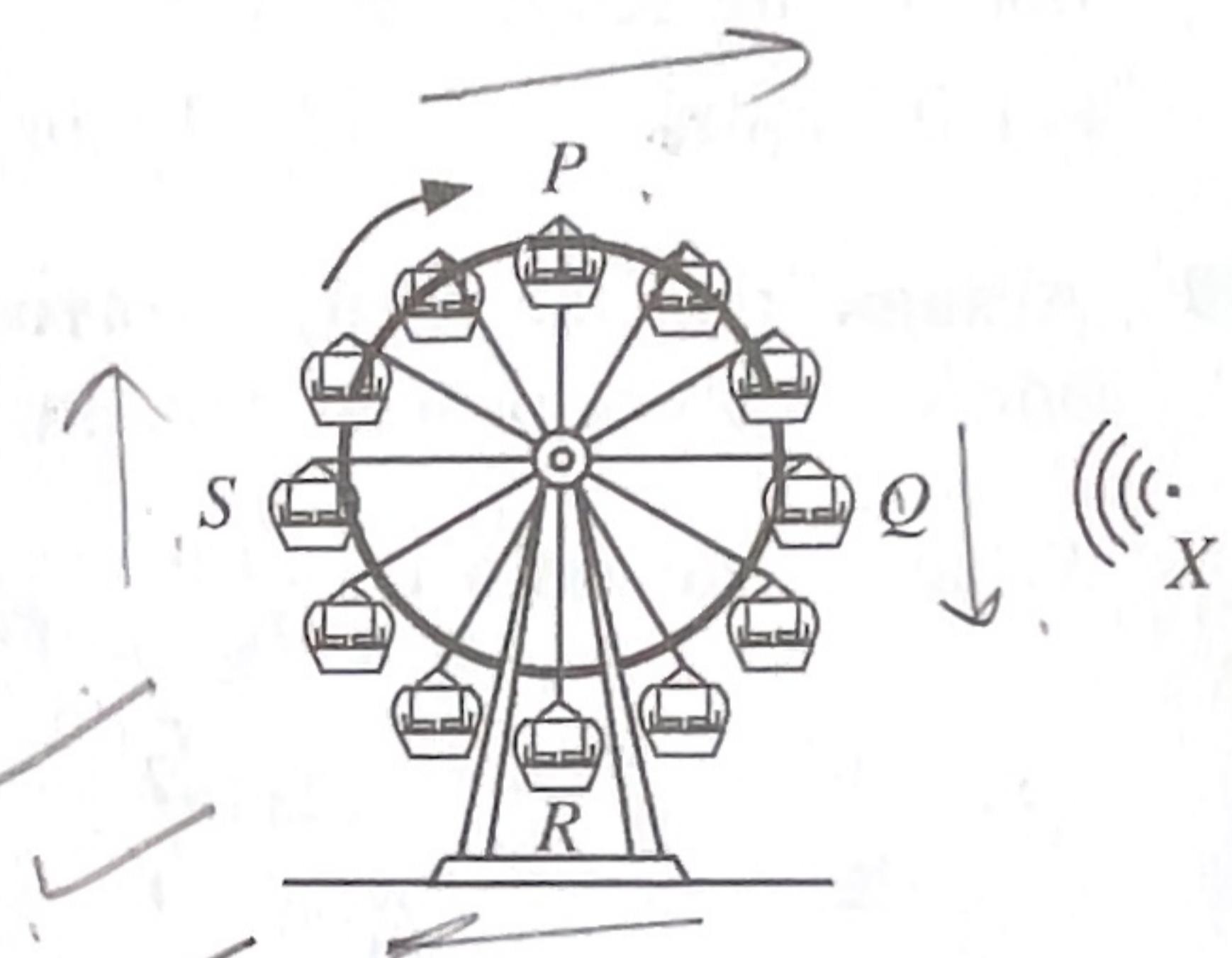
23. Two conducting circular loops A and B are kept on the same plane with a straight current carrying wire at either side of it as shown in the figure. If the current ( $I$ ) in the wire decreases in magnitude, the induced current in the loops

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  - (1) will be clockwise in A and clockwise in B.
  - (2) will be anti-clockwise in A and clockwise in B.
  - (3) will be clockwise in A and anti-clockwise in B.
  - (4) will be anti-clockwise in A and anti-clockwise in B.
  - (5) will be zero in both loops.



24. The figure shows a Ferris-wheel rotating in the clockwise direction. A loud speaker fixed at  $X$  emits continuous sound waves at a constant frequency  $f_0$ . Consider the following statements regarding the pitch of the sound heard by a man in the Ferris-wheel when he passes the positions at  $P$ ,  $Q$ ,  $R$  and  $S$ ?



- (A) The original pitch is heard when the man is at positions  $Q$  and  $S$ .
  - (B) The highest pitch is heard when the man is at position  $P$ .
  - (C) The lowest pitch is heard when the man is at position  $R$ .

Of the above statements

- Of the above statements

  - (1) only (A) is true.
  - (2) only (A) and (B) are true.
  - (3) only (A) and (C) are true.
  - (4) only (B) and (C) are true.
  - (5) all (A), (B) and (C) are true.

25. Consider the following statements regarding the magnitude of the magnetic force acting on a current carrying wire placed in a magnetic field.

- (A) It depends on the length of the wire. ✓
  - (B) It depends on the way that the wire is bended. ✗
  - (C) It depends on the cross-sectional area of the wire. ✗

Of the above statements



26. The speed  $v$  of a liquid having coefficient of viscosity  $\eta$  passing through a horizontal tube of inner radius  $a$  and length  $l$  under a pressure difference  $\Delta p$  can be written as  $v = \frac{Ca^n \Delta P}{\eta l}$ . Here  $C$  is a dimensionless constant. What is the value of  $n$ ?

- (1)  $\frac{1}{2}$       (2) 1      (3) 2      (4) 3      (5) 4

27. A steel measuring tape has been calibrated at  $20^\circ\text{C}$  temperature. A student uses this tape to measure a length at  $40^\circ\text{C}$ . The value that he reads off the tape is 50.00 m. What is the actual length? The linear expansivity of steel is  $2 \times 10^{-5} \text{ }^\circ\text{C}^{-1}$ .

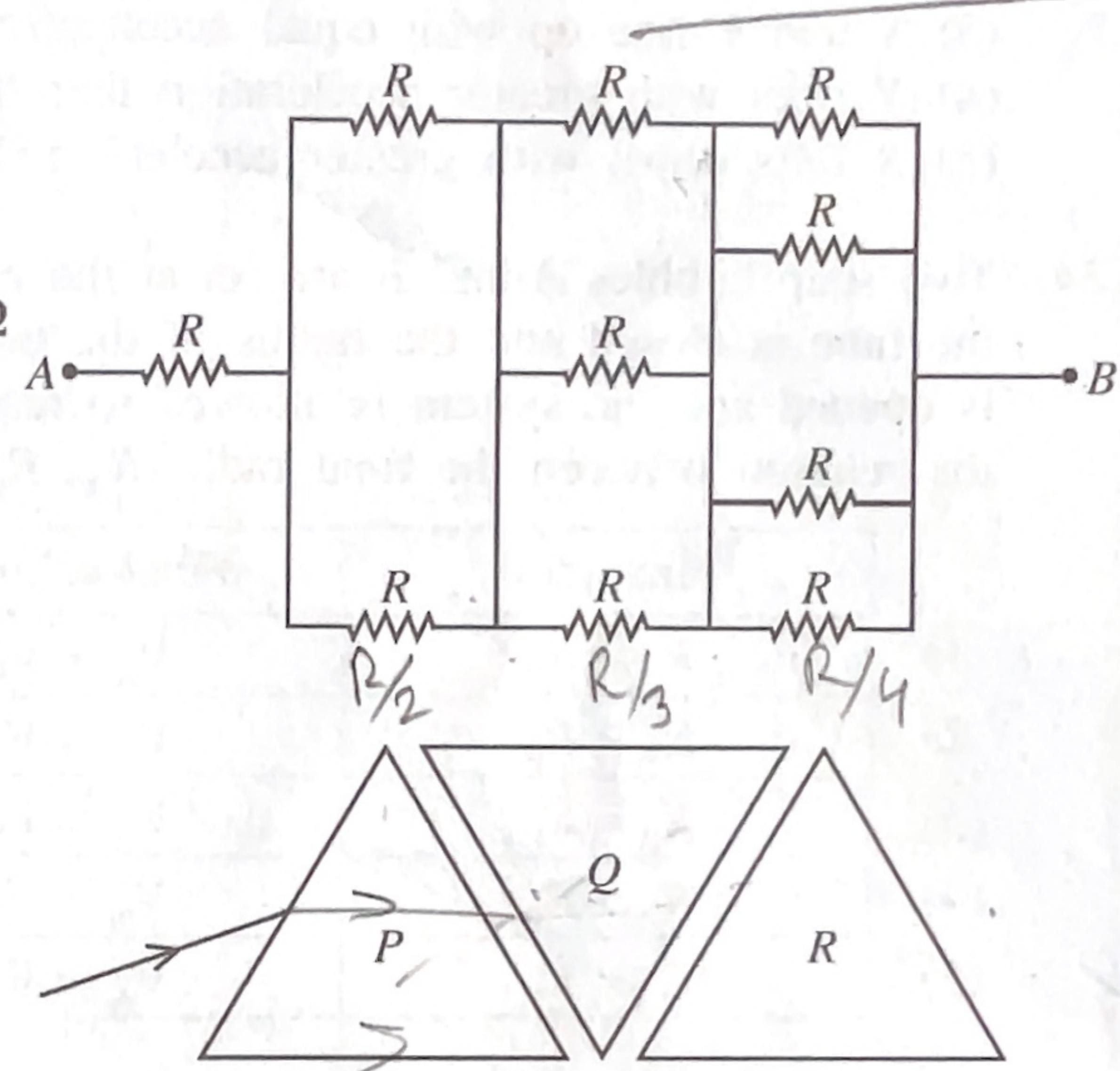
- (1) 49.96 m      (2) 49.98 m      (3) 50.02 m      (4) 50.04 m      (5) 50.06 m

28. An incompressible, non-viscous fluid of density  $\rho$  flows through a horizontal pipe of inner radius  $r$  and then passes through a narrow part of the pipe of inner radius  $\frac{r}{2}$ . If the fluid pressure and the velocity in the wider part are  $P_0$  and  $v_0$  respectively, what is the pressure of the fluid in the narrow part of the tube?

(1)  $\frac{P_0}{4}$       (2)  $\frac{P_0}{2}$       (3)  $P_0 - \frac{1}{2} \rho v_0^2$       (4)  $P_0 - \frac{3}{2} \rho v_0^2$       (5)  $P_0 - \frac{15}{2} \rho v_0^2$

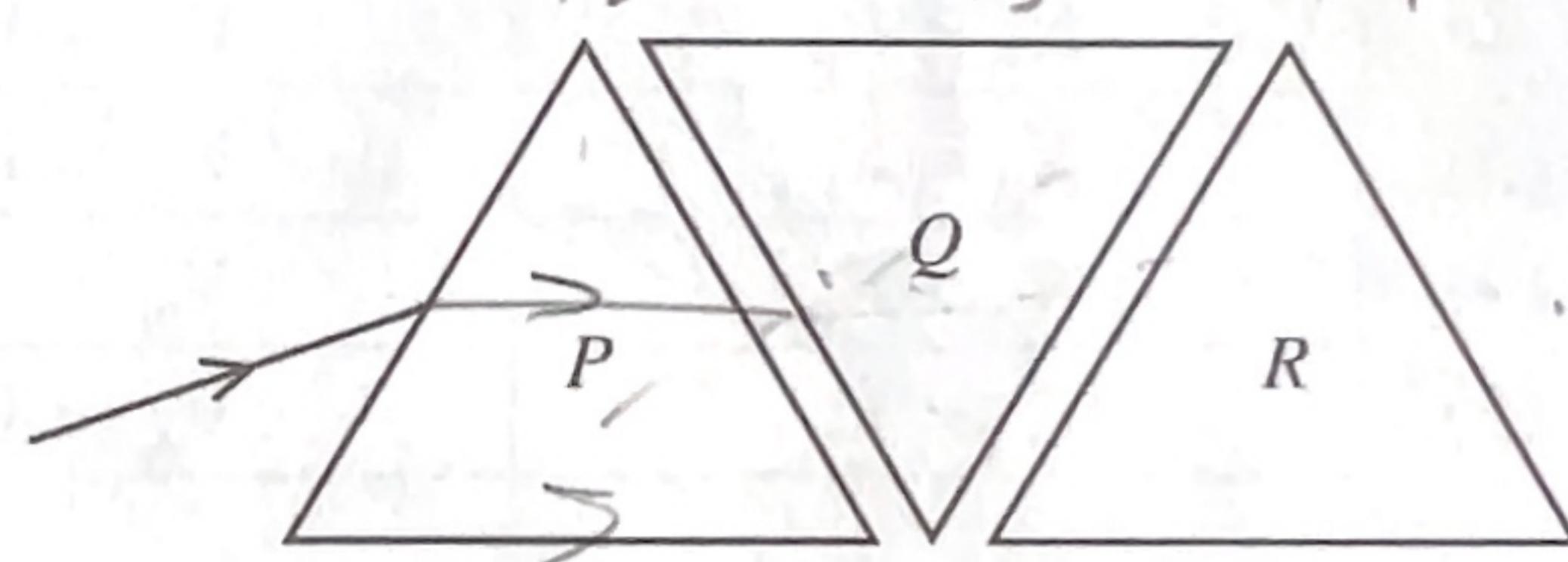
29. Ten resistors, each of resistance  $R$ , are connected as shown in the diagram. If the resistance between the ends  $AB$  is  $50\text{k}\Omega$ , what is the value of  $R$ ?

(1)  $12\text{k}\Omega$       (2)  $15\text{k}\Omega$       (3)  $18\text{k}\Omega$   
 (4)  $24\text{k}\Omega$       (5)  $36\text{k}\Omega$



30. A monochromatic ray of light suffers minimum deviation  $D$  in an equilateral prism  $P$ . Three such identical prisms  $P$ ,  $Q$  and  $R$  are placed as shown in the figure. What is the total deviation of the ray after passing through the prism combination?

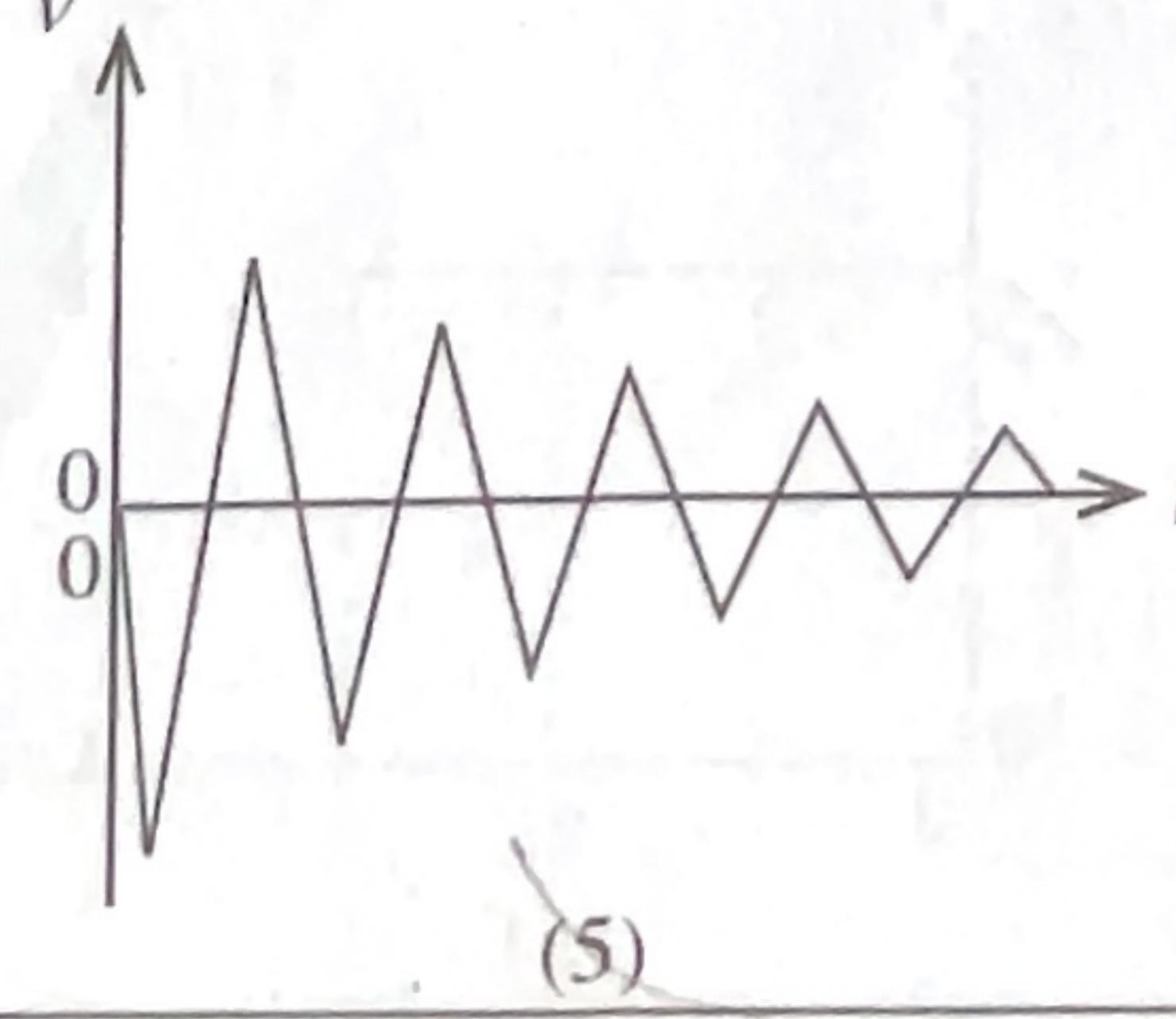
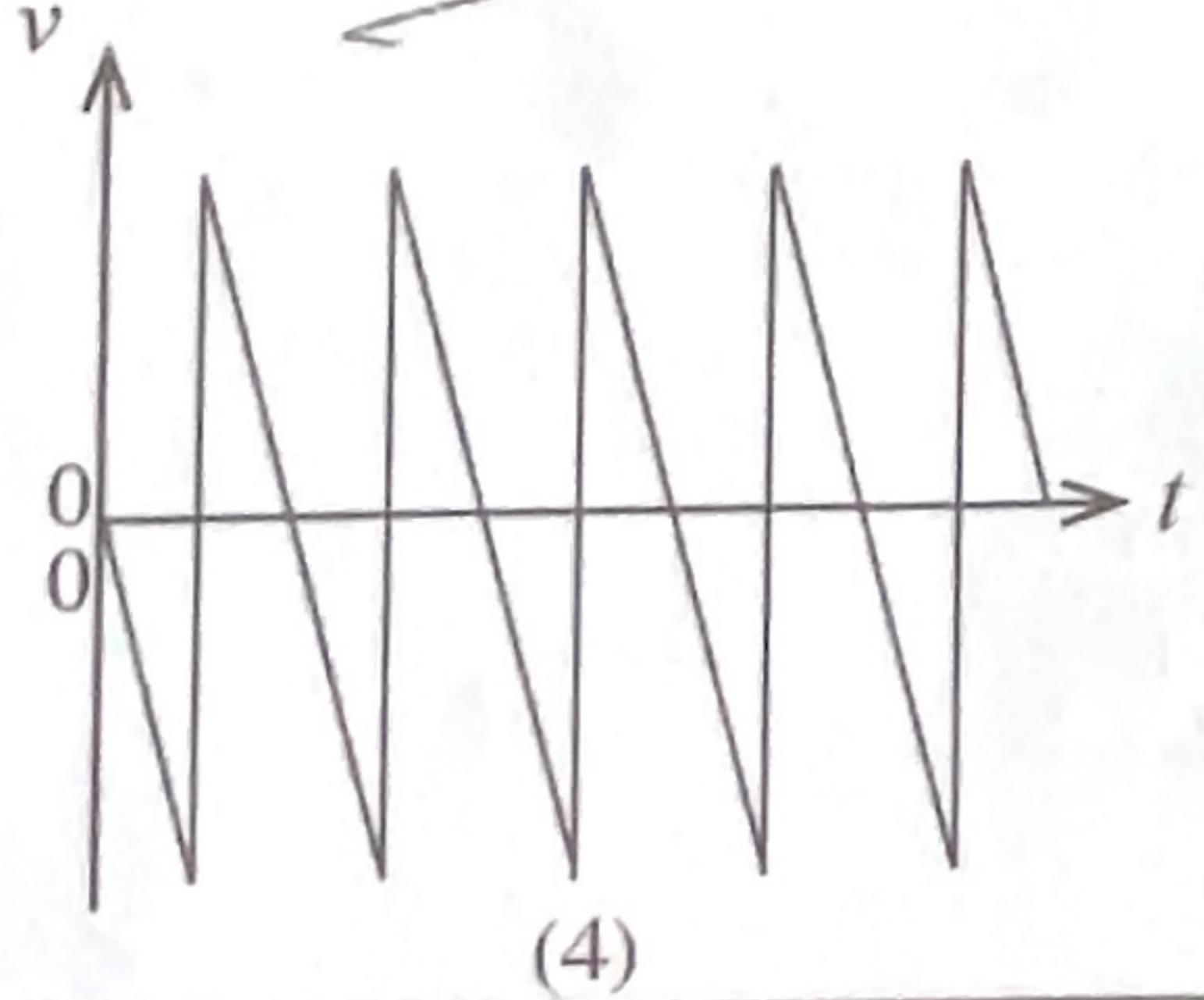
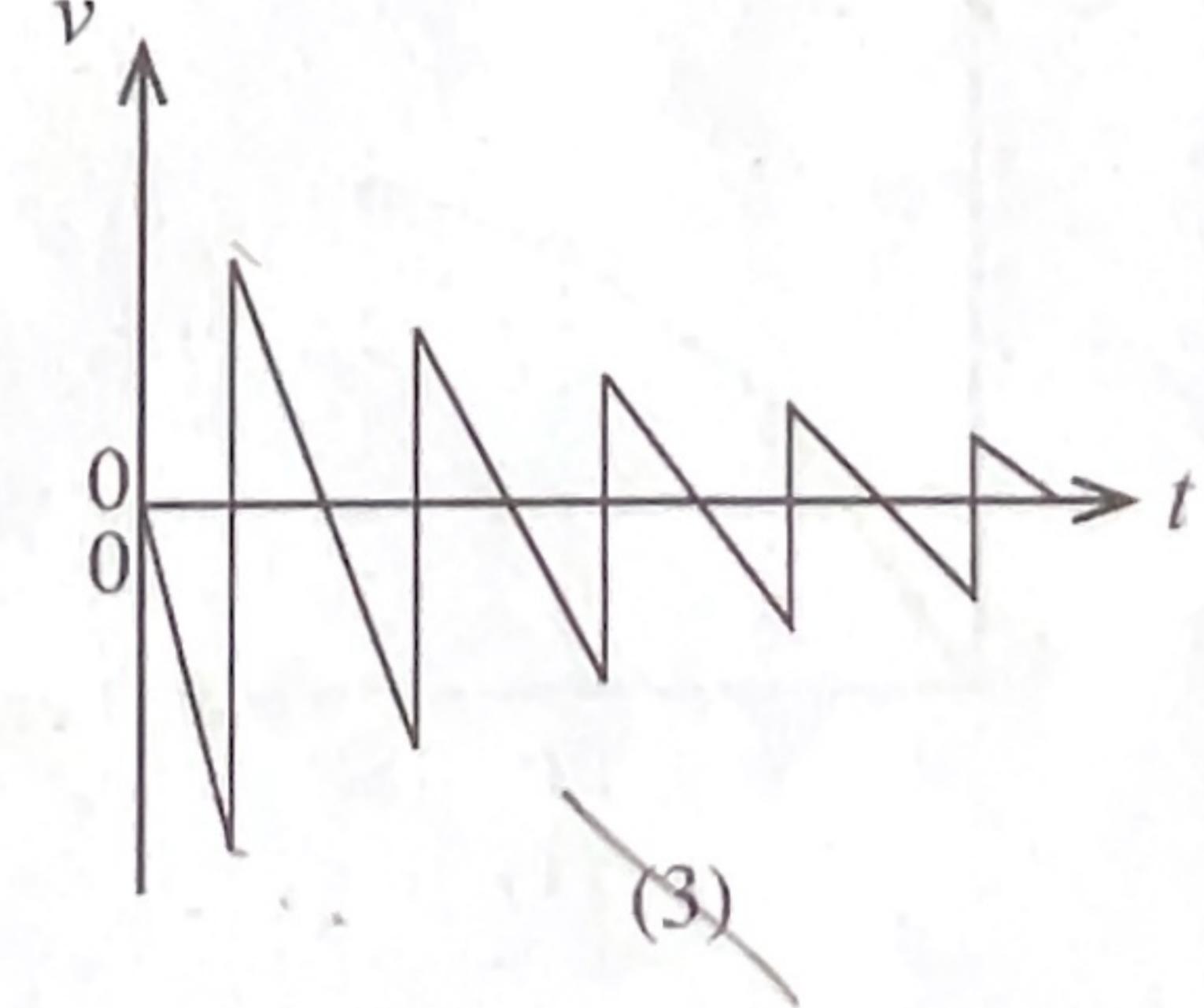
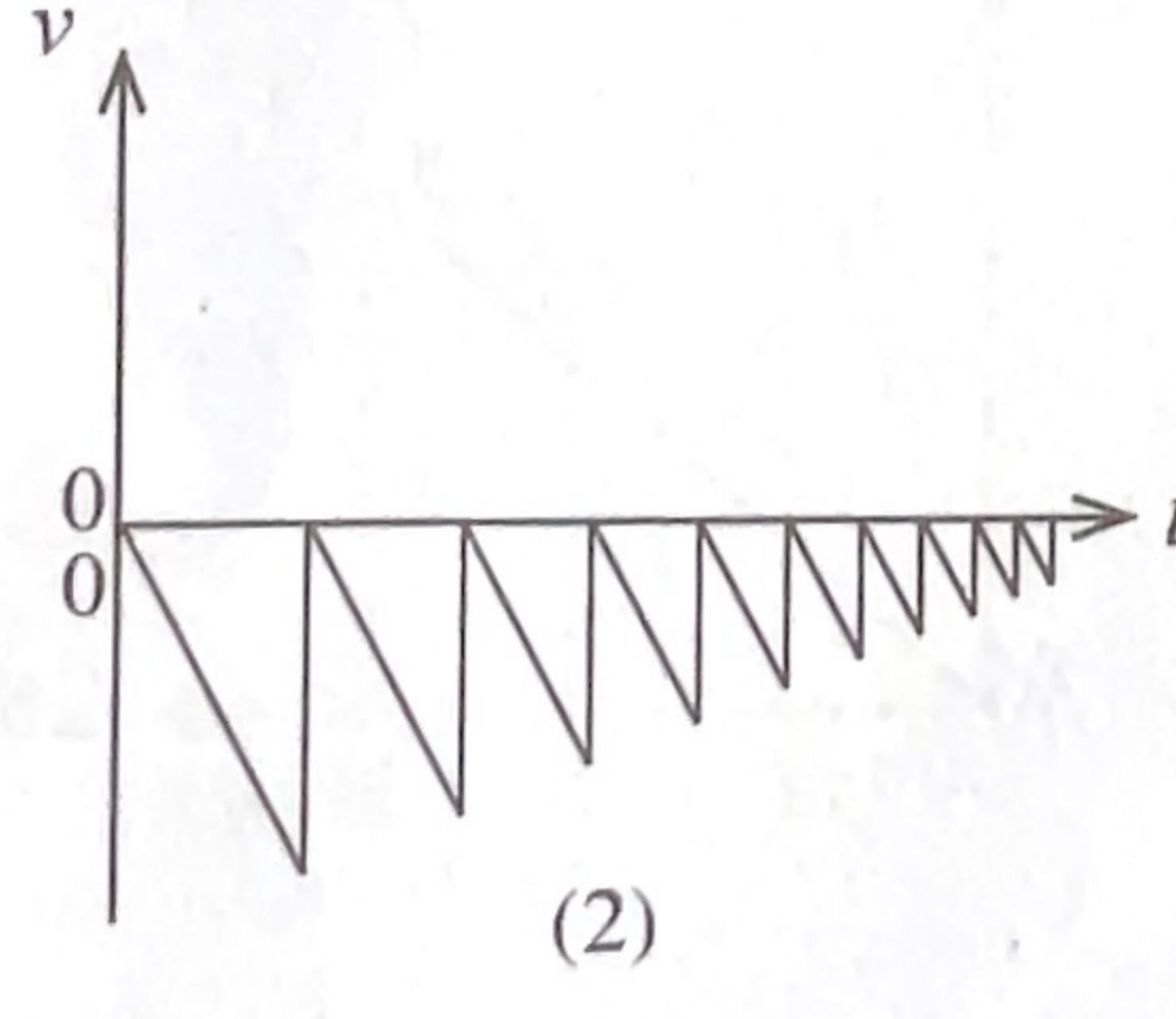
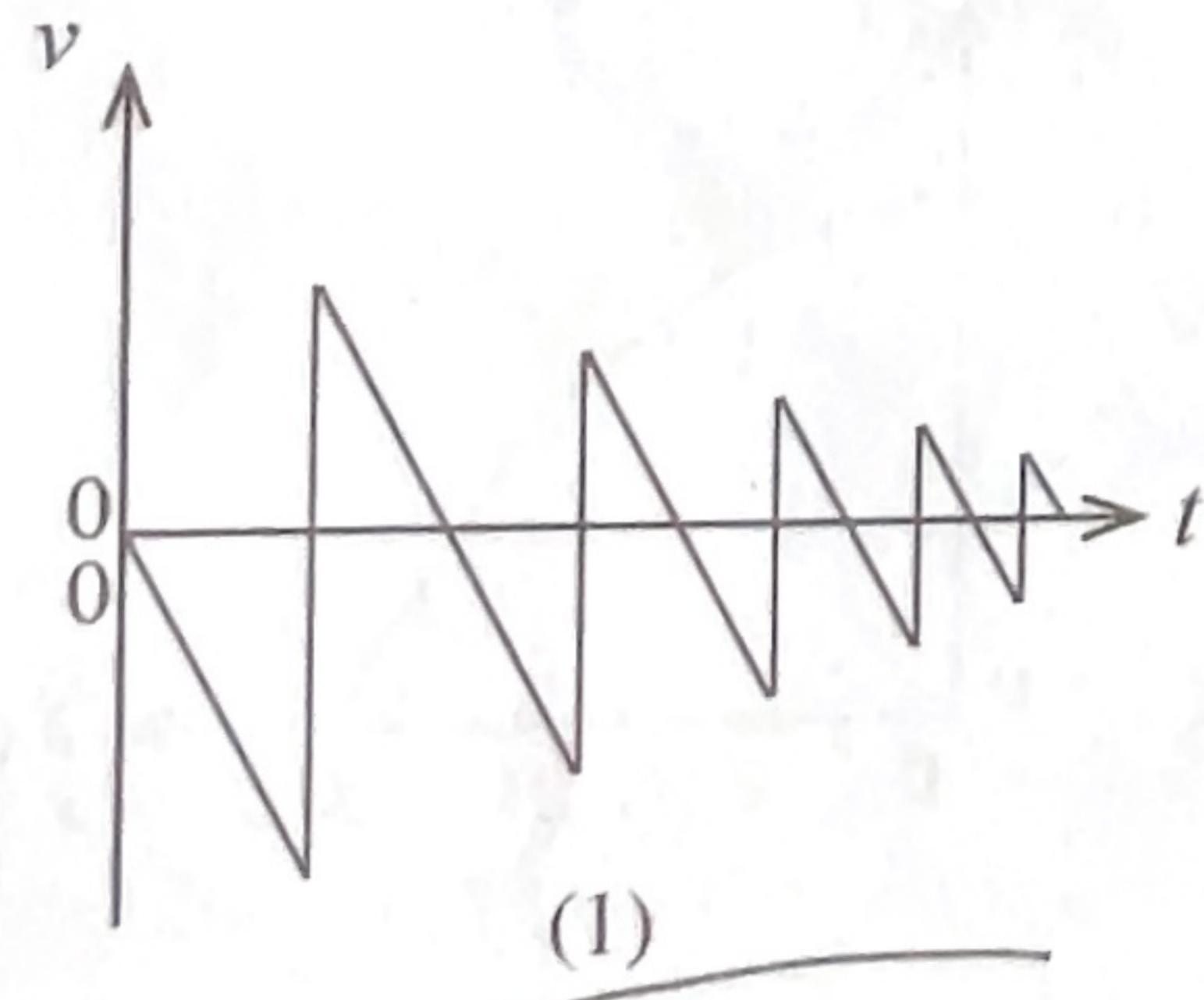
(1)  $\frac{D}{3}$       (2)  $\frac{D}{2}$       (3)  $D$   
 (4)  $2D$       (5)  $3D$



