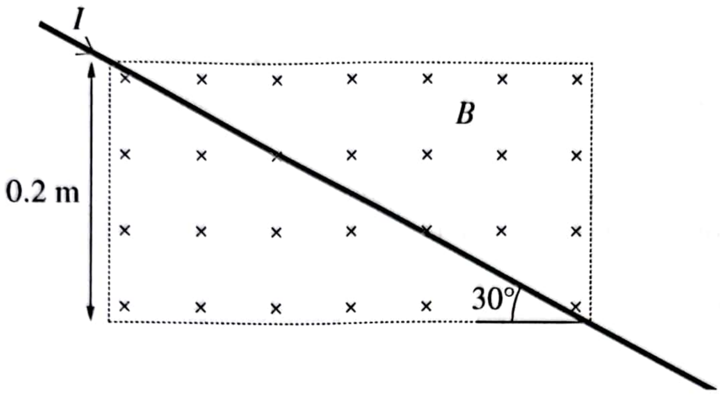
6.2 The Motor Effect

Multiple-choice questions: 1 mark each

1. A current-carrying wire passes through a region of uniform magnetic field, magnitude 0.05 T, and as a result experiences a force of magnitude 0.03 N.



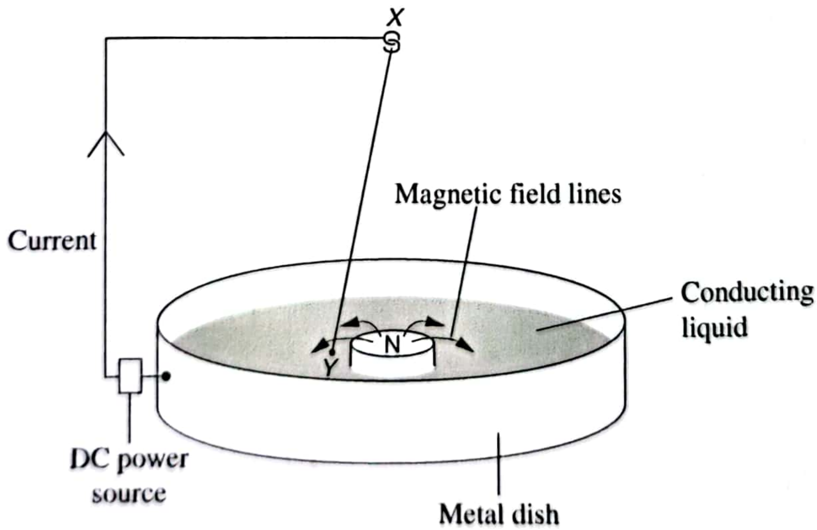
What is the current I?

(A) 1.5 A (B) 1.7 A

(C) 3.0 A (D) 6.0 A

2012 HSC Q8

2. The diagram shows equipment attached to a battery.



In which direction will the wire XY move?

(A) Clockwise