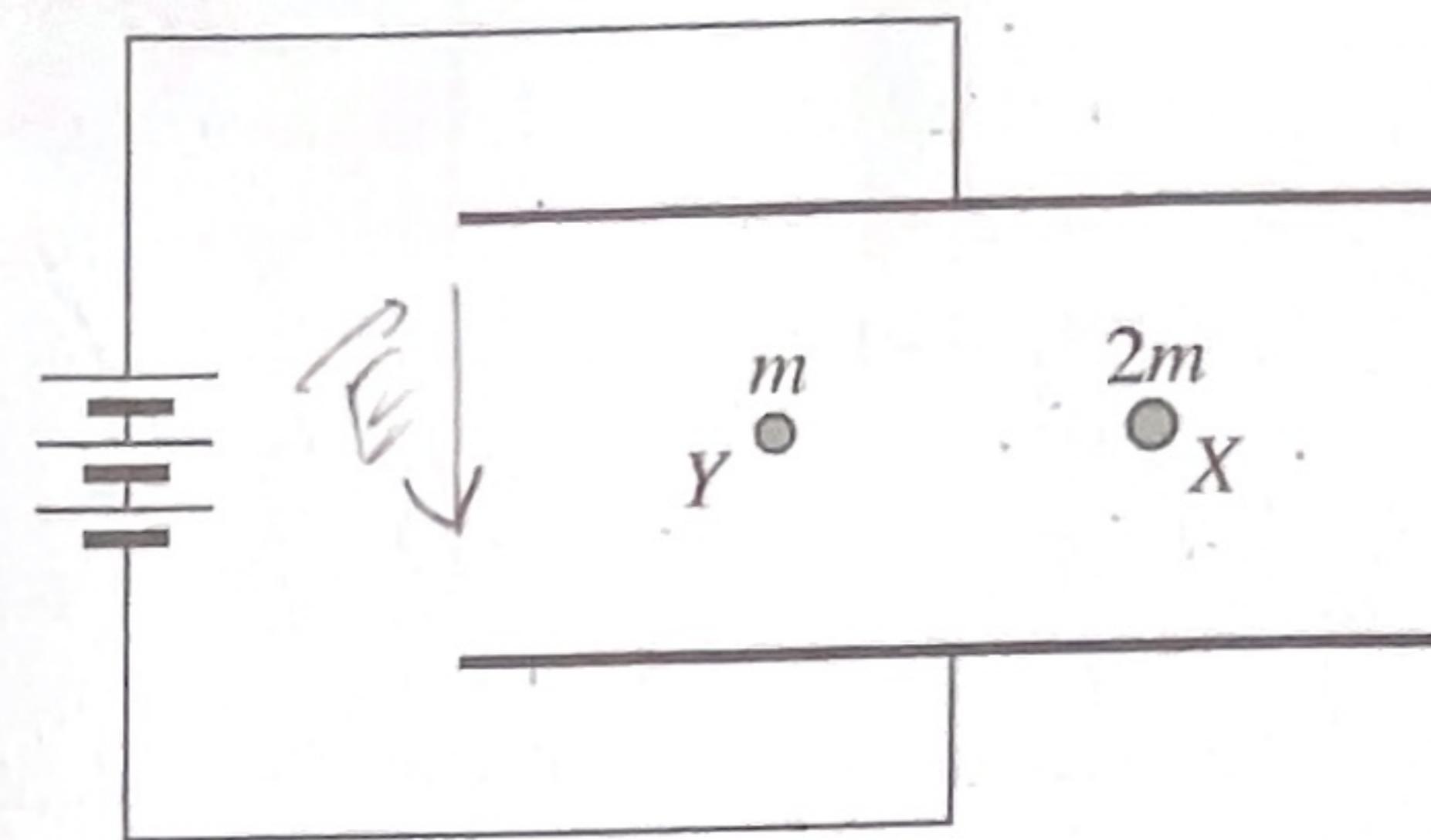
31. A sinusoidal a.c. voltage with r.m.s. value of  $200\text{V}$  is supplied to a full-wave rectifier circuit. Each diode in the rectifier has a forward bias voltage of  $0.7\text{V}$ . What is the peak value of the rectified voltage? (Take  $\sqrt{2} = 1.4$ )

(1)  $141.5\text{V}$       (2)  $142.2\text{V}$       (3)  $277.2\text{V}$       (4)  $278.6\text{V}$       (5)  $280.0\text{V}$

32. A ping pong ball is dropped from a height of  $1\text{m}$  above a table. In every successive bounce, the ball loses its kinetic energy by the same amount. The velocity ( $v$ )–time ( $t$ ) graph of the ping pong ball is best represented by

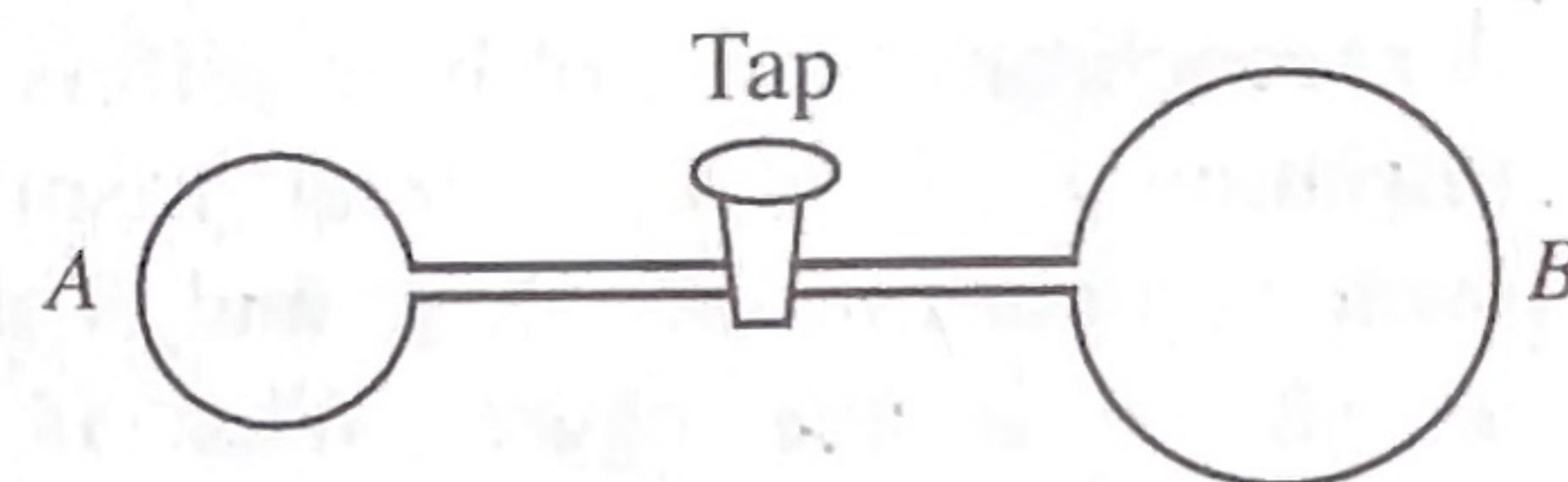


33. A voltage is applied across two parallel conducting plates. As shown in the figure two charged droplets  $X$  and  $Y$  of masses  $2m$  and  $m$  respectively are at rest between the plates. Neglect the interaction between  $X$  and  $Y$ . When two plates are brought closer,
- $X$  and  $Y$  remain at equilibrium.
  - $X$  and  $Y$  fall down with equal accelerations.
  - $X$  and  $Y$  rise up with equal accelerations.
  - $X$  rises with greater acceleration than  $Y$ .
  - $X$  falls down with greater acceleration than  $Y$ .



34. Two soap bubbles  $A$  and  $B$  are set at the ends of a narrow tube. Initially the tap at the middle of the tube is closed and the radius of the bubble  $A$  is smaller than that of bubble  $B$ . Then the tap is opened and the system is allowed to reach equilibrium without breaking bubbles. What will be the relation between the final radii ( $R_A$ ,  $R_B$ ) and the final volumes ( $V_A$ ,  $V_B$ ) of the bubbles?

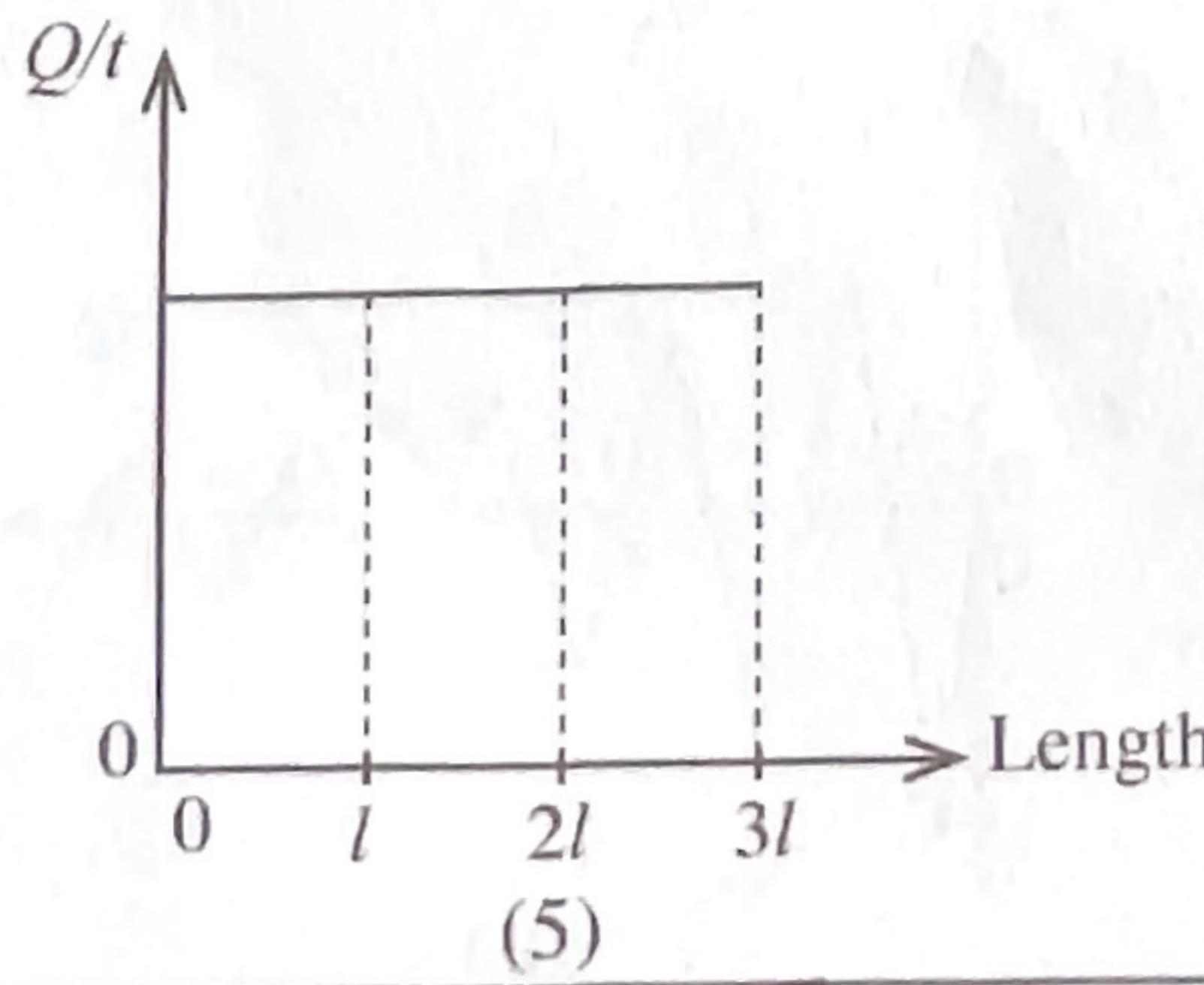
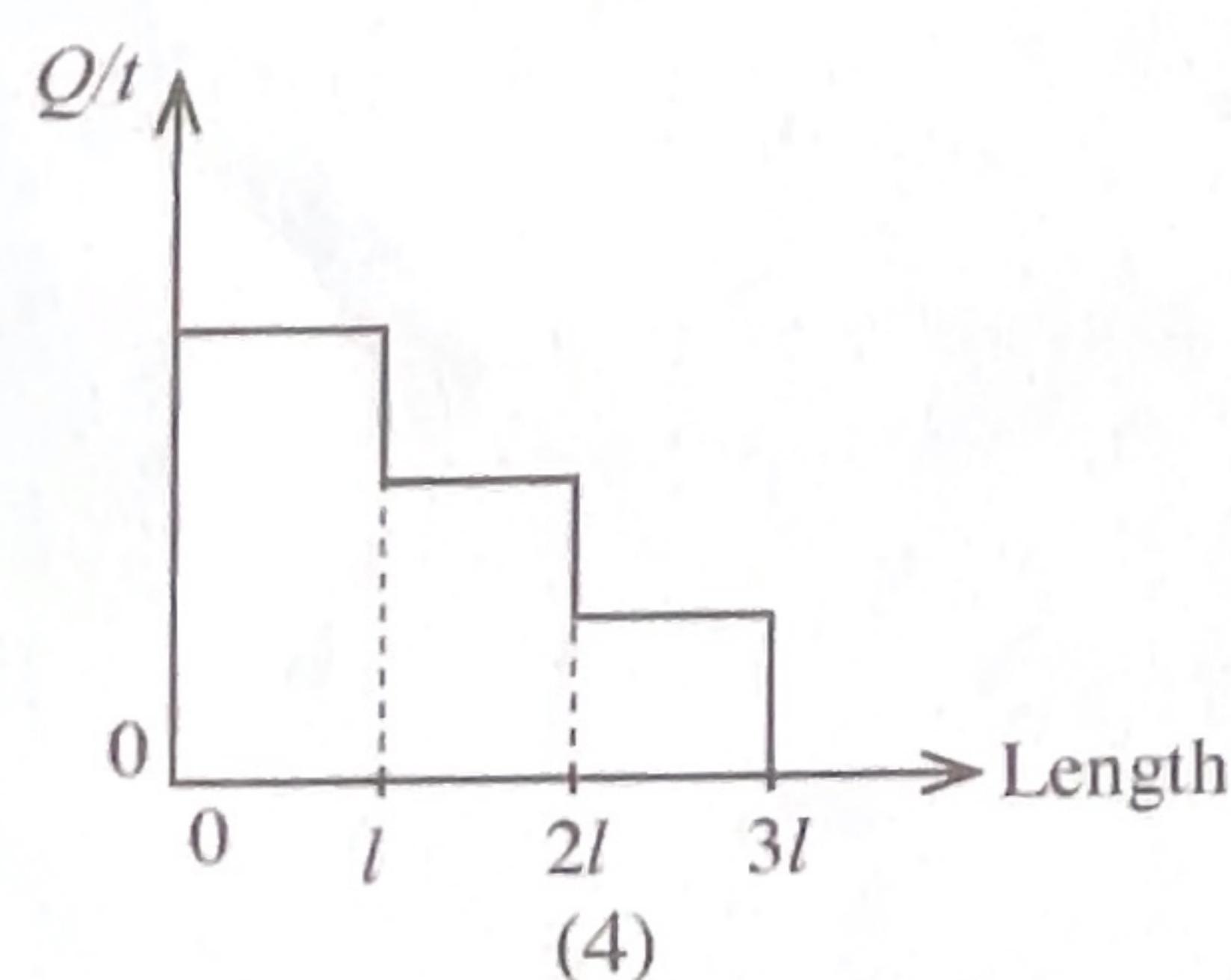
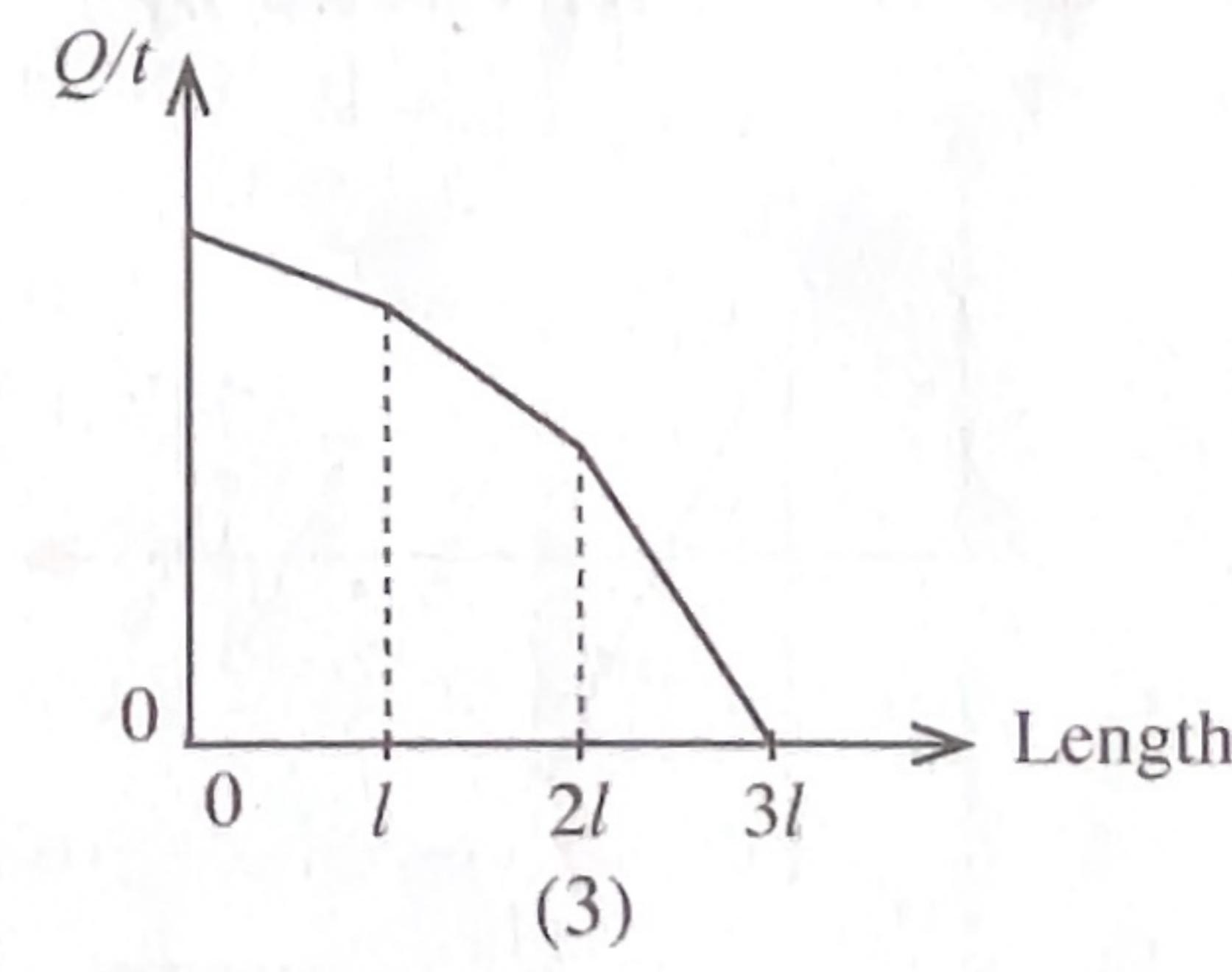
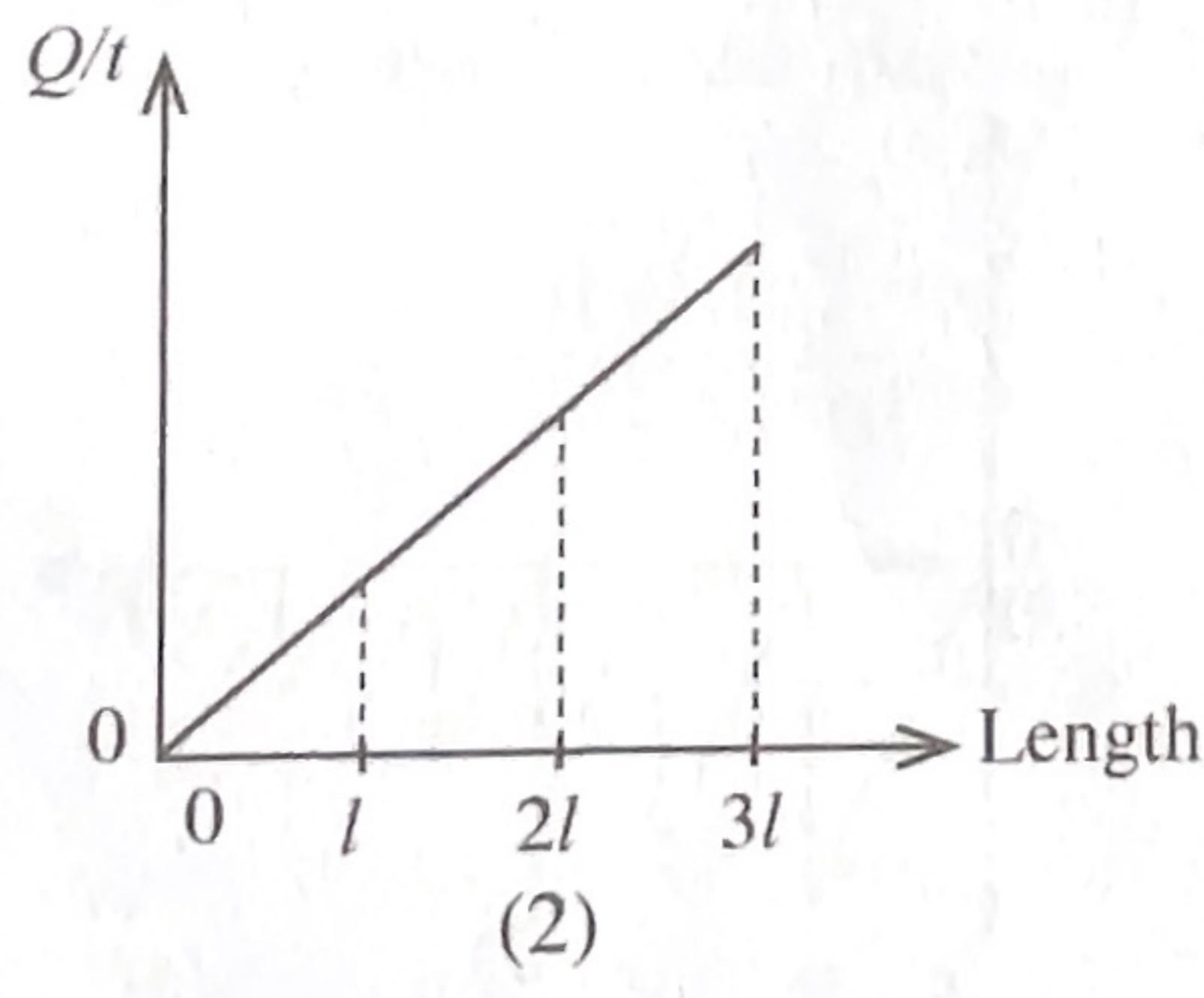
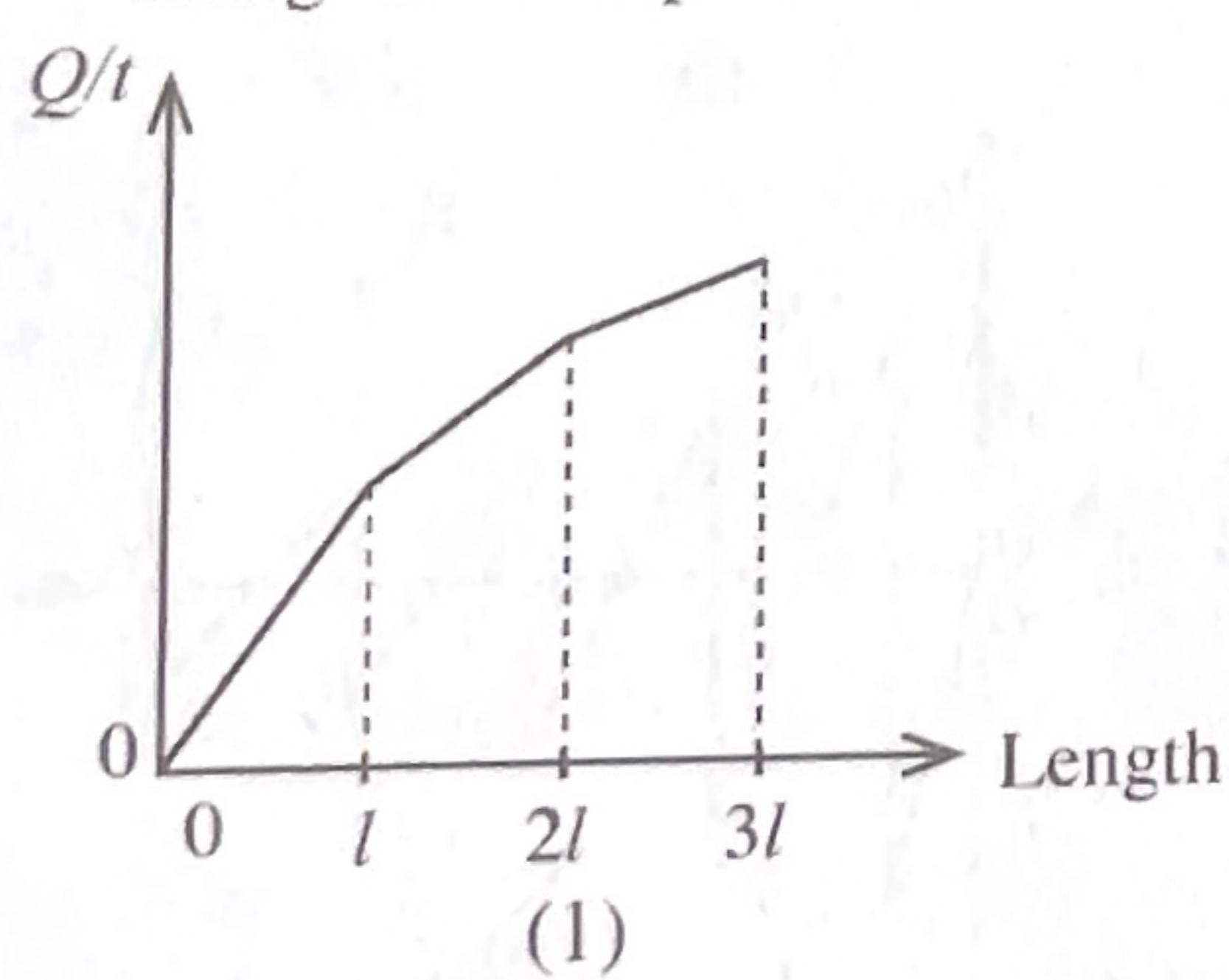
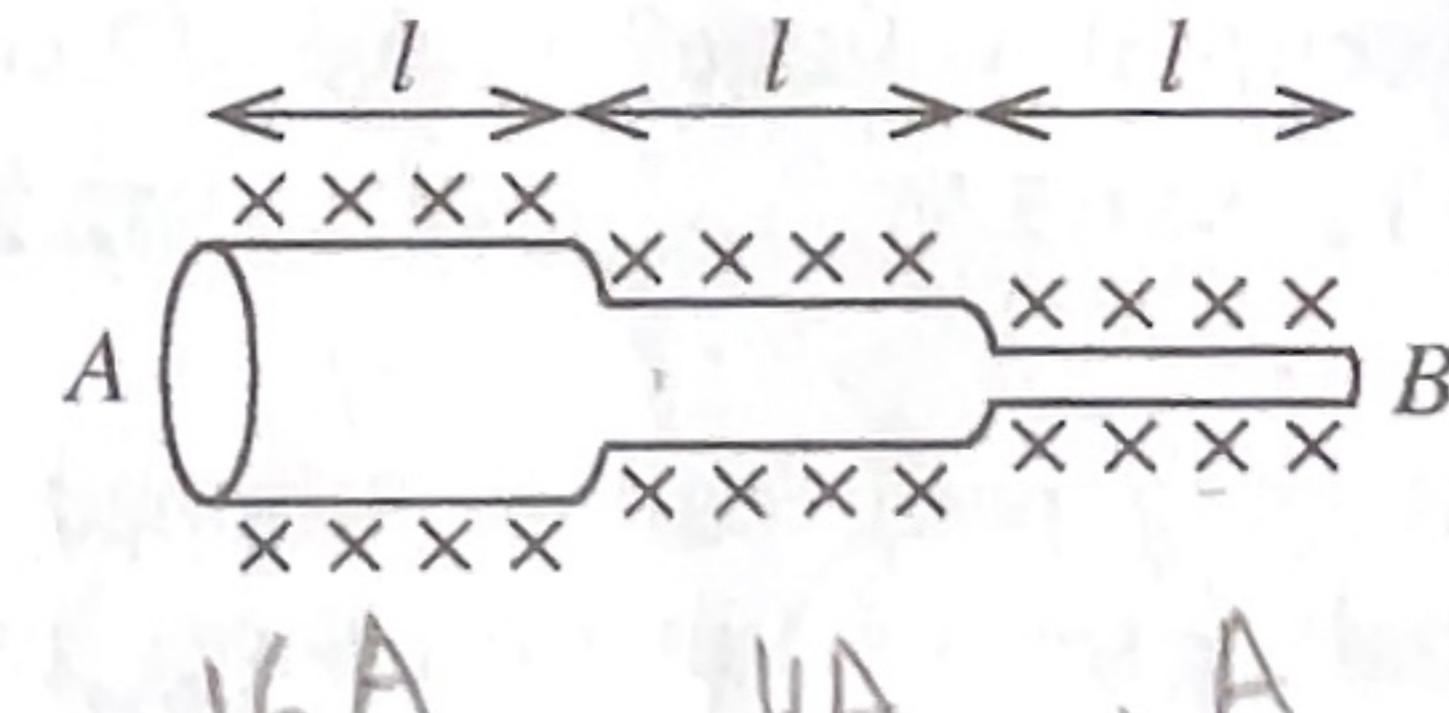
	Final radii	Final volumes
(1)	$R_A < R_B$	$V_A < V_B$
(2)	$R_A < R_B$	$V_A = V_B$
(3)	$R_A = R_B$	$V_A = V_B$
(4)	$R_A > R_B$	$V_A < V_B$
(5)	$R_A = R_B$	$V_A < V_B$



35. At a certain temperature  $T$ , a pipe open at both ends resonates at a frequency of 400 Hz. At what frequency does the same pipe resonate on a day when the speed of sound is 2% lower than it would be at  $T$ ?

- 384 Hz
- 392 Hz
- 396 Hz
- 408 Hz
- 416 Hz

36. Three perfectly lagged rods made of same conducting material of equal length  $l$  are connected to make a composite rod  $AB$  as shown in the figure. The radii of their cross-sections have the ratio 4:2:1 respectively. Heat flows from end  $A$  of the rod to end  $B$ . At steady state, the rate of heat flow ( $\frac{Q}{t}$ ) along the composite rod is best represented by



37. Two rods of negligible mass each of initial length  $L$  and cross-sectional area  $A$  made of materials of Young's moduli  $Y_1$  and  $Y_2$  are connected in series to make a composite rod. One end of the composite rod is firmly fixed to a rigid ceiling as shown in the figure. A sphere of volume  $V$  made of material of density  $\beta$  is connected to the free end of the rod, and the sphere is fully immersed in a liquid of density  $\rho$  ( $\beta > \rho$ ). What will be the change of the length of the composite rod?

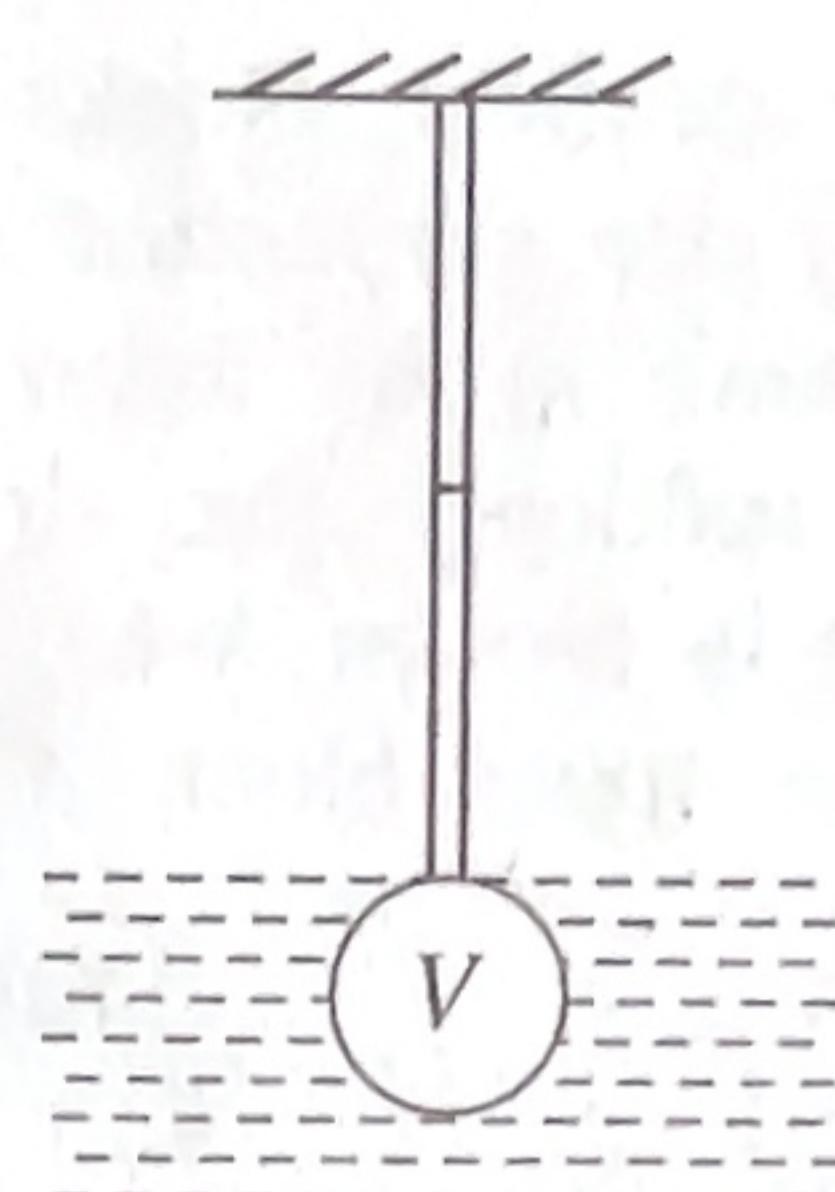
(1)  $\frac{V(\beta - \rho)gL}{A} \left( \frac{1}{Y_1} + \frac{1}{Y_2} \right)$

(2)  $\frac{V(\beta - \rho)gL}{A} \left( \frac{1}{Y_1} - \frac{1}{Y_2} \right)$   $\times$

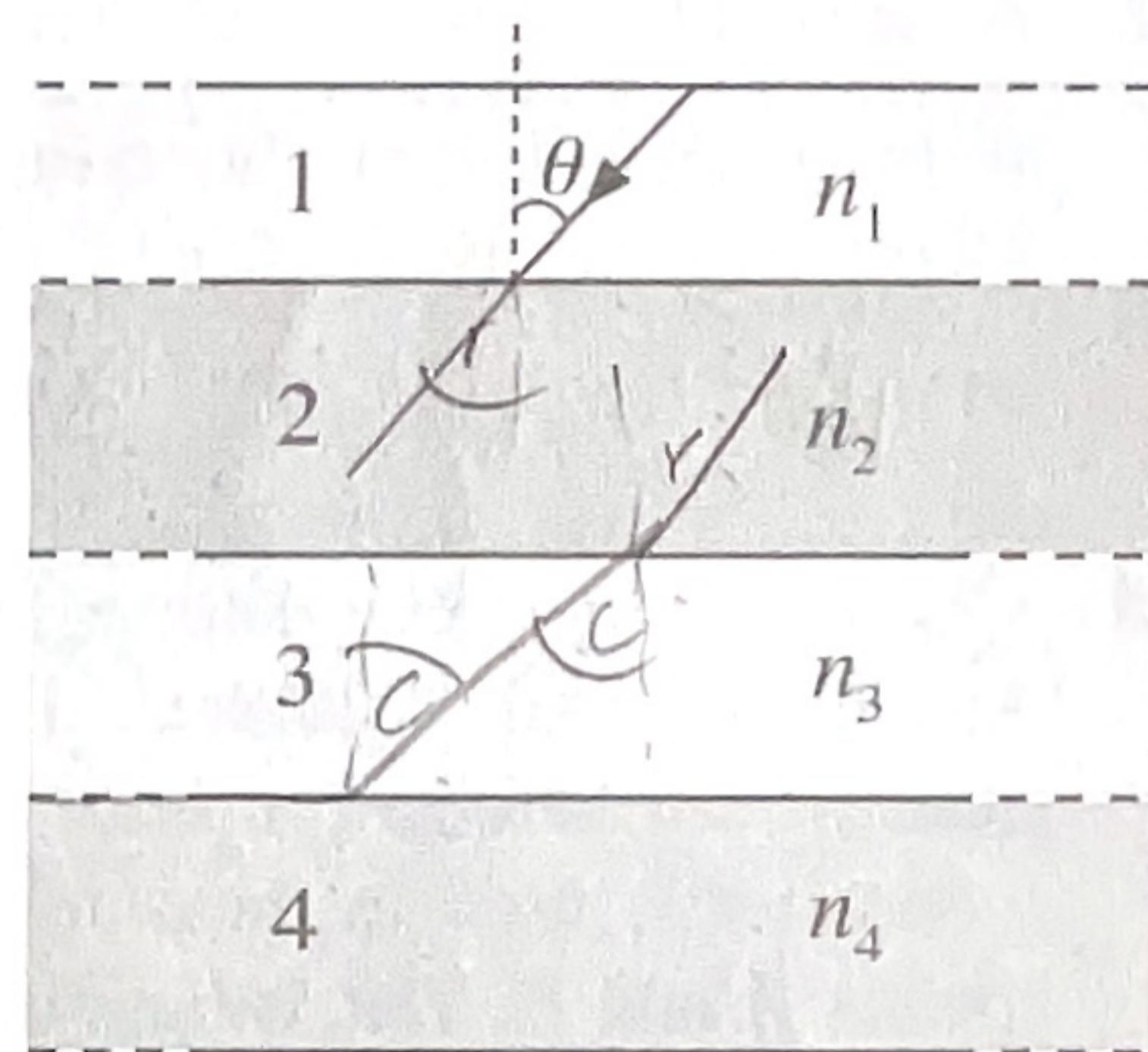
(3)  $\frac{A}{V(\beta - \rho)gL} \left( \frac{1}{Y_1} + \frac{1}{Y_2} \right)$

(4)  $\frac{A}{V(\beta - \rho)gL} (Y_1 - Y_2)$   $\times$

(5)  $\frac{V(\beta - \rho)gL}{A} (Y_1 + Y_2)$



38. Four thick transparent parallel sheets are placed on top of each other as shown in the figure. The refractive indices of materials made of the sheets are  $n_1$ ,  $n_2$ ,  $n_3$  and  $n_4$  respectively. A monochromatic ray of light is incident with angle  $\theta$  at the interface of sheet 1 and sheet 2 as shown. What should be the value of  $\theta$  for the ray to go along the interface of sheet 3 and 4?



(1)  $\theta = \sin^{-1} \left( \frac{n_4}{n_1} \right)$

(2)  $\theta = \sin^{-1} \left( \frac{n_3 n_4}{n_1} \right)$

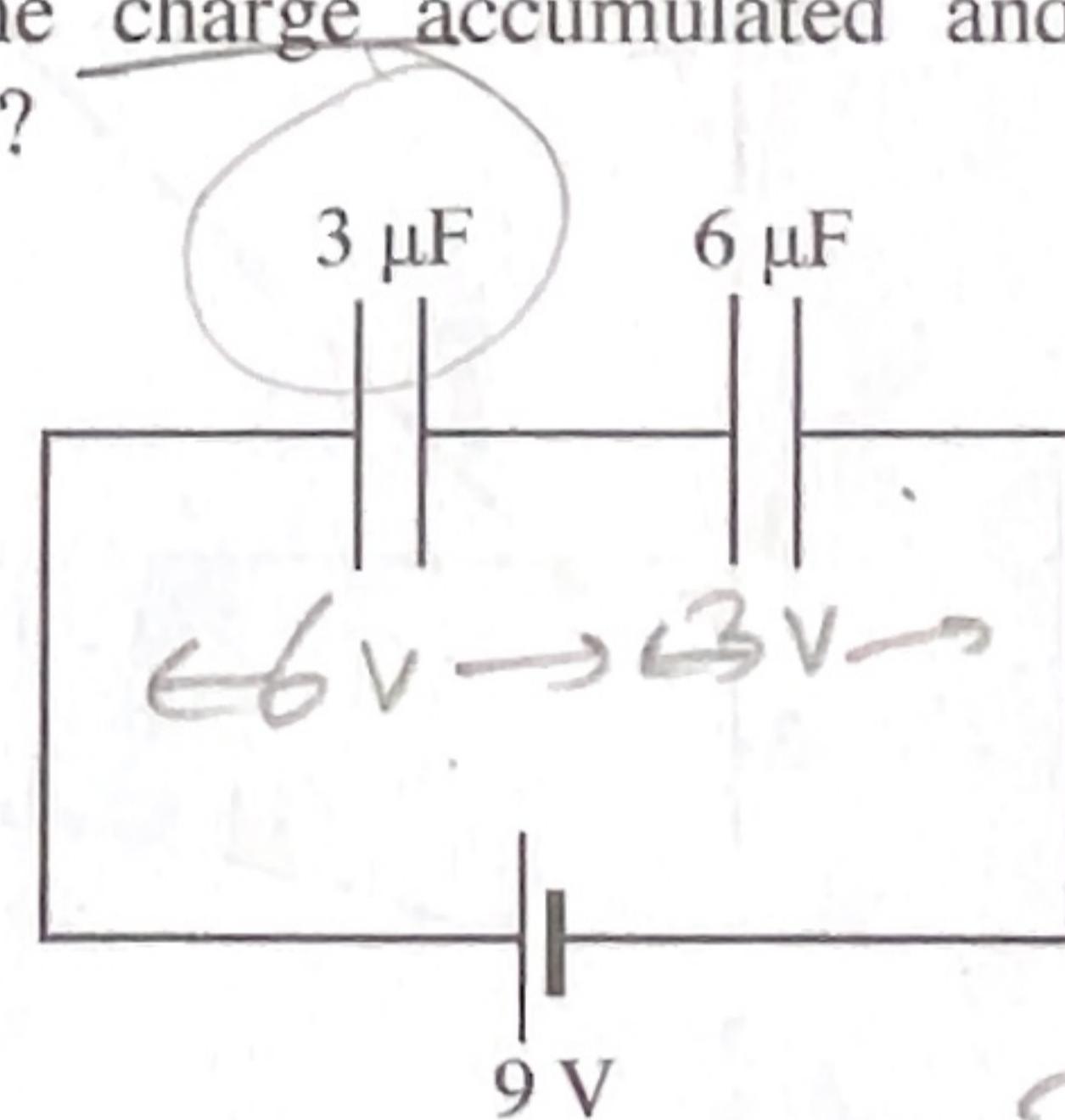
(4)  $\theta = \sin^{-1} \left( \frac{n_2 n_3 n_4}{n_1} \right)$

(5)  $\theta = \sin^{-1} \left( \frac{n_3 n_4}{n_1 n_2} \right)$

(3)  $\theta = \sin^{-1} \left( \frac{n_2 n_4}{n_1} \right)$

39. Two capacitors of capacitance  $3\ \mu\text{F}$  and  $6\ \mu\text{F}$  respectively are connected in series with a  $9\text{ V}$  battery as shown in the figure. What are the voltage across, the charge accumulated and the energy stored in the  $3\ \mu\text{F}$  capacitor after steady state has reached?

	Voltage (V)	Charge ( $\mu\text{C}$ )	Energy ( $\mu\text{J}$ )
(1)	3	9	27
(2)	3	9	54
(3)	3	18	108
(4)	6	18	27
(5)	6	18	54



40. In the circuit shown the internal resistance of the cell is negligible. What is the current through the cell?

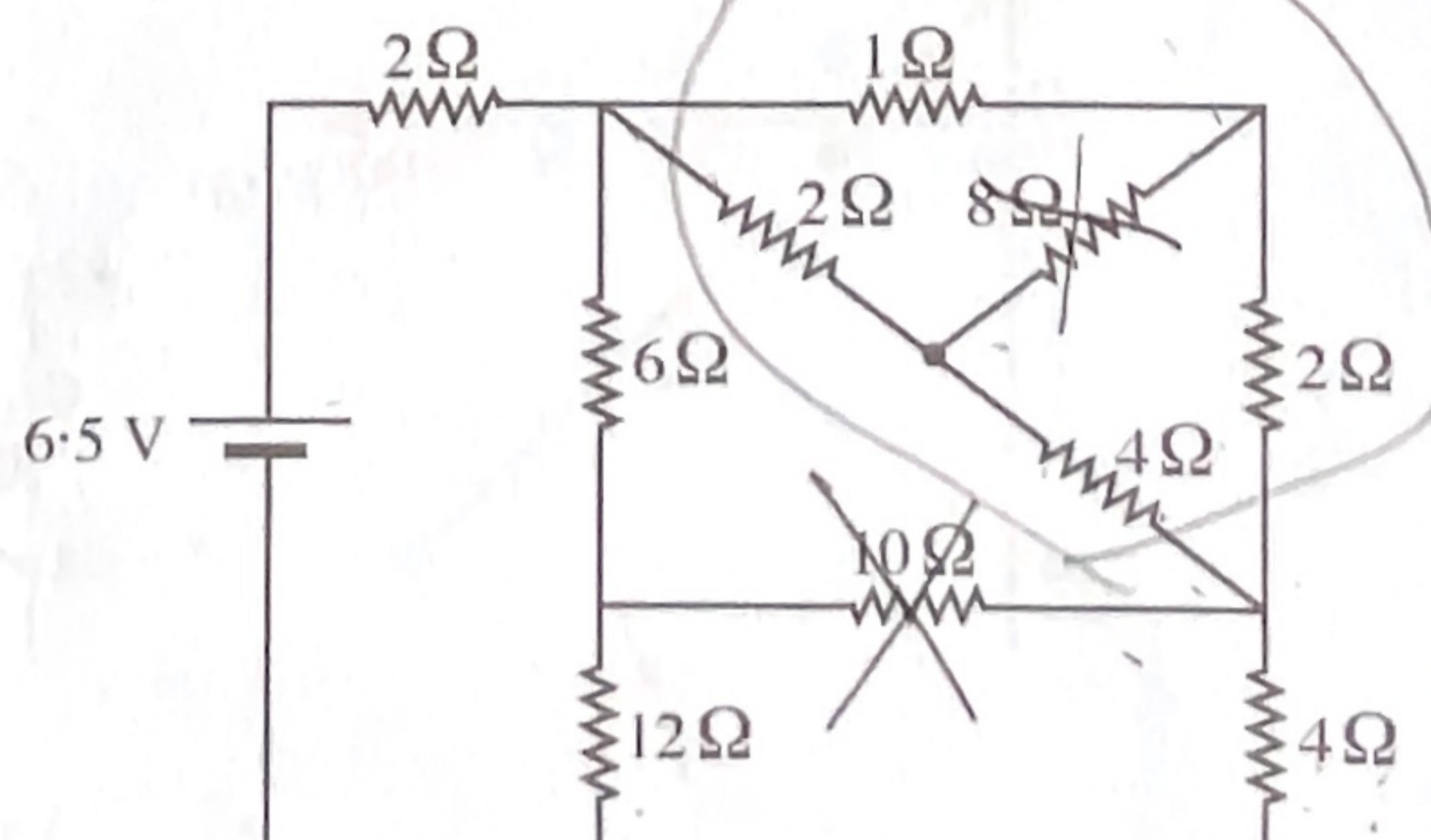
(1)  $0.5\text{ A}$

(2)  $1.0\text{ A}$

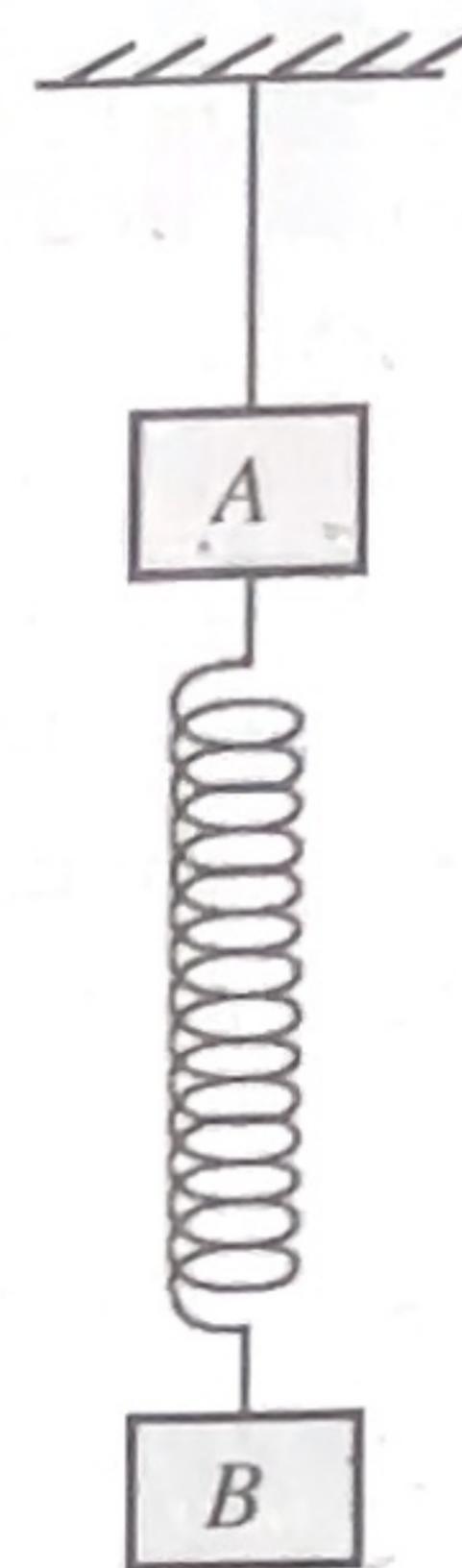
(3)  $1.2\text{ A}$

(4)  $1.5\text{ A}$

(5)  $2.0\text{ A}$



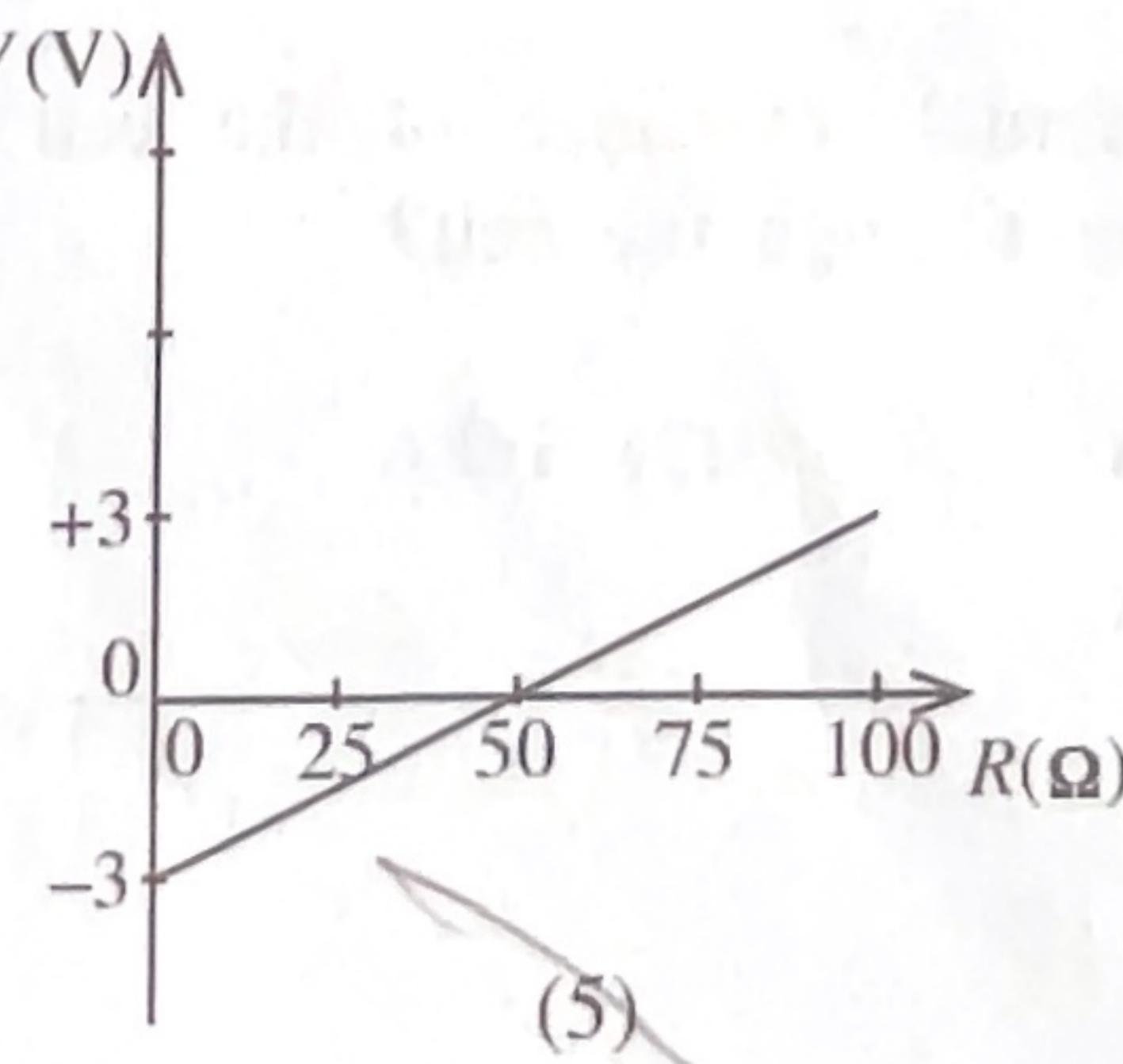
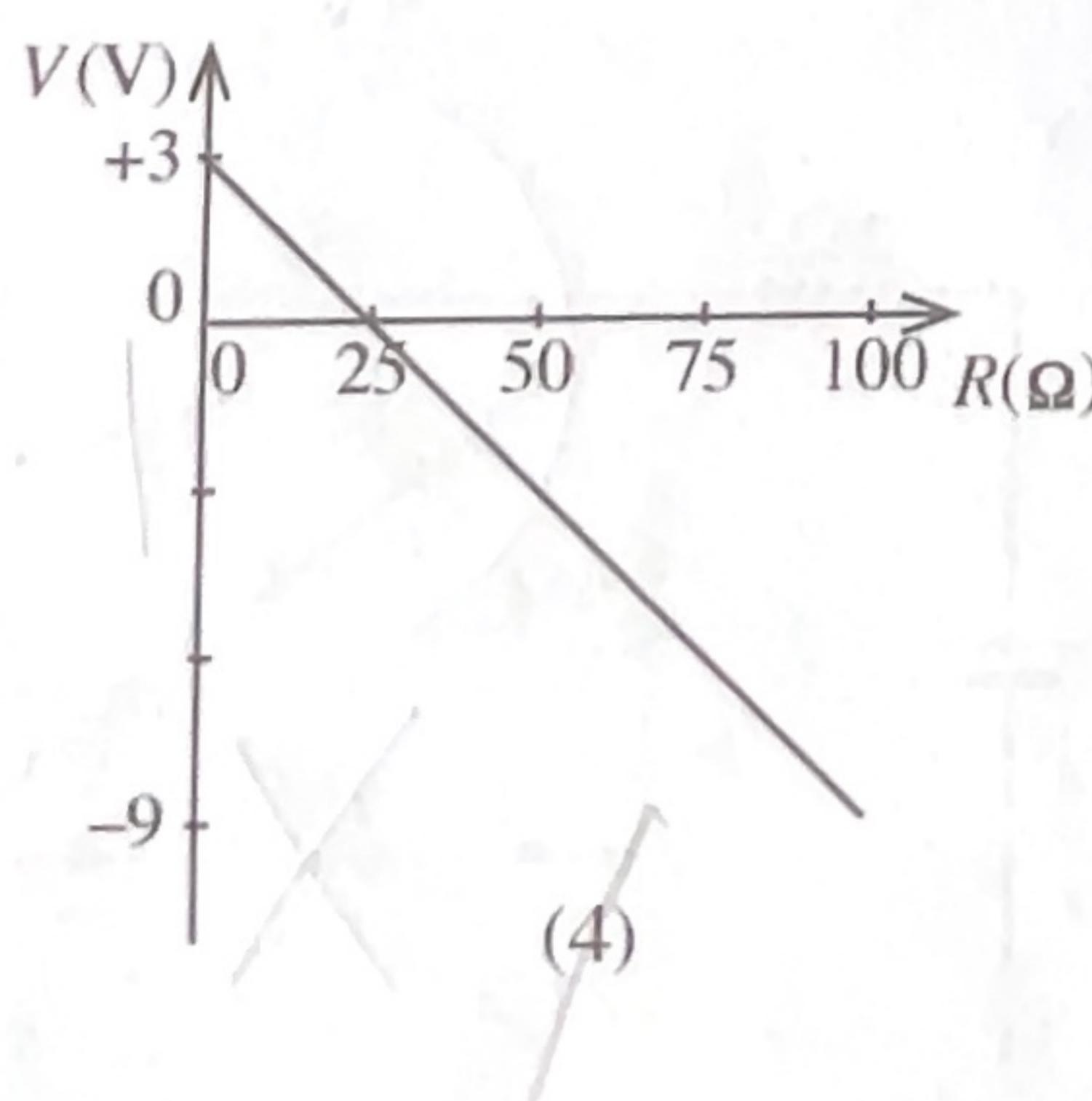
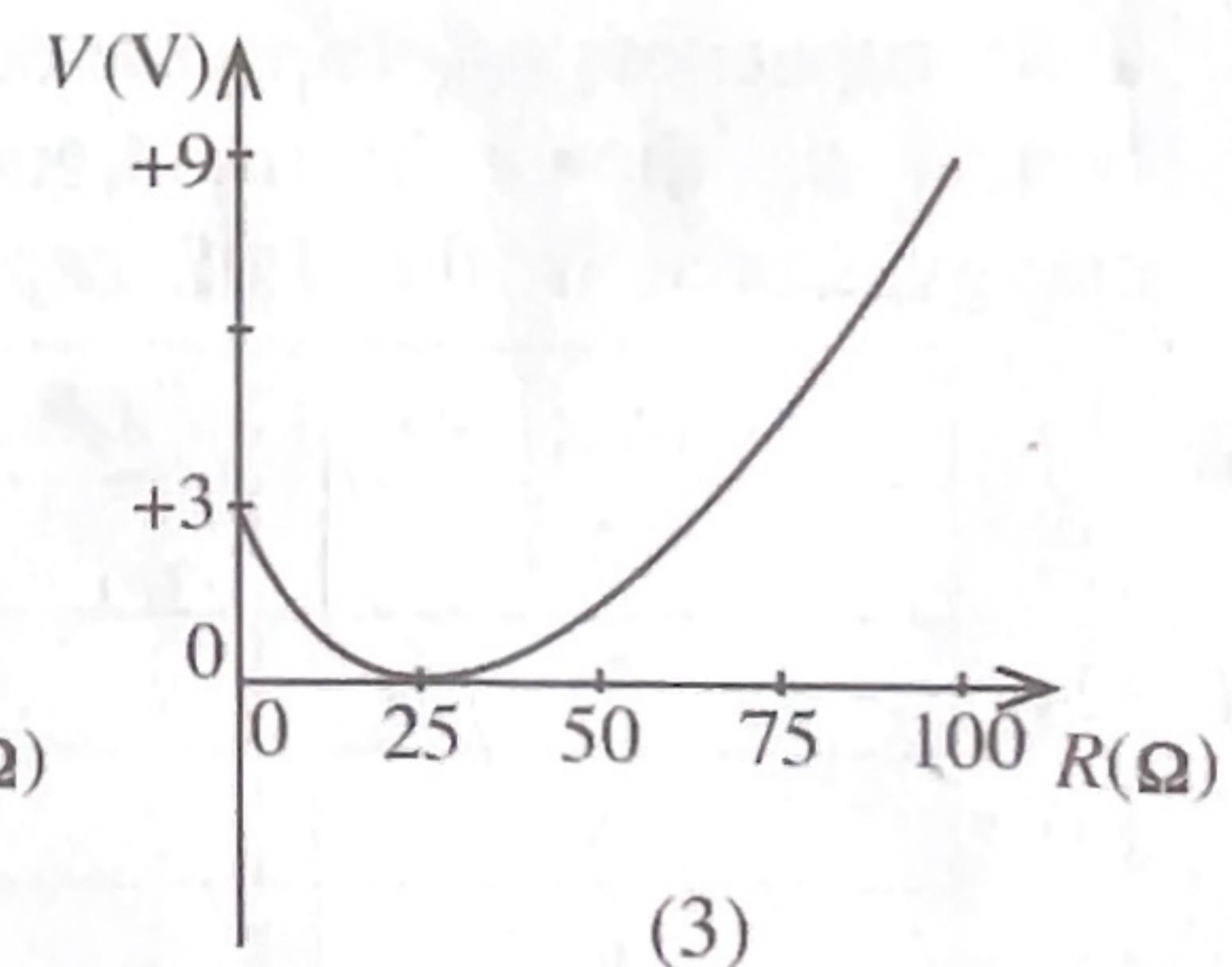
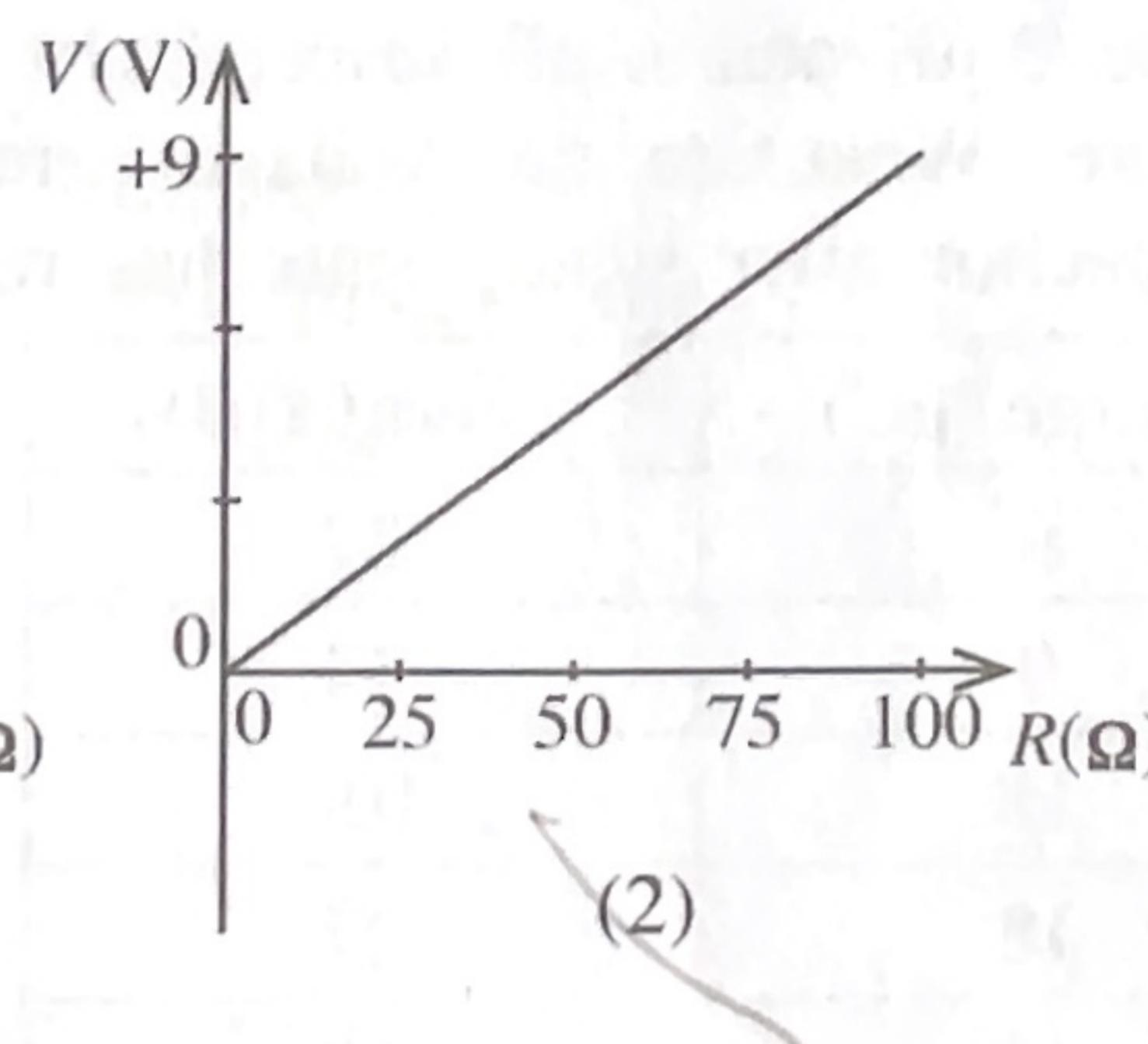
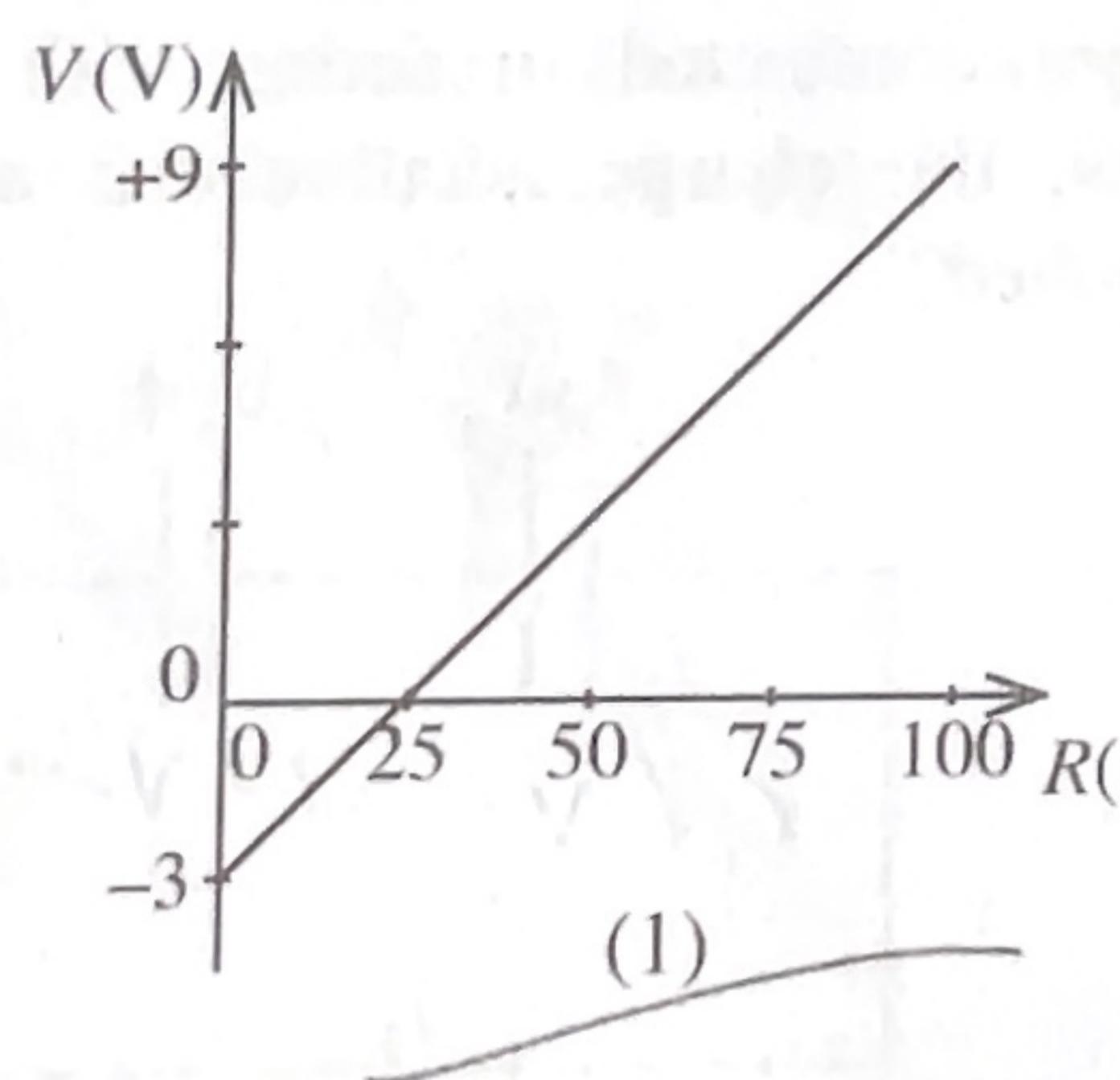
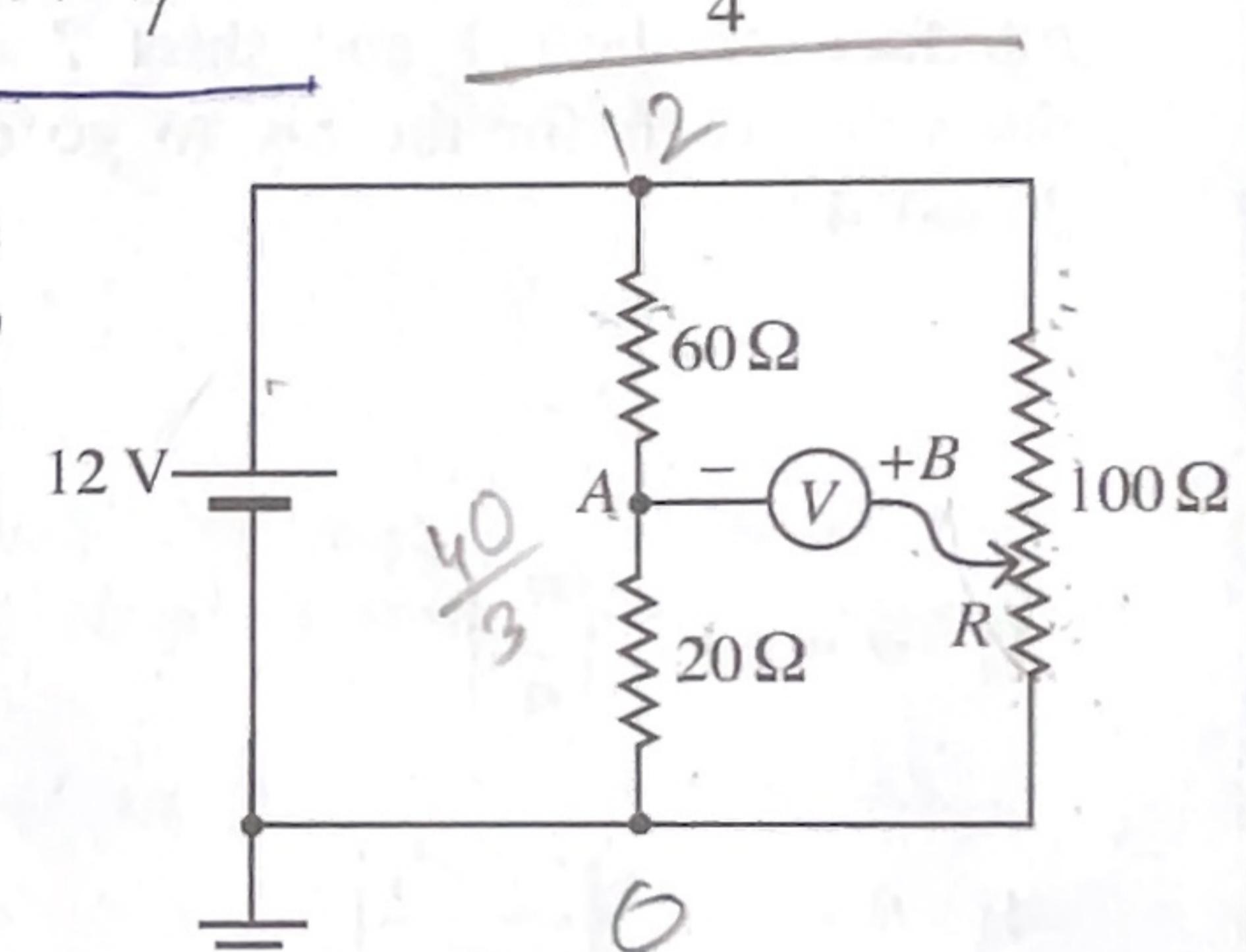
41. Two identical blocks A and B connected by a light spring are suspended by a string attached to the ceiling as shown in the figure. Initially the system is at rest and then suddenly the string breaks. Immediately after the string is broken, what will be the downward acceleration of the upper block A?



42. A vertical container of height  $h$  contains water up to a height  $y$ . When viewed from above it is observed that the container is half filled with water. The refractive index of water is  $\frac{4}{3}$ . What is the value of  $y$ ?

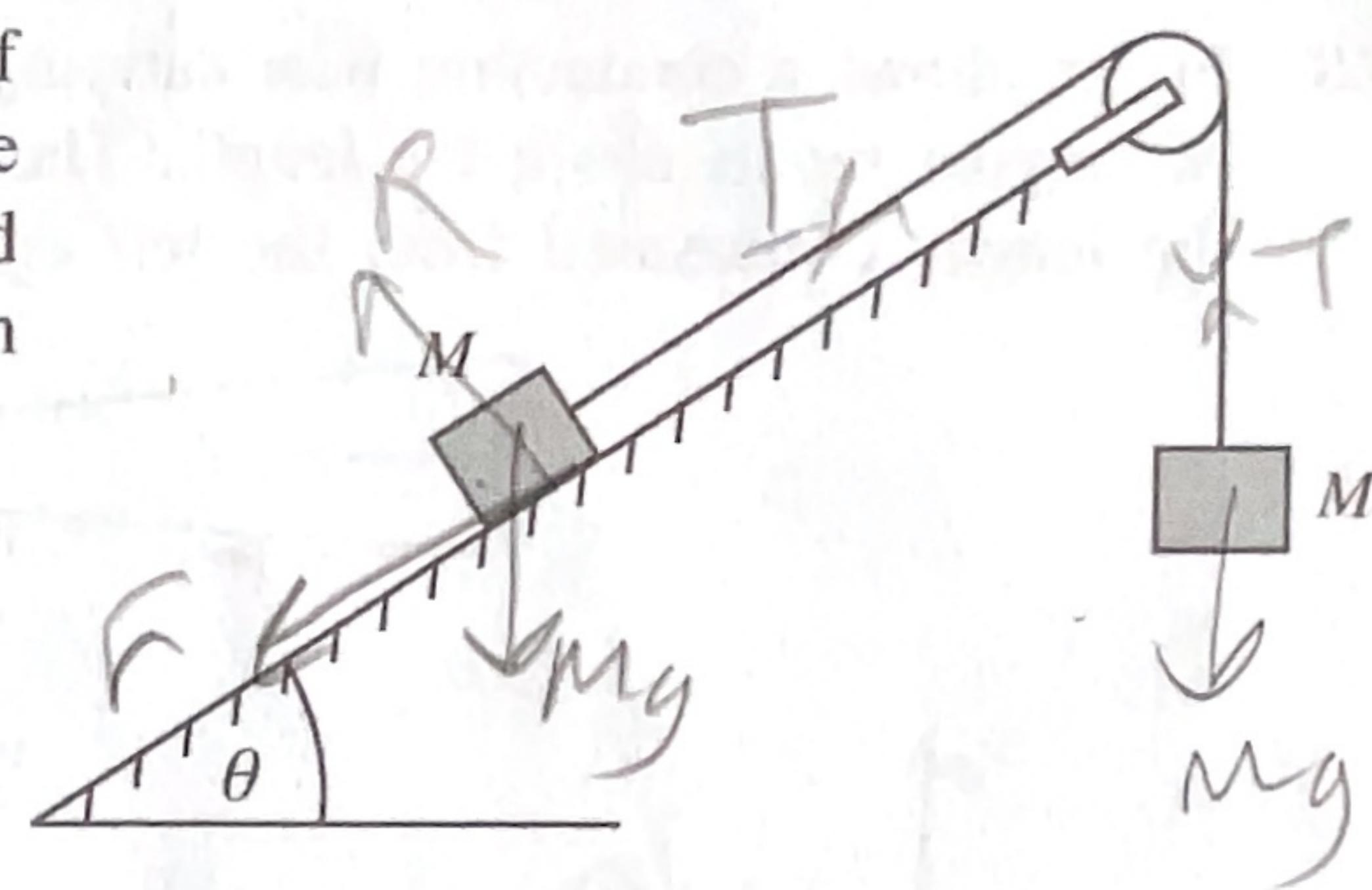
(1)  $\frac{1}{4}h$       (2)  $\frac{1}{3}h$       (3)  $\frac{1}{2}h$       (4)  $\frac{4}{7}h$       (5)  $\frac{3}{4}h$

43. Consider the circuit shown in the figure. The 12 V battery has no internal resistance. The resistance  $R$  of the variable resistor can be changed from 0 to  $100 \Omega$ . An ideal center-zero voltmeter is used to measure the potential difference between points  $A$  and  $B$ . The variation of the voltmeter reading  $V$  with  $R$  is best represented by,



44. In the system shown, the two equal masses, each of mass  $M$  connected by an inextensible light string are moving with a uniform velocity. The pulley is light and frictionless. The coefficient of dynamic friction between the inclined plane and the mass  $M$ , is

- (1)  $\tan \theta$       (2)  $1 - \sin \theta$       (3)  $\frac{1 - \sin \theta}{\cos \theta}$   
 (4)  $\frac{\sin \theta - 1}{\cos \theta}$       (5)  $\frac{1 + \sin \theta}{\cos \theta}$



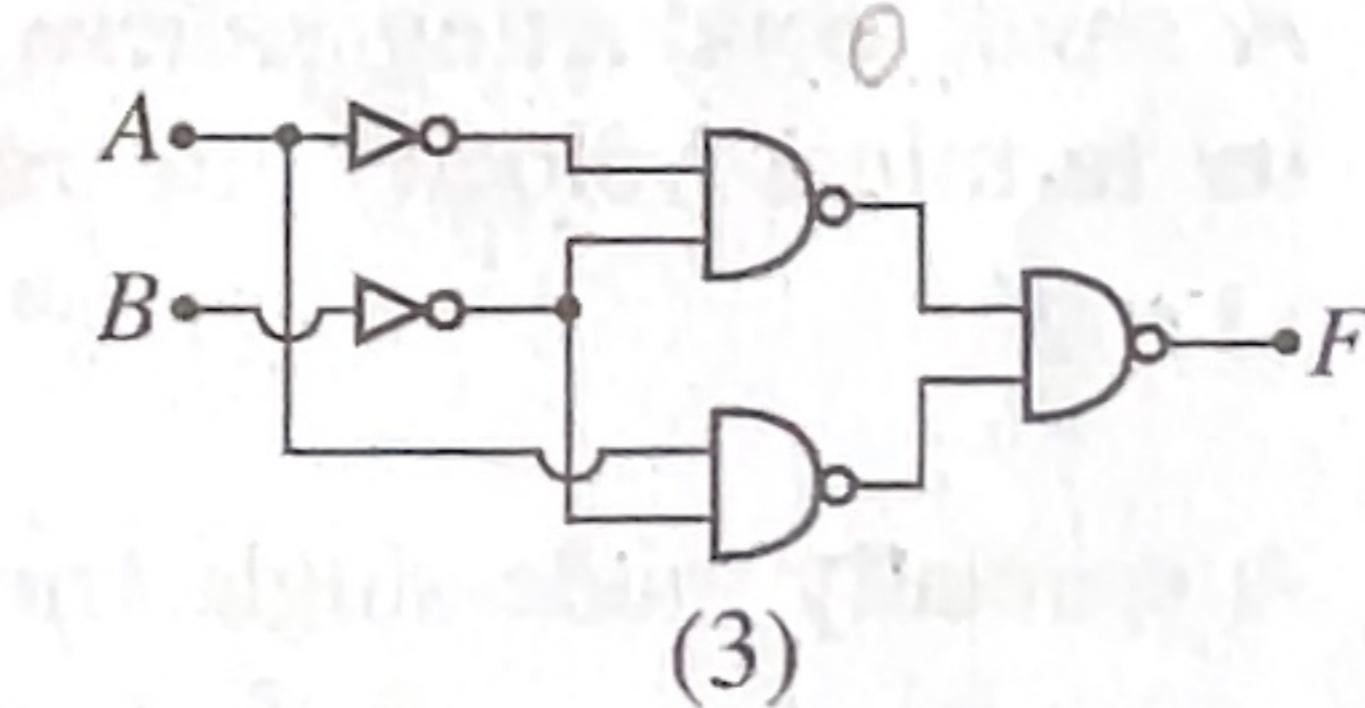
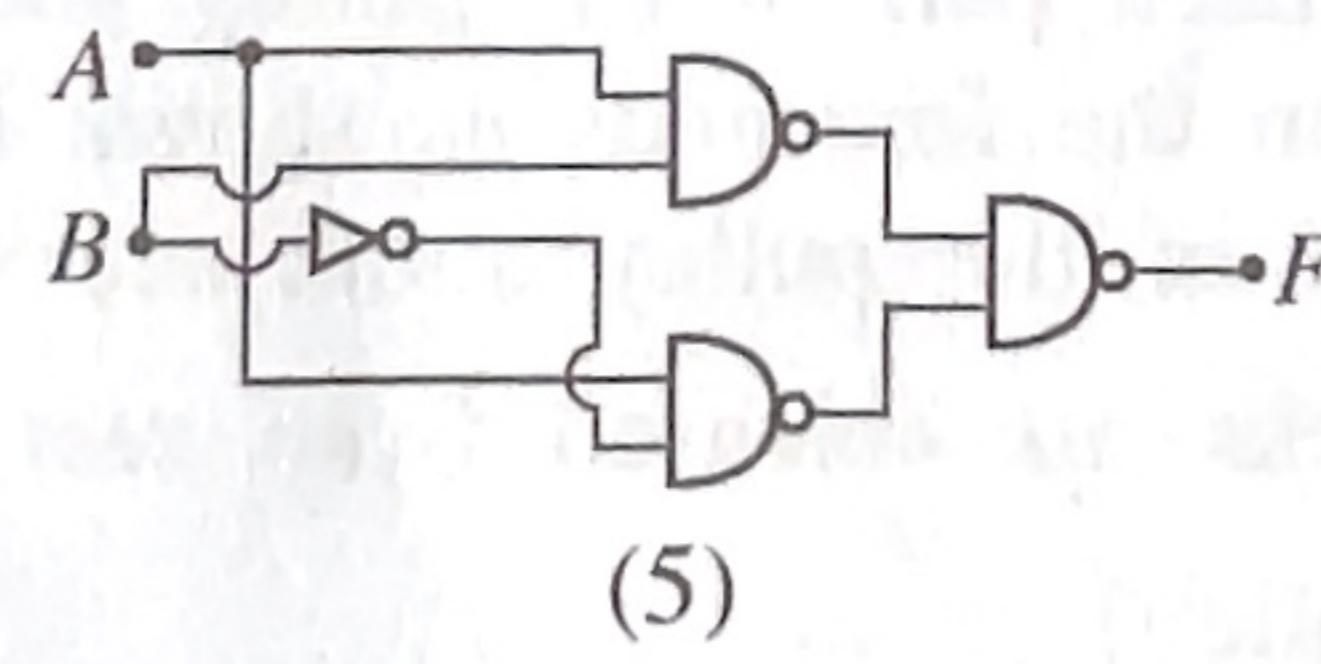
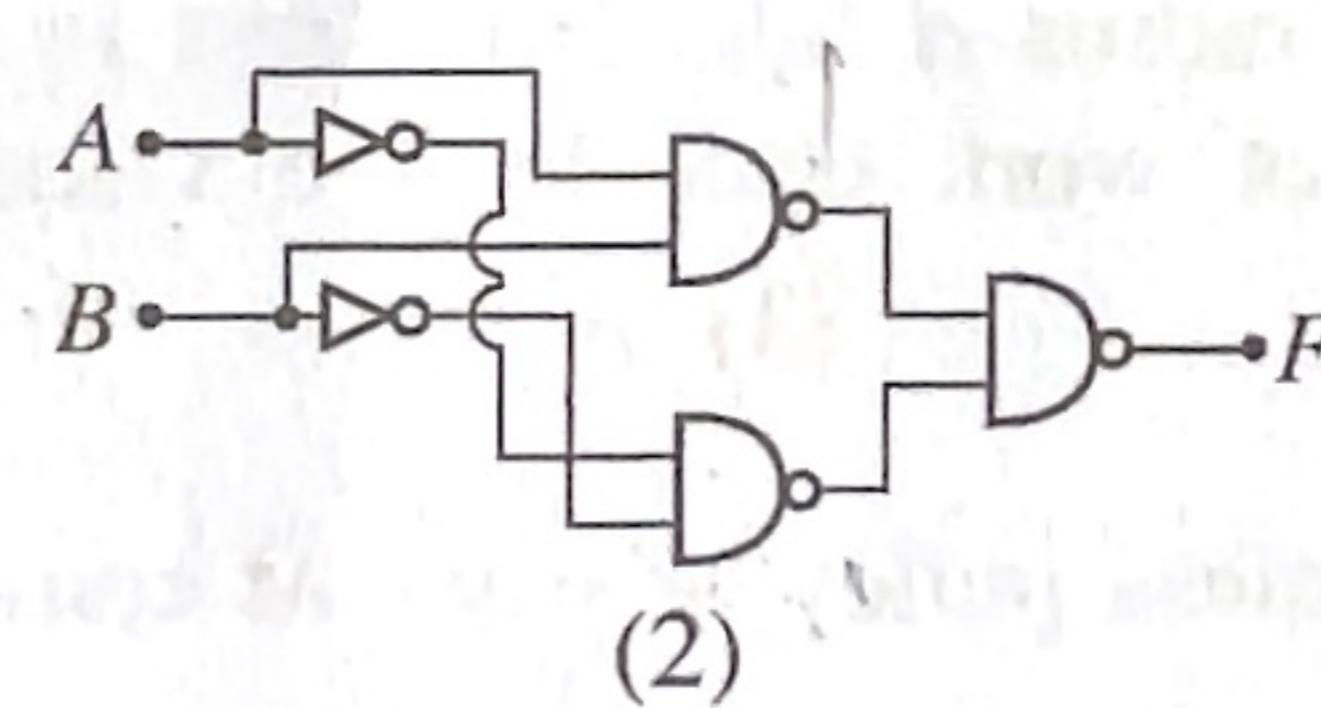
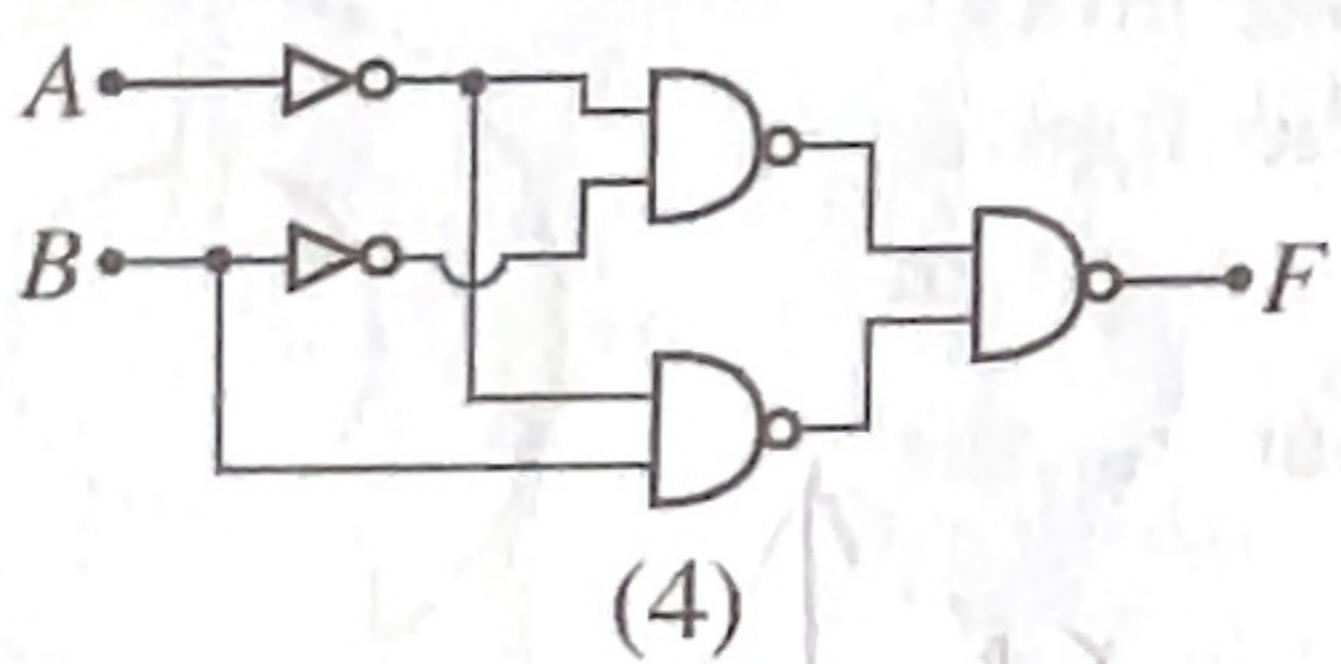
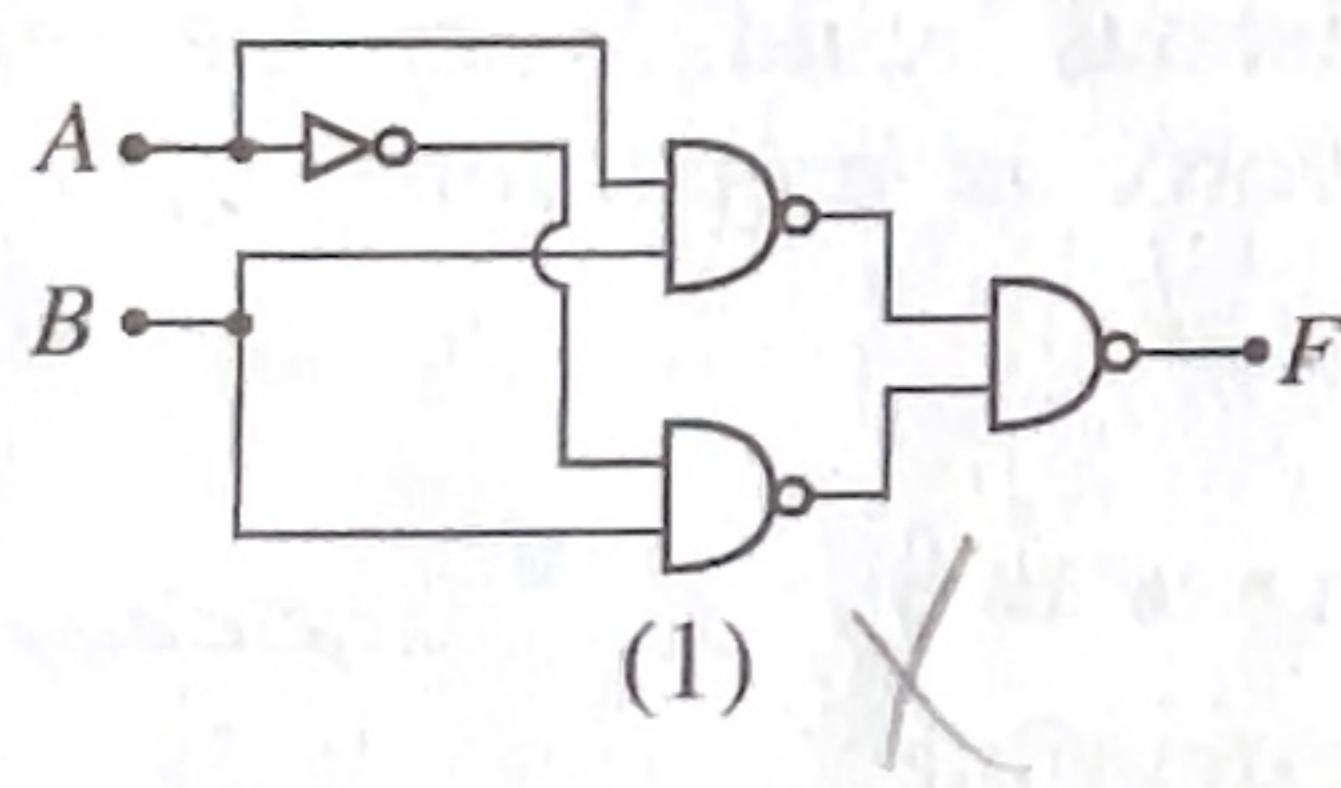
45. A car of mass 1200 kg is traveling at constant speed of  $20 \text{ m s}^{-1}$  on a horizontal straight road with the engine power of 22 kW. To climb with the same speed on a straight identical road but inclined at  $3^\circ$  to the horizontal, what should be the power of the engine?

(Take  $\pi = 3$ . For small angles  $\theta$  in radians take  $\sin \theta = \theta$ )

- (1) 25 kW      (2) 34 kW      (3) 35 kW      (4) 42 kW      (5) 47 kW

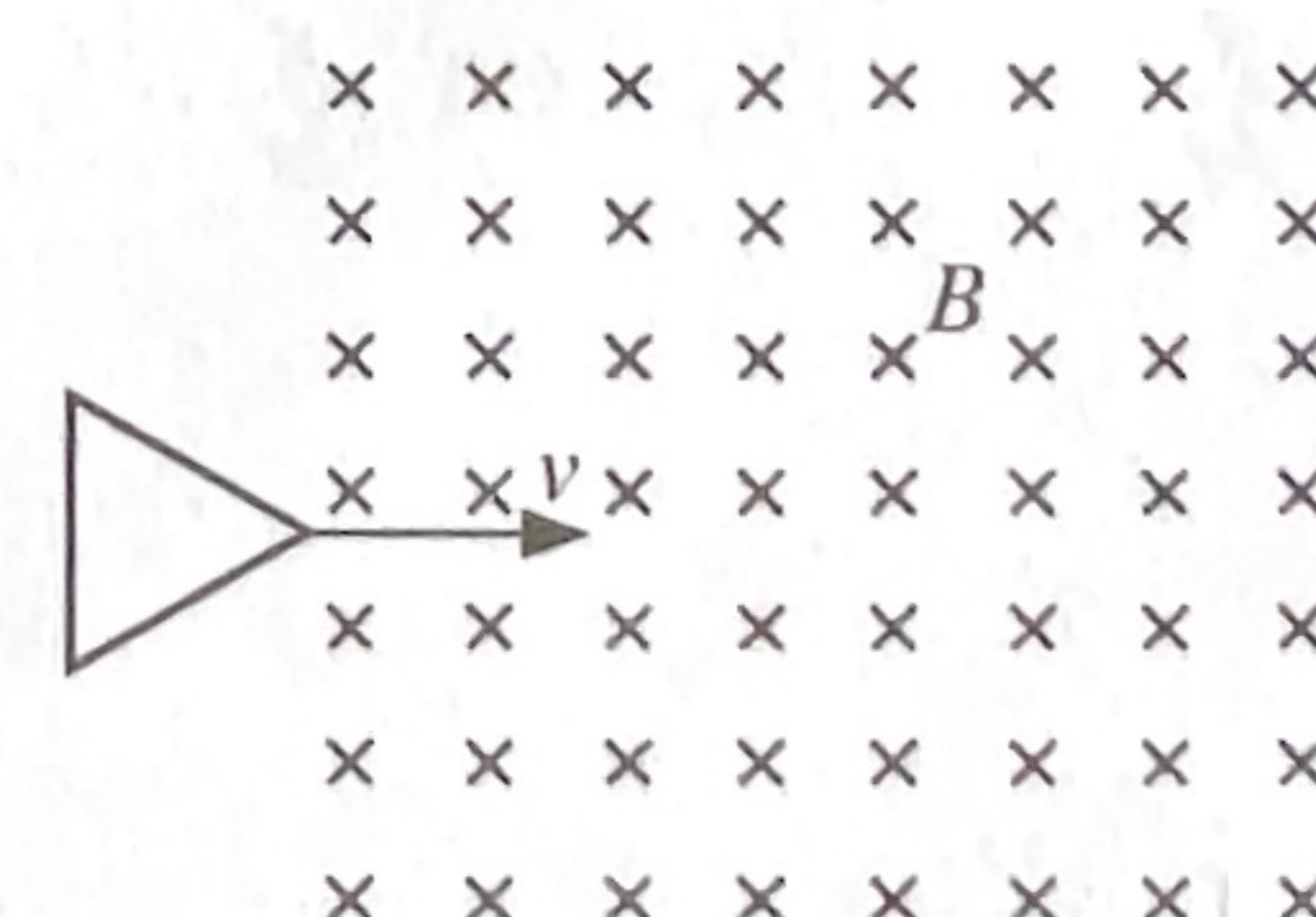
46. Which of the circuits represents the truth table given below?

A	B	F
0	0	1
0	1	0
1	0	1
1	1	0

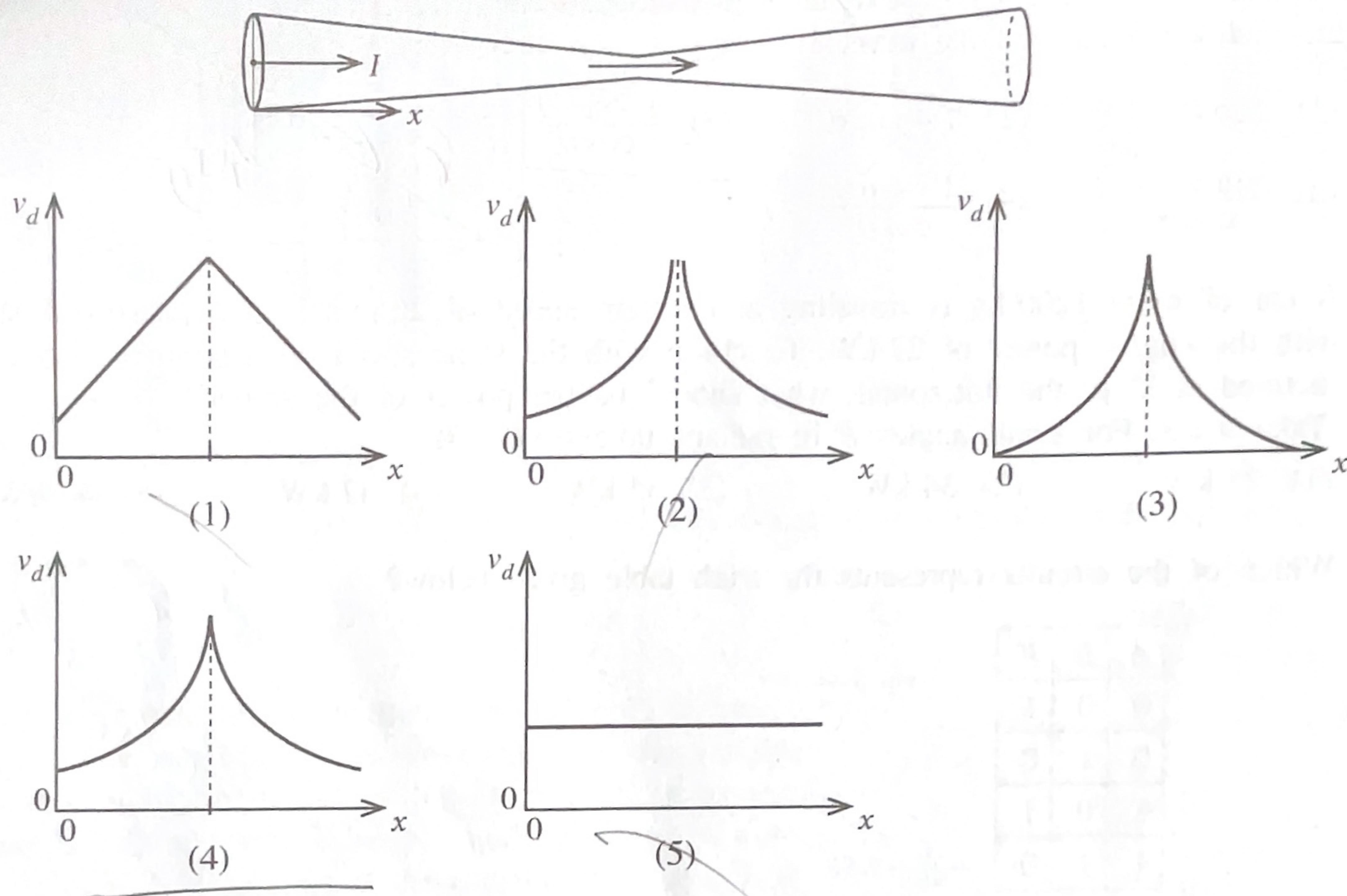


47. An equilateral triangular conducting loop of side 0.05 m passes a region of uniform magnetic field of flux density  $B = 0.1 \text{ T}$  at a uniform velocity  $v = 0.5 \text{ m s}^{-1}$  as shown in the figure. What are the magnitude of the maximum induced e.m.f. and the direction of the current in the loop as the loop enters the field?

- (1) 2.5 mV, anticlockwise  
 (2) 2.5 mV, clockwise  
 (3) 0.5 mV, anticlockwise  
 (4) 0.5 mV, clockwise  
 (5) 0.25 mV, clockwise



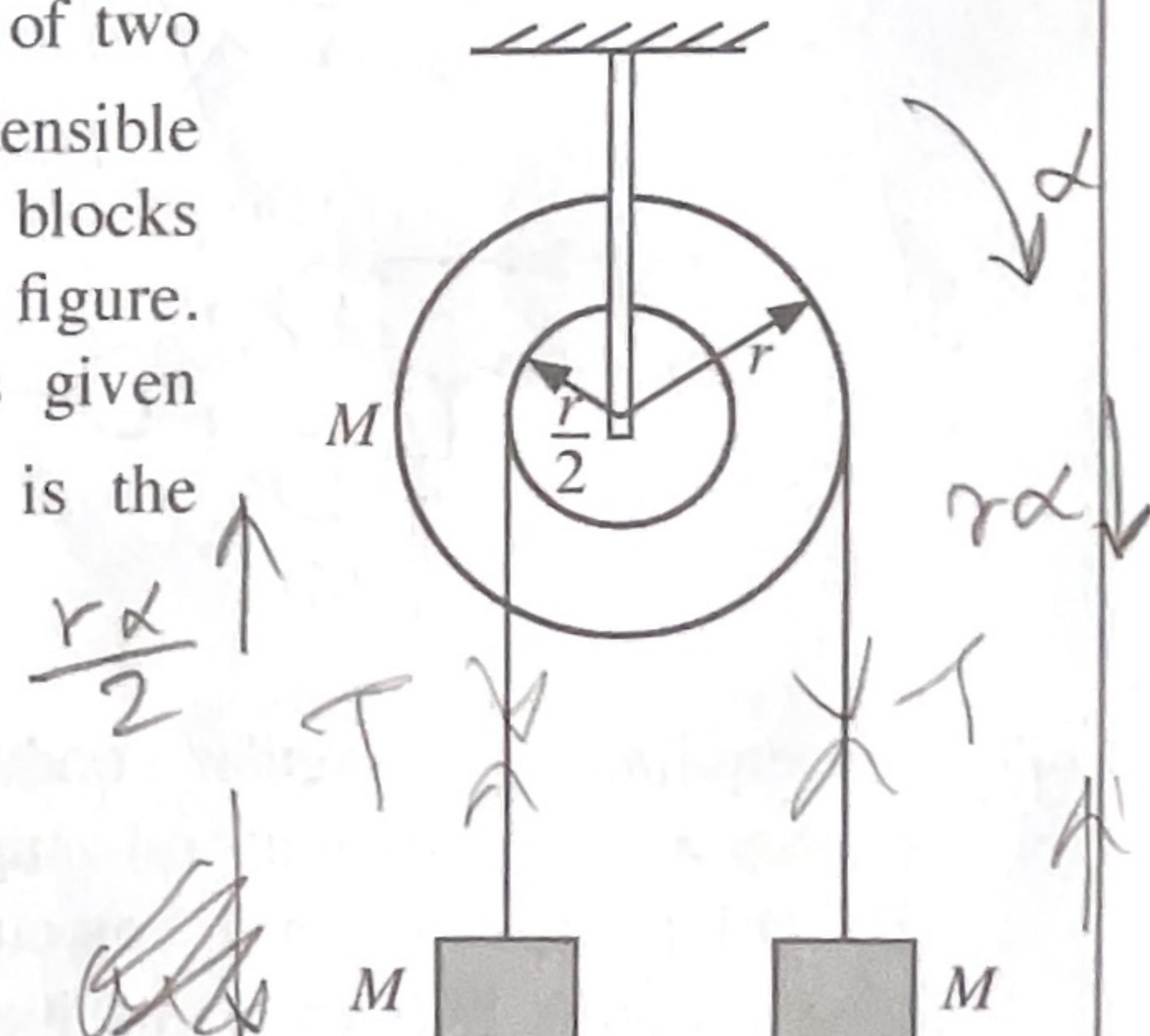
48. Figure shows a conducting wire carrying a current  $I$ . The wire has a non-uniform circular cross-section of varying radius along the length. The variation of the drift velocity  $v_d$  of electrons in the wire with the length  $x$  measured from the left end of the wire is best represented by



49. A small conducting sphere of radius  $a$  falls from rest in a viscous liquid. When the sphere attains its terminal velocity the rate of work done by the viscous force is proportional to  
 (1)  $a^5$       (2)  $a^4$       (3)  $a^3$       (4)  $a^2$       (5)  $a$

50. A specially made single frictionless pulley of mass  $M$  consisting of two parts of radii  $r$  and  $\frac{r}{2}$  is hung from a ceiling. Two light inextensible strings are wound around on each part of the pulley and two blocks each of mass  $M$  are hung from the free ends as shown in the figure. The total moment of inertia  $I$  of the pulley about the axis is given by  $I = \frac{3}{4}Mr^2$ . When the blocks are released from rest what is the angular acceleration of the pulley?

- (1) 0      (2)  $\frac{g}{2r}$       (3)  $\frac{g}{3r}$   
 (4)  $\frac{g}{4r}$       (5)  $\frac{g}{5r}$



\* \* \*

# ශ්‍රී ලංකා උග්‍ර දෙපාර්තමේන්තුව

## ඇලංකා ප්‍රජාතාන්ත්‍රික සමාජ ආර්ථික මධ්‍යස්ථානය

# **Department of Examinations, Sri Lanka**

අධ්‍යෙන පොදු සහතික පත්‍ර (සේස් පෙල) විභාගය 2023(2024)

கல்வி பொது கல்வி துறை (பாரிசு), தமிழகம் 2023(2024) கல்விப் பொதுக் குரைப்பு பக்கிர (உயர் கு)ப் பரிசீலனை, 2023(2024)

# General Certificate of Education (Adv. Level) Examination, 2023(2024)

# සොතික විද්‍යාව පොතිකවියල් **Physics**

II

## PART B – Essay

01 E II

*Answer four questions only.*  
 $(g = 10 \text{ m s}^{-2})$

- Note: For example the number 65210 can be written as  $6.52 \times 10^4$  in scientific notation after rounding off to two decimal places.

- 5.** (a) In a cricket match, a fast bowler delivers a ball without hitting the ground (full toss ball) with horizontal velocity of  $35\cdot0 \text{ m s}^{-1}$  at a height of  $2\cdot0 \text{ m}$  from the ground level as shown in the figure (1). The ball travels a horizontal distance of  $17\cdot5 \text{ m}$  before touching the bat. Assume there is no air resistance.

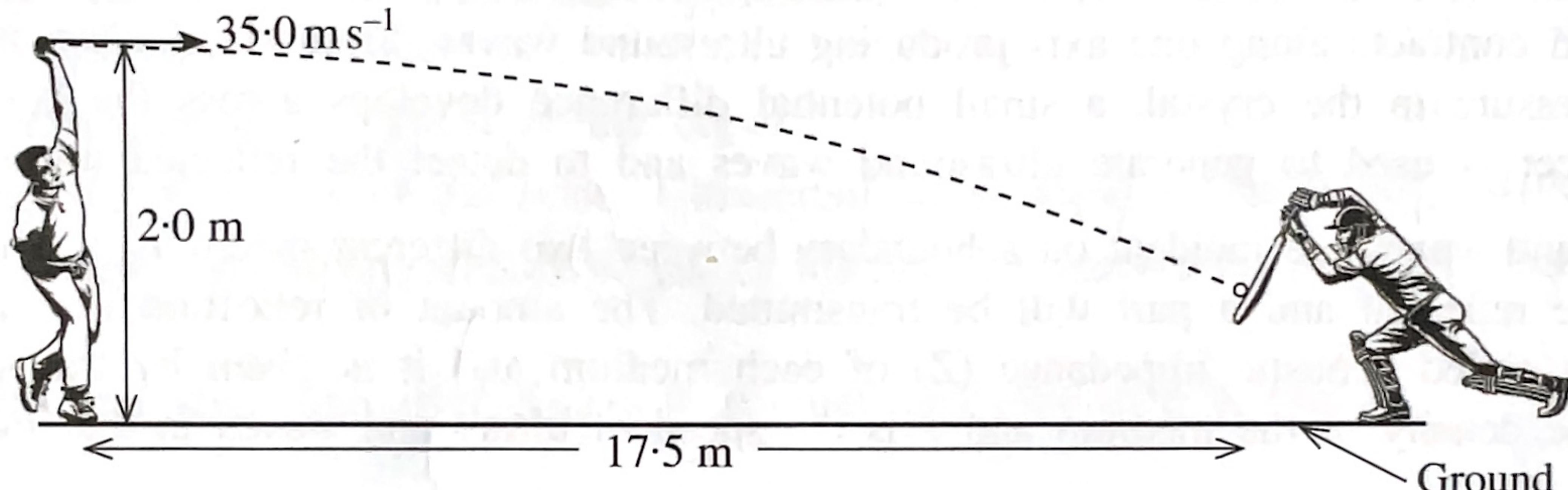


Figure (1)

- (i) How long will it take for the ball to touch the bat?

(ii) At what height from the ground will the ball touch the bat?

(iii) Calculate the speed of the ball just before touching the bat. Give your answer to the nearest first decimal place in  $\text{m s}^{-1}$ . You may take  $\sqrt{2} = 1.41$ .

(iv) The ball approaching perpendicular to the bat is successfully hit by the batsman so that it rebounds and returns in the same incoming line with the same speed as it approached the bat. If the mass of the ball is 0.16 kg and time of contact with the bat is 0.2 s calculate the force exerted on the ball by the bat. Give your answer to the nearest first decimal place in N.

(b) Cricket batsmen use mechanical bowling machines to practise in the net for improving their skills. A certain bowling machine consists of two identical heavy wheels  $A$  and  $B$  fitted with rubber tyres. The radius  $R$  of wheels with tyres is 50 cm. The top view of the setup is shown in the figure (2). Each wheel is driven by its own electric motor but in opposite directions. They are mounted in a **horizontal plane** with a gap in between two wheels. The gap is slightly less than the diameter of a specially designed uniform ball.

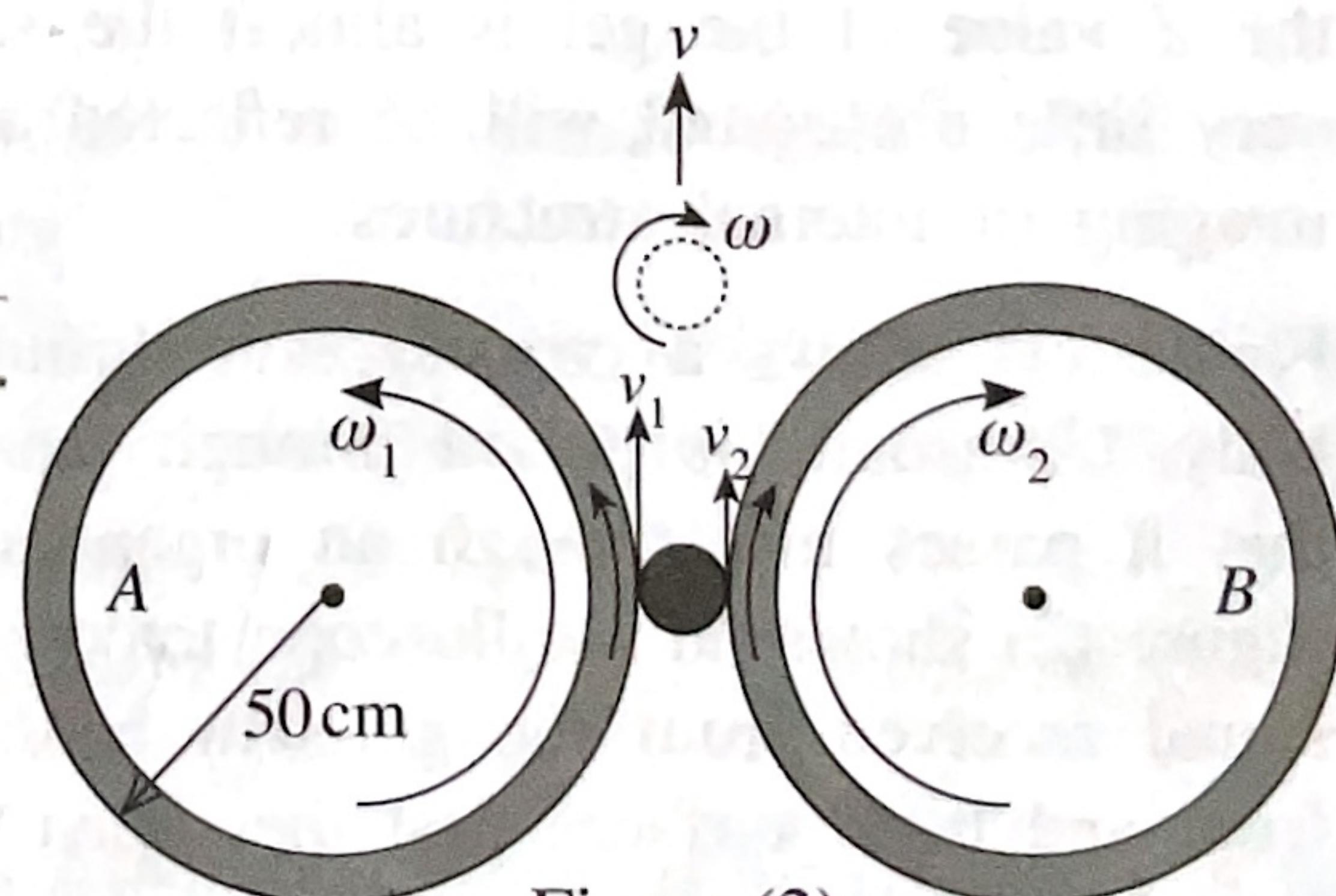


Figure (2)

- (i) For sending a spinning ball, the rotational speed of wheels A and B are set at  $\omega_1 = 640 \text{ rpm}$  and  $\omega_2 = 560 \text{ rpm}$  respectively while keeping the plane of the wheels horizontally. rpm denotes number of rotations per minute. The linear velocity  $v$  of the centre of mass (CM) of the ball is given

by  $v = \frac{v_1 + v_2}{2}$ . The angular velocity  $\omega$  of the ball is given by  $\omega = \frac{(v_1 - v_2)}{2r}$  where  $r$  is the radius of the ball.  $v_1$  and  $v_2$  are the velocities of the surface of the ball at contact points. The radius of the ball  $r = 4.0$  cm. Take  $\pi = 3$ .

- I. Calculate the angular velocities ( $\omega_1$  and  $\omega_2$ ) of wheels in  $\text{rad s}^{-1}$ .
  - II. Calculate the linear velocity ( $v$ ) of the CM of the ball when ejects.
  - III. Calculate the angular velocity ( $\omega$ ) of the ball in rpm when ejects.

IV. If the mass of the ball is  $m$ , write down an expression for the total kinetic energy of the ball when it ejects in terms of  $m$ ,  $r$ ,  $v$  and  $\omega$ . The moment of inertia  $I$  of a uniform ball of radius  $r$  about an axis through the centre is given by  $I = \frac{2}{5}mr^2$ .

V. When the ball ejects calculate the **maximum** speed that a point on the surface of the ball can have.

- (ii) For sending a fast ball without spin the angular speeds of the wheels are set equal so that  $\omega_1 = \omega_2 = \omega_0$ . To eject a fast ball at velocity of  $35 \text{ m s}^{-1}$  what should be the angular speed  $\omega_0$  of each wheel in rpm?

6. Read the following passage and answer the questions.

Audible range of human ear extends from  $20 \text{ Hz}$  to  $20 \text{ kHz}$ . Ultrasound waves are also sound waves but differ from audible sound only in its frequency. Ultrasound is used in many different areas such as in industry, medicine, navigation, imaging, cleaning, mixing, communication and testing.

An ultrasound transducer converts electrical signals into ultrasound waves and ultrasound waves into electrical signals. The key component of the transducer is a piezoelectric crystal which works on the principle of piezoelectric effect. When a high frequency alternating voltage is applied across such a piezoelectric crystal, it expands and contracts along one axis producing ultrasound waves. Similarly if ultrasound waves produce a variable pressure in the crystal, a small potential difference develops across the crystal. Therefore the same transducer is used to generate ultrasound waves and to detect the reflected ultrasound waves.

When ultrasound waves are incident on a boundary between two different media, a part of the ultrasound waves will be reflected and a part will be transmitted. The amount of reflection or transmission depends on a property called acoustic impedance ( $Z$ ) of each medium and it is given by the relationship  $Z = \rho v$ . Here  $\rho$  is the density of the medium and  $v$  is the speed of ultrasound waves in that medium. For normal

incidence, the ratio of the reflected intensity ( $I_r$ ) to the incident intensity ( $I_i$ ) is given by 
$$\frac{I_r}{I_i} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$
.

Here  $Z_1$  and  $Z_2$  are acoustic impedances of the first medium and the second medium respectively.

Since the  $Z$  value of skin is large compared to that of air, when an ultrasound transducer is placed directly on to a patient's skin, 99.9% of the incident ultrasound intensity is reflected and only 0.1% is transmitted into the body. In order to ensure that most of the ultrasound is transmitted into the patient, a special gel layer is applied in between the patient's skin and the transducer. Since the  $Z$  value of the gel is almost the same as that of the skin, very little ultrasound will be reflected and this ensures effective imaging of internal structures.

Figure (1) shows a cross-section through a part of a patient's body. Ultrasound is pulsed through the center of the section so that it passes first through an organ and then through a bone. Figure (2) shows an oscilloscope trace of the reflected ultrasound signal received from the gel-skin boundary and then from the front and back surfaces first the organ and then the bone.

- What is the audible range of human ear?
- Name **three** areas where ultrasound waves are used.
- What are the functions of an ultrasound transducer?

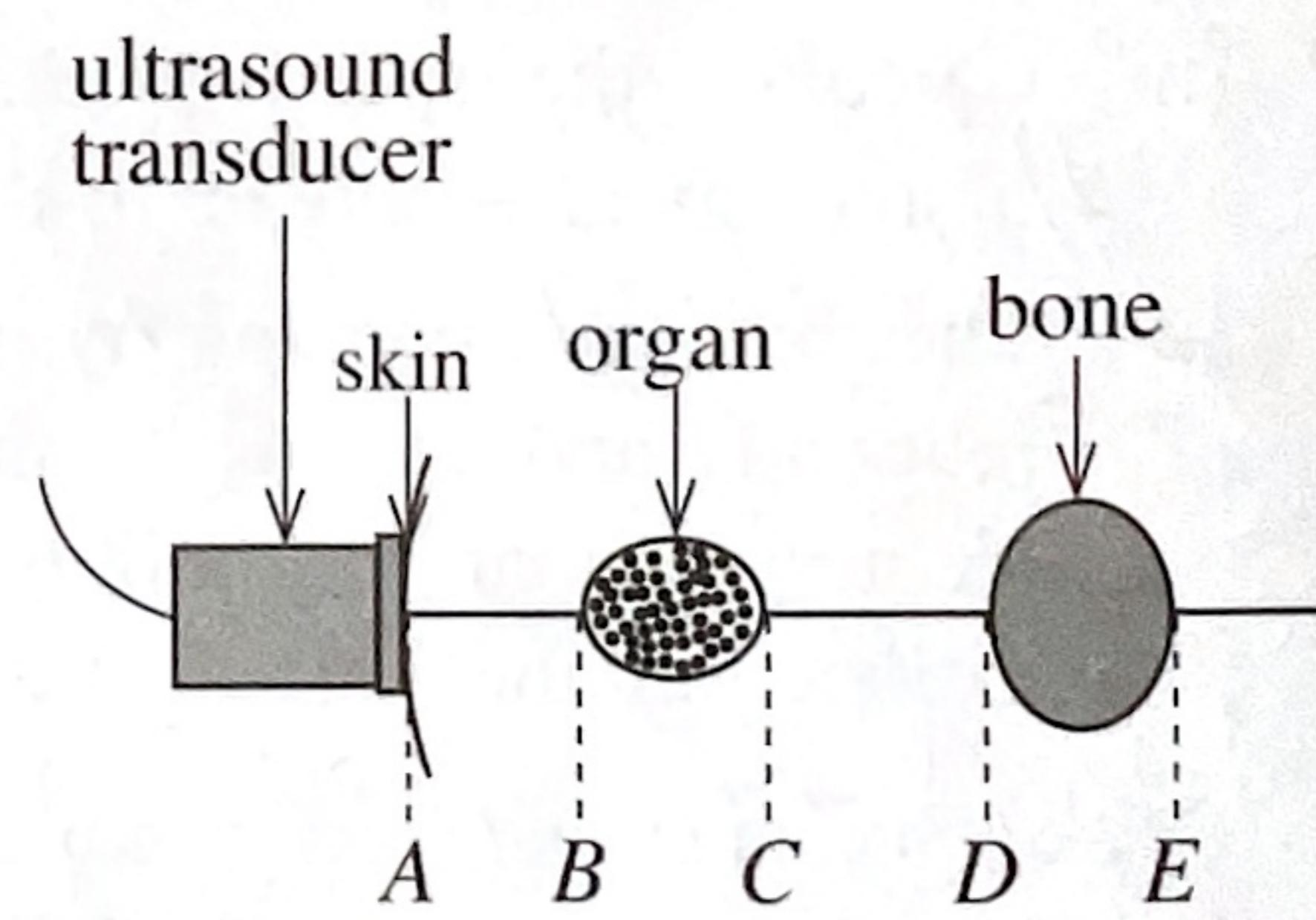


Figure (1)

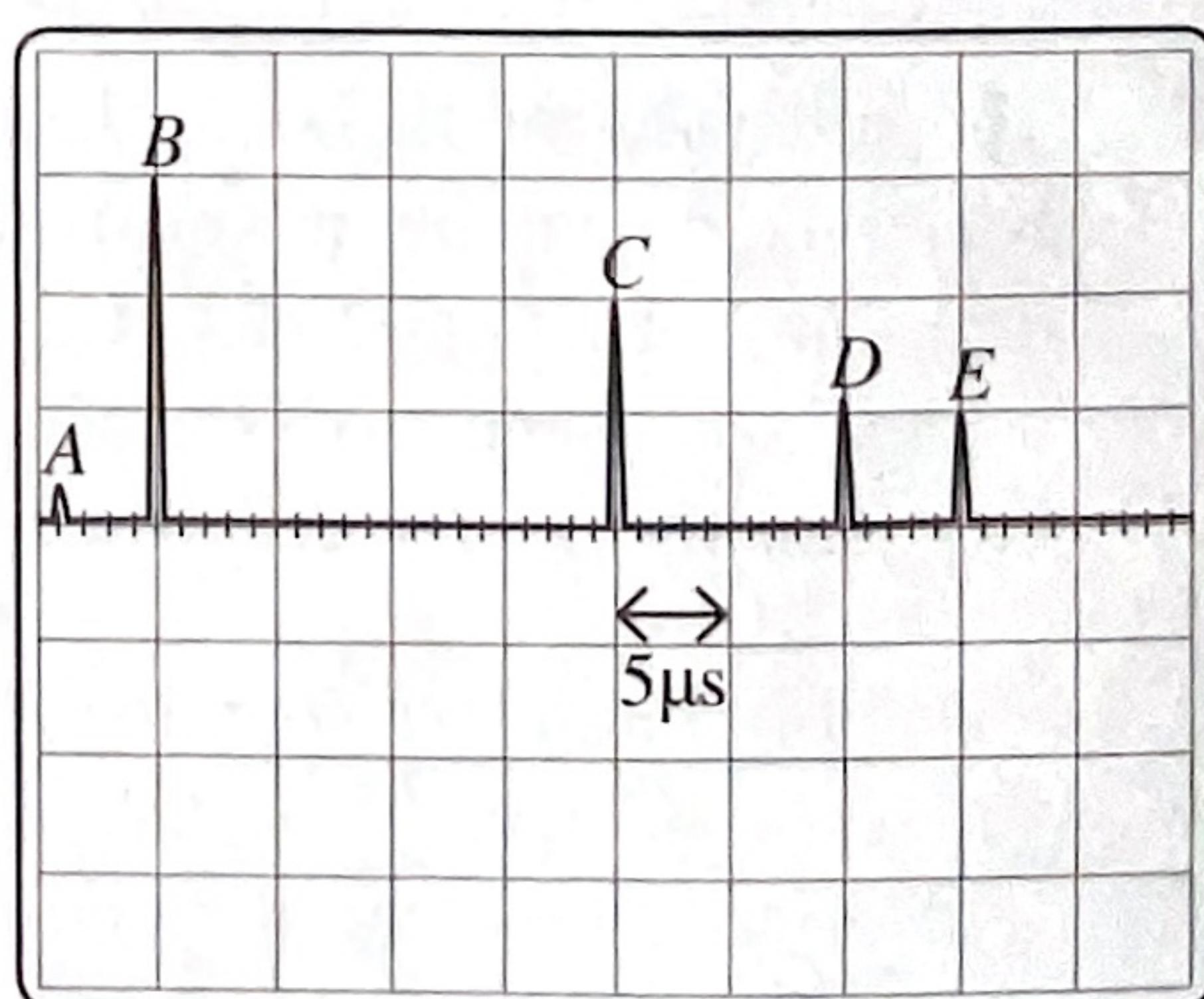


Figure (2)

- (i) Briefly explain how ultrasound waves are produced in an ultrasound transducer.
- If the natural frequency of the piezoelectric crystal in an ultrasound transducer is  $48 \text{ kHz}$ , what is the most appropriate frequency of the alternating voltage that should be applied across the crystal? Give the reason for your answer.
- Is it possible to apply the same equation that is used to find out the speed of sound in a medium to determine the speed of ultrasound waves propagating in that medium? Give the reason to your answer.

(f) (i) In the expression  $\frac{I_r}{I_i} = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$ , show that the dimension of  $I_r$  is **not** equal to that of  $(Z_2 - Z_1)^2$ .

(ii) What will be the value  $\frac{I_r}{I_i}$ , if  $Z_2 = Z_1$ ?

(iii) What will be the value  $\frac{I_r}{I_i}$ , if  $Z_2 \gg Z_1$ ?

(g) What is the reason for applying a special gel between the patient's skin and the transducer?

(h) (i) What is the acoustic impedance  $Z$  of human skull with density  $1600 \text{ kg m}^{-3}$  if ultrasound waves travel through the human skull at a speed of  $3750 \text{ m s}^{-1}$ ?

(ii) The average acoustic impedance of the material that the brain made of is  $4.0 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$ .

Calculate the percentage of  $\frac{I_r}{I_i}$ , when ultrasound waves incident on the boundary of skull and brain.

(i) (i) Using the information given in figure (2), determine the total time interval during which the ultrasound waves travel in the organ.

(ii) Calculate the total distance travelled by ultrasound waves through the organ. Ultrasound wave speed in the organ is  $1600 \text{ m s}^{-1}$ .

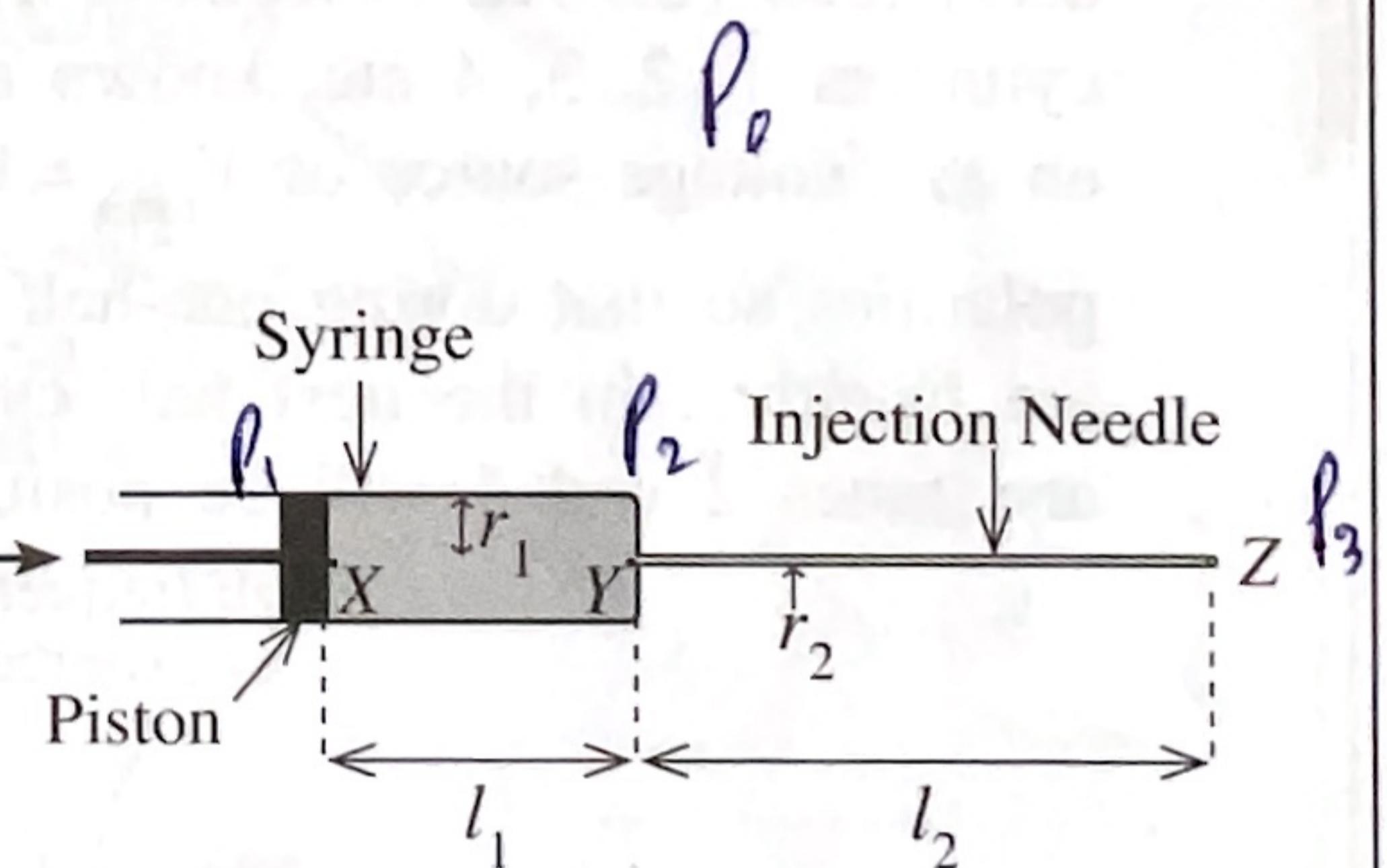
(iii) Hence, calculate the thickness of the organ.

(iv) Calculate the thickness of the bone. Ultrasound wave speed in the bone is  $4100 \text{ m s}^{-1}$ .

(j) What is the reason for sending ultrasound pulses instead of a continuous beam of ultrasound in medical imaging?

(k) Why is ultrasound scan safer over X-rays to examine a foetus in a womb?

7. As shown in the figure a cylindrical syringe is attached to a cylindrical injection needle which is used to inject a liquid medicine into a vein of a patient. Both the syringe and the needle are kept horizontally and completely filled with the medicine. The internal radius of the syringe is  $r_1$  and the length between points  $X$  and  $Y$  is  $l_1$ . The internal radius of the needle is  $r_2$  and the length of the needle is  $l_2$ . The coefficient of viscosity of the medicine is  $\eta$ . When a force  $F$  is applied to the piston of the syringe, the rate of volume flow of the medicine through the system is  $Q$ . The end  $Z$  of the needle is inserted into the vein.



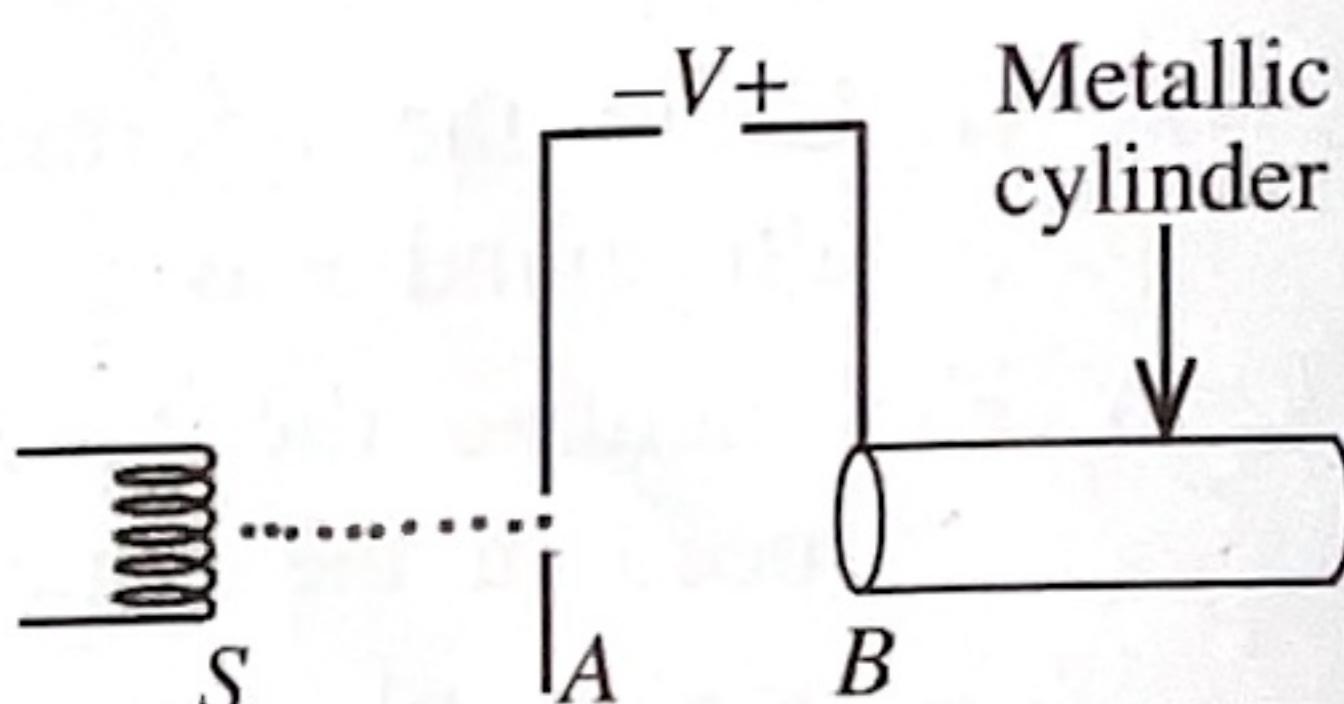
- (a) Write down the Poiseuille equation for the rate of volume flow  $Q$  of a viscous liquid passing through a horizontal narrow tube. Identify each symbol in the equation.
- (b) (i) Write down an expression for the pressure  $P$  at point  $X$  due to the applied force in terms of  $F$  and  $r_1$ . Assume that the force  $F$  is uniformly distributed over the cross-sectional area of the piston.
- (ii) If the atmospheric pressure is  $P_0$  what is the total pressure  $P_1$  at point  $X$ .
- (iii) If the pressure at point  $Y$  is  $P_2$ , write down an expression for  $(P_0 - P_2)$  in terms of  $Q$ ,  $r_1$ ,  $l_1$ ,  $\eta$  and  $F$ .
- (iv) If the pressure at point  $Z$  (inside the vein) is  $P_3$ , write down an expression for  $(P_2 - P_3)$  in terms of  $Q$ ,  $r_2$ ,  $l_2$  and  $\eta$ .
- (v) Using the expressions written in (b) (iii) and (b) (iv) above, write down an expression for  $(P_0 - P_3)$  in terms of  $Q$ ,  $r_1$ ,  $l_1$ ,  $\eta$ ,  $r_2$ ,  $l_2$  and  $F$ .
- (vi) Hence write down an expression for  $F$  in terms of  $Q$ ,  $r_1$ ,  $l_1$ ,  $\eta$ ,  $r_2$ ,  $l_2$ ,  $P_3$  and  $P_0$ .
- (c) The pressure  $P_3$  in the vein is  $10 \text{ mmHg}$  higher than the atmospheric pressure.
- (i) Determine  $(P_3 - P_0)$  in Pa. Density of mercury (Hg) is  $1.36 \times 10^4 \text{ kg m}^{-3}$ .
- (ii) If  $r_1 = 2.5 \text{ mm}$ ,  $l_1 = 50 \text{ mm}$ ,  $r_2 = 0.10 \text{ mm}$ ,  $l_2 = 60 \text{ mm}$  and  $\eta = 2.0 \times 10^{-3} \text{ Pa s}$  determine the magnitude of the force  $F$  needed to inject a volume flow rate of  $3.0 \times 10^{-7} \text{ m}^3 \text{ s}^{-1}$  liquid medicine into the vein. Take  $\pi = 3$ . [Hint: In the determination of  $F$ , two terms having small values can be neglected].
- (iii) What is the flow speed of the liquid medication inside the needle? Take  $\pi = 3$ .

(d) In a modern jet injection method (needle free) liquid medicine is delivered into the body using a high-pressure nozzle just touching the skin. A narrow stream of liquid medicine penetrates the skin and delivers the medicine into the tissue. The inner radius of the opening of the nozzle is  $4 \mu\text{m}$ . When the liquid medicine is filled in the horizontal syringe, the liquid starts to release from the opening of the nozzle at a certain pressure.

- Write down an expression for the excess pressure ( $\Delta p$ ) across a spherical meniscus of radius  $r$  of a liquid of surface tension  $T$ .
- Calculate the pressure  $P'$  needed to be in the liquid medicine near the nozzle when a liquid drop is just detached from the opening of the nozzle. Surface tension of the liquid medicine is  $8.0 \times 10^{-2} \text{ N m}^{-1}$  and atmospheric pressure is  $1.0 \times 10^5 \text{ Pa}$ .

8. (a) As shown in figure (1) electrons emitting from a hot filament  $S$ , pass through an aperture  $A$  and then move along the axis of a metallic, open ended hollow cylinder. The system is kept in vacuum. A potential difference  $V$  is applied across the cylinder and the aperture so that the cylinder is kept at positive potential and the aperture is kept at negative potential.

- If the velocity of the electrons passing through the aperture  $A$  is negligible write down an expression for the kinetic energy  $K_1$  of electrons at  $B$  in terms of  $V$  and electron charge  $e$  after crossing the gap between the cylinder and the aperture.



- Hence write down an expression for the velocity  $v_1$  of the electrons at  $B$  in terms of  $e$ ,  $V$  and mass of the electron  $m$ .

Figure (1)

- The setup shown in figure (1) can be modified to accelerate electrons to a higher kinetic energy by placing a series of coaxial metallic cylinders in line. This type of arrangement is known as a linear accelerator (LINAC). Electrons leaving the aperture  $A$  move along the axis of a series of coaxial metallic cylinders 1, 2, 3, 4 etc. known as drift tubes as shown in figure (2). The drift tubes are connected to an a.c. voltage source of  $V_{\text{r.m.s.}} = V$  and high frequency  $f$ . The alternate tubes have potentials of opposite polarities so that during one-half cycle of the a.c. source the tubes 1 and 3 are positive while 2 and 4 are negative. In the next half cycle the polarities are reversed, that is tubes 1 and 3 will be negative and tubes 2 and 4 will be positive.

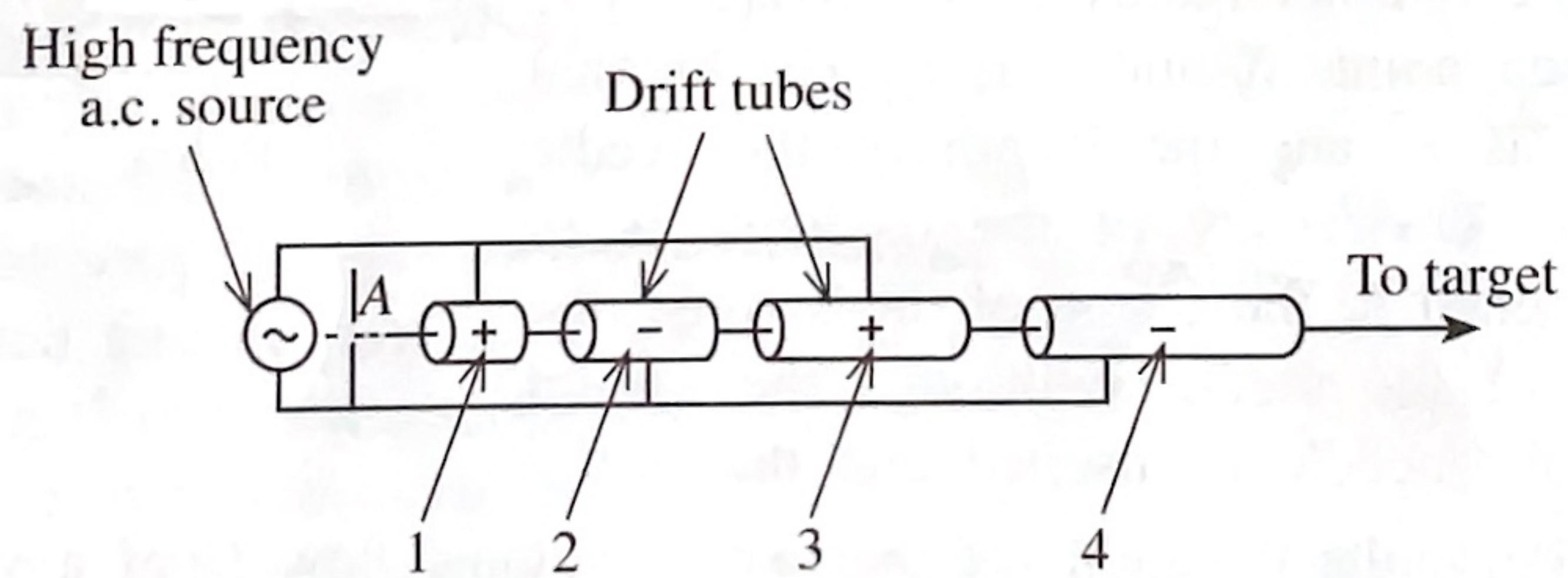


Figure (2)

Electrons leaving  $A$  accelerate during the half cycle when the drift tube 1 is positive with respect to  $A$ . Then the velocity  $v_1$  of the electrons reaching the tube 1 is given by the expression you have written in (a) (ii) above. The length of the tube 1 is designed so that as the electrons come out of it, the potential of the tube 1 turns to negative and the potential of tube 2 turns to positive. Therefore electrons are again accelerated in the gap between the tubes 1 and 2. The electrons accelerate in the gaps between the tubes but travel with constant velocities within the tubes.

- What is the reason for electrons to travel with constant velocities inside the tubes?
  - Derive an expression for velocity  $v_2$  of electrons reaching the tube 2 in terms of  $v_1$ .
  - Write down an expression for kinetic energy  $K_2$  of electrons reaching the tube 2 in terms of  $e$  and  $V$ .
- Similarly the length of the tube 2 is designed so that as the electrons come out of it, the potential of the tube 2 turns positive to negative and the potential of tube 3 turns negative to a positive. Therefore electrons are again accelerated in the gap between the tubes 2 and 3.
  - Derive an expression for velocity  $v_3$  of electrons reaching the tube 3 in terms of  $v_1$ .
  - Write down an expression for kinetic energy  $K_3$  of electrons reaching the tube 3 in terms of  $e$  and  $V$ .
  - If there are  $n$  number of tubes, looking at the answers in (a) (i), (b) (iii) and (c) (ii) above or otherwise, write down an expression for the kinetic energy  $K_n$  of electrons leaving the  $n^{\text{th}}$  tube.

- (d) As electrons are accelerated in the gap between two consecutive tubes, the time taken by electrons to travel through tubes should be equal to half of the periodic time of the high frequency a.c. voltage.
- Write down an expression for time  $t$  taken by electrons to travel through each of drift tubes in terms of the frequency  $f$  of the a.c. voltage.
  - Hence show that the length  $L_n$  of  $n^{\text{th}}$  tube is given by  $L_n = \frac{1}{f} \sqrt{\frac{neV}{2m}}$ .
- (e) A medical linear accelerator (medical LINAC) is the device most commonly used for external beam radiation treatments for patients with cancer. Accelerated electrons are allowed to collide with a heavy metal target like tungsten to produce high energy X-rays. These high energy X-rays are used to destroy cancer cells. The accelerated electrons coming out from a medical LINAC have a kinetic energy of 10 MeV. Determine the **minimum** wavelength of X-rays emitted.  
( $hc = 1.24 \times 10^{-3}$  MeV nm)

**9. Answer either part (A) or part (B) only.**

**Part (A)**

A source  $X$  with zero internal resistance is shown in figure (1). The voltage of  $X$  is linearly dependant on temperature and it produces a current ( $I$ ) from 0 to 20 mA for temperatures ranging from  $0^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ . The current is linearly converted into a voltage between 0 - 5 V range and is measured across the resistance  $R$  as a output voltage ( $V$ ).

- (i) If  $R$  is an ohmic resistance, sketch the  $I-V$  characteristic of  $R$ .  
(ii) What should be the value of the resistance  $R$ ?  
(iii) Calculate the values of voltage and current across the resistor when the temperature of  $X$  is  $25^{\circ}\text{C}$ . Hence find the power dissipation in the resistor.
- Suppose that resistance  $R_1$  is connected parallel to  $X$  and the wire segment  $BC$  in the circuit shown in figure (1) is replaced by resistor  $R_2$  as shown in figure (2). Let  $R$  remains constant at the value calculated in (a) (ii) above.  
(i) When the source produces a voltage ( $V_s$ ), write down an expression for the current ( $I$ ) passing through resistance  $R$ .  
(ii) Hence write down an expression for the source current ( $I_s$ ).  
(iii) Using the expressions in (b) (i) and (b) (ii) above, state what will happen to the ratio  $\frac{I_s}{I}$  if  $R_1 \gg (R + R_2)$ . What is the physical significance of this?

- In a computer hard disk drive (HDD), data is stored by magnetizing tiny regions of a thin film deposited on a flat, circular disk. As shown in figure (3), a cylindrical rod passing through the axis of the disk is used to spin the disk. When the disk spins, the information stored in the disk is read as an induced e.m.f. generated in the read/write head which is a conducting horizontal square loop of side length  $d$  placed just above the disk. The disk is spinning with constant angular velocity  $\omega$ . When the disk spins, an isolated magnetic region of the same size as the loop located at mean distance  $r$  from the center of the disk passes under the conducting loop, where  $r \ggg d$ . The magnetic region produces a uniform magnetic field of flux density  $B$  pointing upwards. An enlarged picture of the square loop seen from above is shown in figure (4). When the magnetic region is completely underneath the loop, the magnetic field produced by the magnetic region is directed out of the plane of the loop.

- Sketch the variation of the induced e.m.f.  $\xi$  with time  $t$ , as follows.

$t_1$  as the time when the field just enters the loop,  
 $t_2$  as the time when the loop is fully inside the field, and  
 $t_3$  as the time when the field just completely leaves the loop.

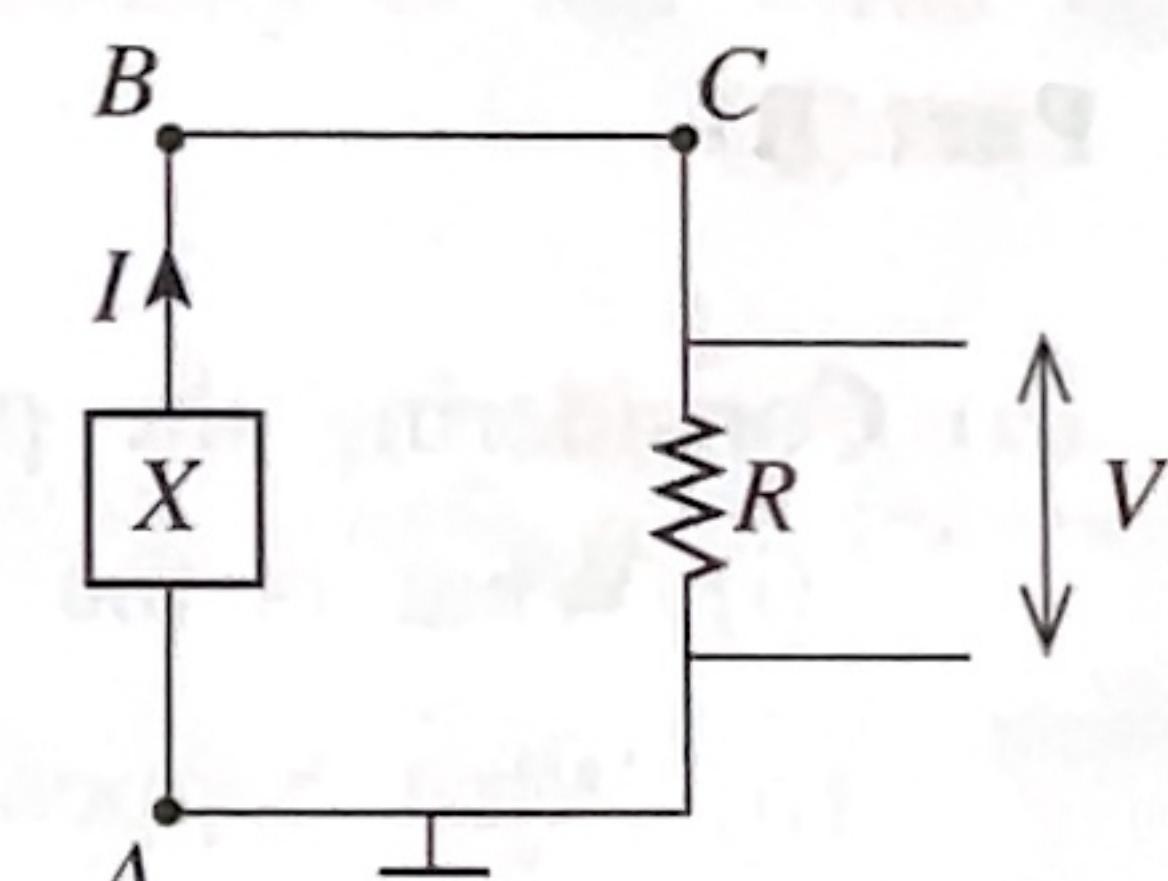


Figure (1)

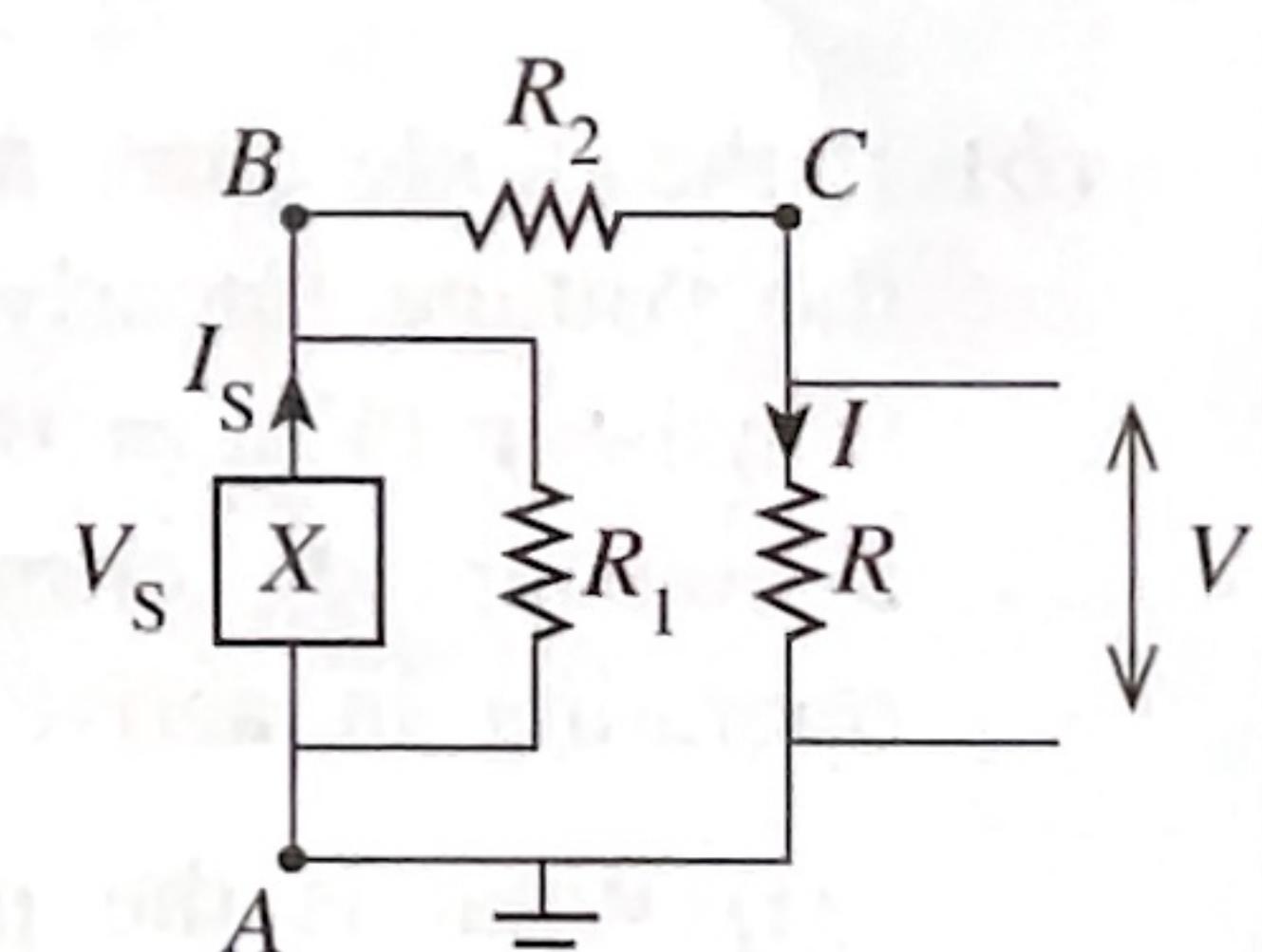


Figure (2)

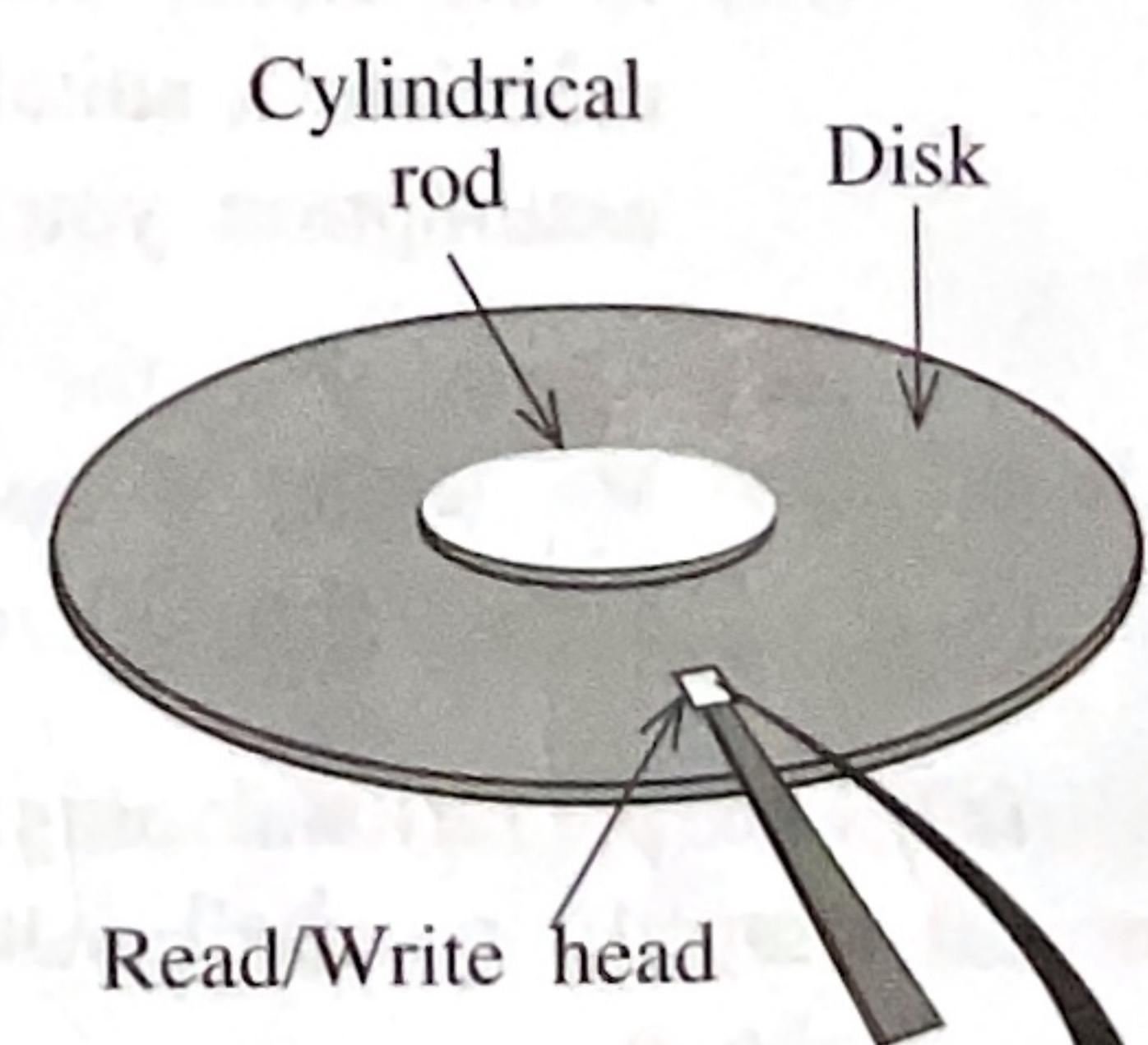


Figure (3)

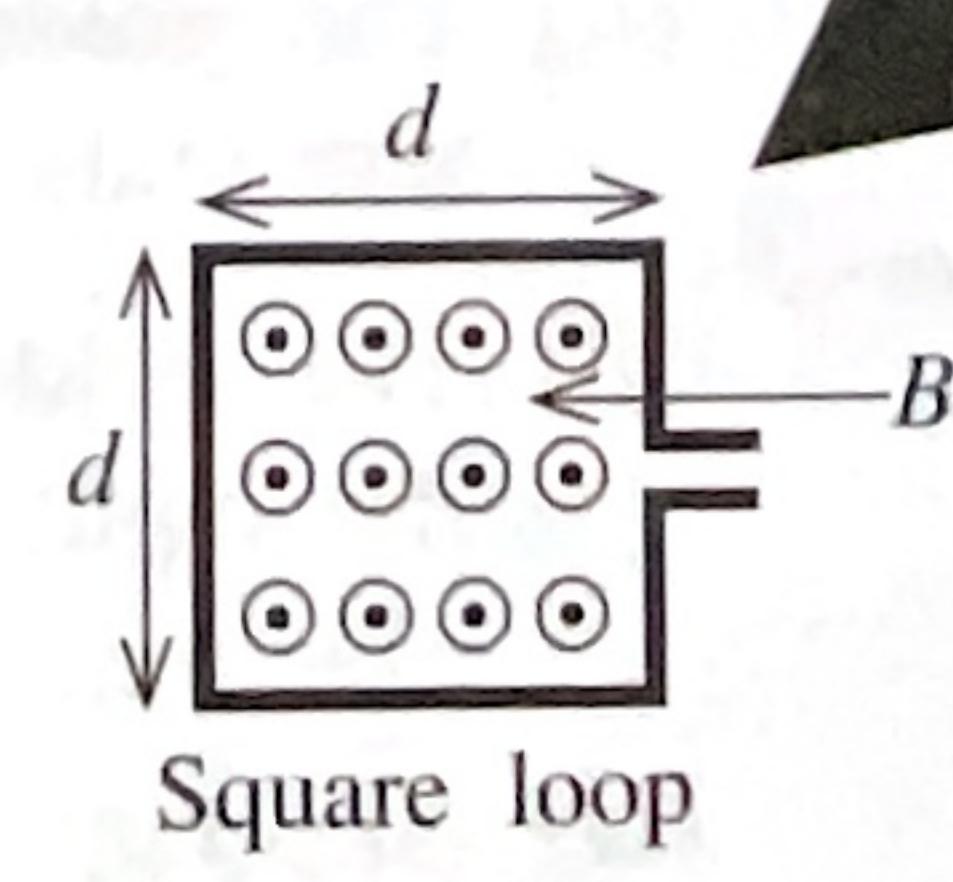


Figure (4)

- (ii) Write down an expression for the magnetic flux ( $\phi$ ) through the square loop in terms of  $B$  and  $d$ , when the loop is completely within the magnetic region.
- (iii) Write down an expression for the time ( $\Delta t$ ) taken for the magnetic region to pass the loop in terms of  $d$ ,  $r$  and  $\omega$ . Assume that the magnetic region is at a mean distance  $r$  from the centre of the disk.
- (iv) Using your answers to part (c) (ii) and (c) (iii) above or otherwise, write down an expression for the magnitude of the induced e.m.f. ( $\xi$ ) in the loop in terms of  $B$ ,  $d$ ,  $r$  and  $\omega$ .
- (v) The area of the circular disk with a radius of 62.5 mm is half filled with  $1.0 \times 10^{13}$  isolated uniformly distributed square magnetic regions. There are no magnetic regions in the cylindrical rod of radius 12.5 mm. Calculate the side length  $d$  of a single magnetic region. Take  $\pi = 3$  and  $\sqrt{562.5} = 24$ .
- (vi) If  $B = 1.0 \times 10^{-3}$  T and the angular speed of the spinning disk is  $540 \text{ rad s}^{-1}$ , calculate the induced e.m.f.  $\xi$  on the loop when a magnetic region situated at the circumference ( $r = 62.5$  mm) of the disk passes under the loop.

### Part(B)

- (a) Considering the properties of a silicon p-n junction diode, answer the following questions,
- What is the reason for the formation of a depletion region in the diode?
  - What happens to the width of the depletion region when the diode is
    - forward biased and
    - reverse biased?
  - What is the reason for generating a very small reverse-biased leakage current in the diode?
- (b) If the diode current of a forward biased silicon diode is kept constant, the voltage linearly drops with temperature. The circuit with a silicon transistor ( $V_{BE} = 0.7$  V) and a Zener diode ( $Z$ ) can be used to keep a constant  $I_D$  current through the diode ( $D$ ) when the transistor is operating in active mode as shown in figure (1).
- What is the purpose of the Zener diode in the circuit?
  - If the Zener voltage is  $V_Z$ , write down an expression for  $R_E$  in terms of  $I_E$ ,  $V_Z$  and  $V_{BE}$ .
  - If the circuit needs to produce a constant current of  $I_D = 20$  mA, calculate a suitable value for  $R_E$ . Take  $V_Z = 5.7$  V. Write down the assumption you made during the calculation with regard to  $I_E$ .
  - Show that the circuit works as a constant current source if  $V_{CC} = +12$  V and  $V_Z = 5.7$  V. The forward biased voltage drop across the silicon diode is 0.7 V.
- (c) The operational amplifier circuit shown in figure (2) can be used to amplify a small voltage similar to the diode voltage given in (b) above.
- What is the op-amp configuration shown in figure (2)?
  - The golden rule-one states that no current flows into the input terminals of an op-amp. What is the reason for this?
  - The golden rule-two states that the voltage difference between the input terminals of an op-amp is zero. How is it achieved in practice?
  - Applying the two golden rules, derive an expression for the output voltage  $V_o$  in terms of the small input voltage  $V_i$ ,  $R_1$  and  $R_2$ .

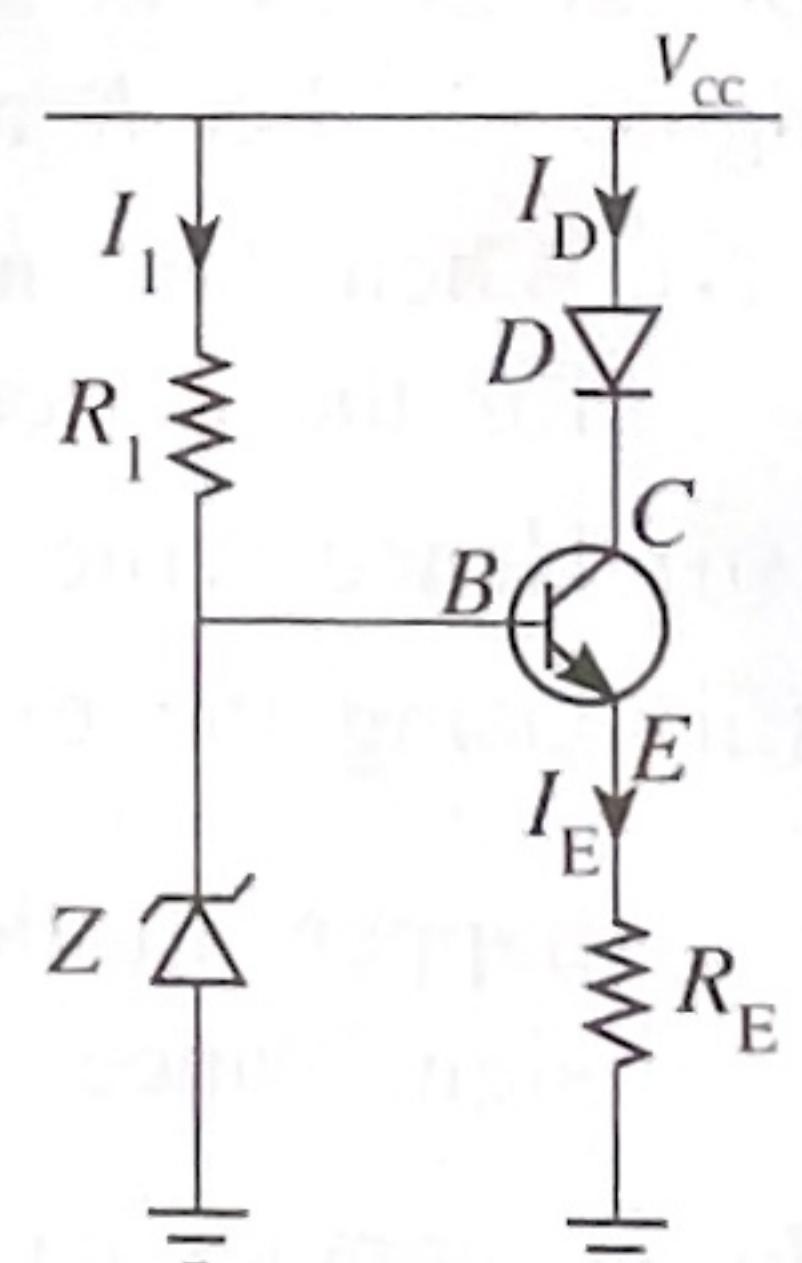


Figure (1)

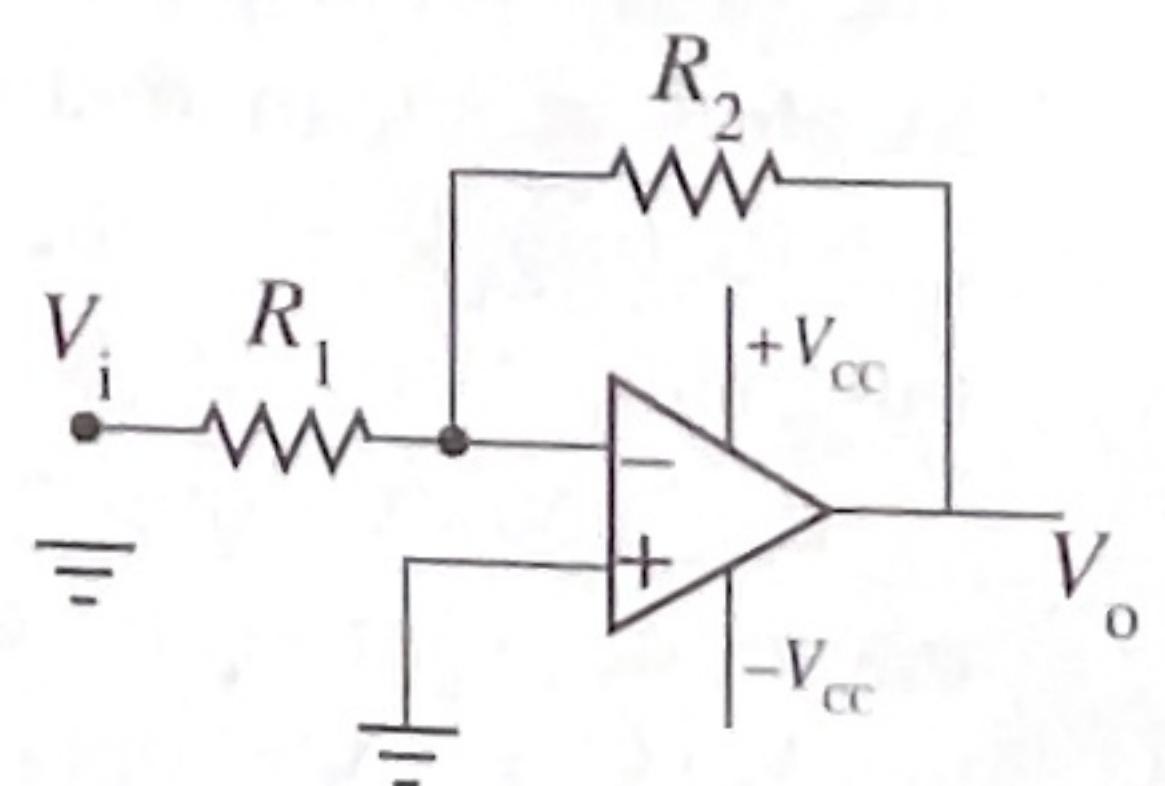


Figure (2)

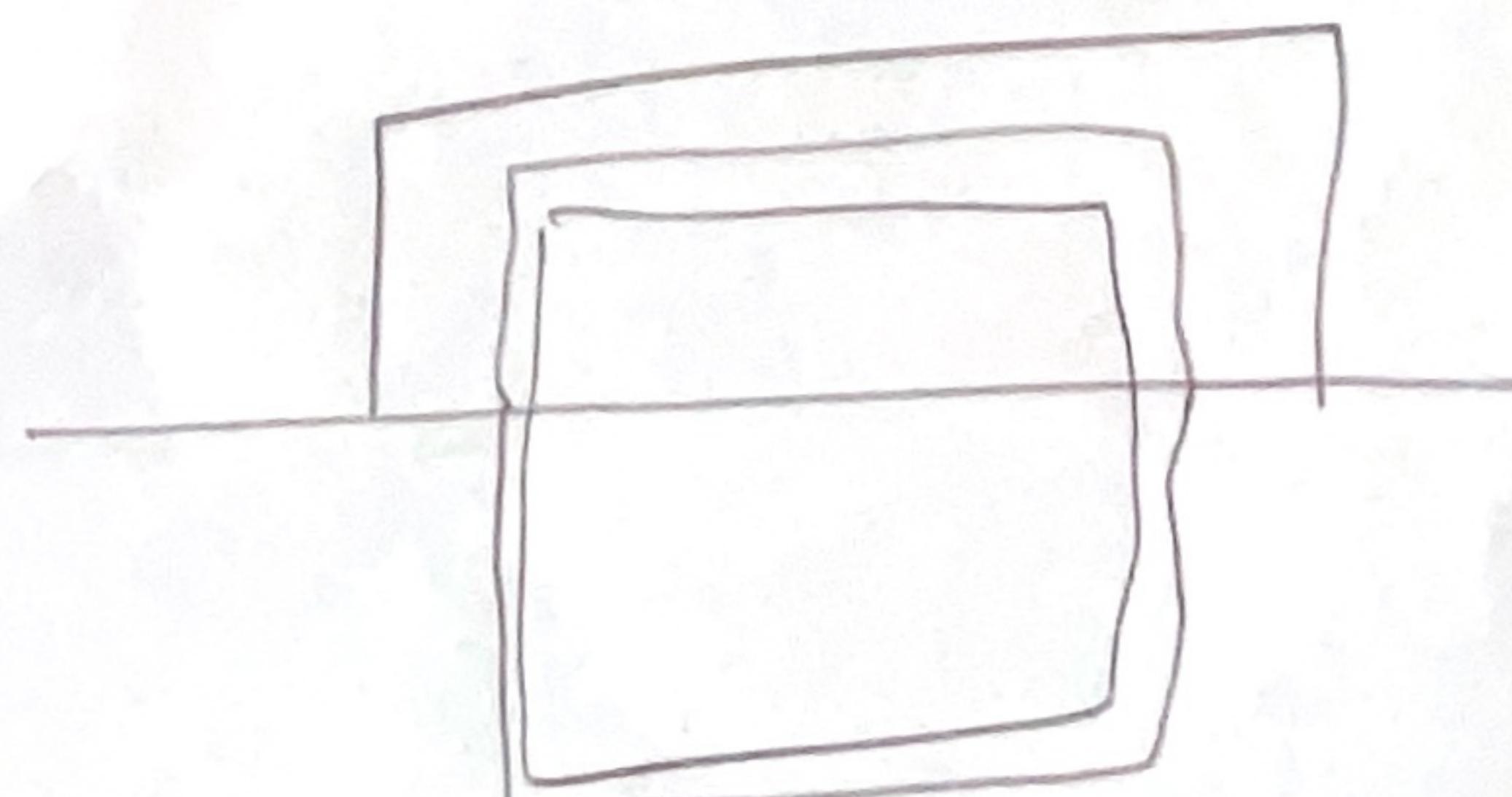
- (v) If small input voltages between 0 and 0.7 V need to be converted to values between 0 V and 3.5 V output range, determine the voltage gain of the op-amp.
- (vi) The small input voltage at 0.7 V linearly drops with temperature by 2 mV per 1 °C. Calculate the output voltage of the op-amp corresponding to 10 °C increase in temperature in  $V_i$ .
- (vii) The voltage gain of the op-amp circuit can be set by choosing  $R_1$  and  $R_2$  values in ohm range. However, in practice resistor values in kΩ or larger range are used in the op-amp circuit. What is the reason for using large resistor values in the circuit?

**10. Answer either part (A) or part (B) only.**

**Part (A)**

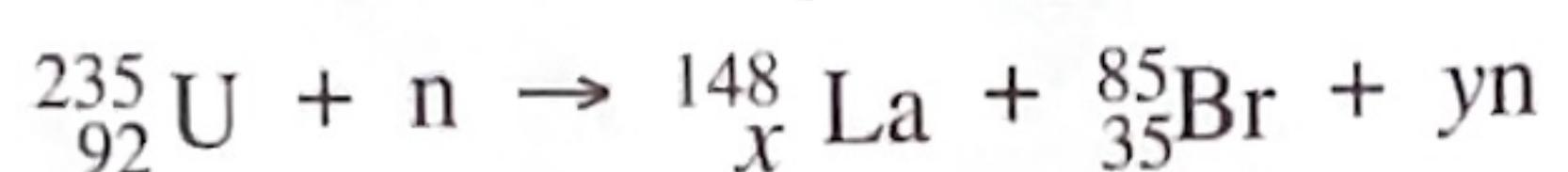
As a solution to scarcity of drinking water, United Arab Emirates (UAE) planned to introduce the iceberg project. The concept of the project is to bring a massive iceberg from Antarctica to the sea of Persian Gulf at UAE and to produce drinking water. A huge cubical iceberg of volume  $1.0 \times 10^7 \text{ m}^3$  in Antarctica has to be pulled with the help of a massive tugboat. Assume that the average density of sea water and ice are  $1000 \text{ kg m}^{-3}$  and  $900 \text{ kg m}^{-3}$  respectively at Antarctica and Persian Gulf.

- (a) (i) What is the total initial mass of the iceberg?
- (ii) Calculate the volume percentage of part of the iceberg submerged below the surface of the sea.
- (iii) If 80 % of initial mass remains as ice when the iceberg is at the Persian Gulf, how many cubic metres ( $\text{m}^3$ ) of water can be produced using this iceberg?
- (b) The iceberg brought to the sea of Persian Gulf is completely wrapped with an insulating material A of thickness 4.0 cm. The part of the iceberg above the sea water level is covered with an additional insulating material B with thickness 4.0 cm. Assume that the average temperature of sea water below the water level is  $20^\circ\text{C}$  and air temperature is  $30^\circ\text{C}$ . Thermal conductivity of insulating material A is  $0.2 \text{ W m}^{-1} \text{ K}^{-1}$  and that of B is  $0.1 \text{ W m}^{-1} \text{ K}^{-1}$ . Assume that the iceberg has cubical shape and the temperature of the outer layer of the iceberg is at  $0^\circ\text{C}$ . Neglect the mass of insulating material. Assume that there are no edge effects and heat flows perpendicular to all the surfaces.
- (i) Write down an expression for rate of heat flow ( $Q$ ) at steady state through a material and identify all the symbols you used.
- (ii) Find the side length ( $l$ ) of the ice cube in (a) (iii) above.
- Round off your answers of parts (iii), (iv), (v) and (vi) below to two decimal places in scientific notation. See the note given at the beginning of page 9.
- (iii) Calculate the surface area of the cubical iceberg
  - (I) above the water level
  - (II) below the water level
- (iv) Calculate the rate of heat absorbed by the part of the iceberg from sea water below the water level.
- (v) Calculate the rate of heat absorbed by the part of the iceberg from air above the water level.
- (vi) Water produced by melting of ice in the iceberg is used to distribute for consumption. Initially how many  $\text{m}^3$  of water at  $0^\circ\text{C}$  is produced during one day? Take specific latent heat of fusion of ice as  $3.0 \times 10^5 \text{ J kg}^{-1}$  and 1 day =  $9.0 \times 10^4 \text{ s}$ .



**Part (B)**

- (a) The amount of radiation energy absorbed per unit mass of tissue is used to measure the radiation dose. Write down the dimension of radiation dose.
- (b) What is meant by activity of a radioactive sample?
- (c) Write down the radioactive decay (disintegration) law **in words**.
- (d) The symbolic notation of nucleus of atom X is given by  ${}^A_Z X$ .
- What is meant by Z?
  - What is meant by A?
- (e) The fission reaction of U-235 nucleus capturing slow neutron can be written as follows.



Relevant Atomic masses are given below.

$${}_{92}^{235}\text{U} = 235.124 \text{ u}$$

$${}_{92}^{148}\text{La} = 147.961 \text{ u}$$

$${}_{35}^{85}\text{Br} = 84.930 \text{ u}$$

$$\text{n} = 1.007 \text{ u}$$

$$\text{n} = 1.009 \text{ u}$$

$$1 \text{ u} = 932 \text{ MeV}/c^2$$

Take Avogadro number as  $N_A = 6.0 \times 10^{23} \text{ mol}^{-1}$ ,  $1 \text{ MeV} = 1.6 \times 10^{-13} \text{ J}$  and  $c = 3.0 \times 10^8 \text{ m s}^{-1}$ .

- What are the values of x and y in the above nuclear reaction?
  - Calculate the binding energy of U-235 nucleus. Give your answer to the nearest integer in MeV.
  - Calculate the energy released from the above nuclear reaction. Give your answer to the nearest integer in MeV.
- (f) It has been proposed to generate electricity by using a floating nuclear power plant when electricity generated by hydropower is insufficient. One of the advantage of a floating nuclear power plant is that it can be assembled in highly advanced factories with well-trained experts and brought to the place where energy need is acute.

Such an offshore nuclear power plant has been designed to provide 400 MW electricity to the main electricity supply using U-235 as the reactor material. The nuclear power plant converts 75 % of the nuclear energy into electricity and generates electricity for 10 years continuously. Take the mean energy released per U-235 nucleus is equal to the value obtained in part (e) (iii).

Take 1 year =  $3.3 \times 10^7 \text{ s}$ .

- Write down Einstein's mass-energy equivalence equation and define the symbols used.
- Calculate the corresponding **equivalent** mass to the nuclear energy generated during 10 years. Give your answer in grams (g) to the nearest integer.
- Calculate the mass of U-235 consumed in the nuclear power plant to produce electricity during 10 years. Give your answer in kilograms (kg) to the nearest integer.
- Why is **not** essential to consider the decay of U-235 in the above calculation? Half-life of U-235 is  $7.0 \times 10^8 \text{ years}$ . Avoid doing any calculation.

\* \* \*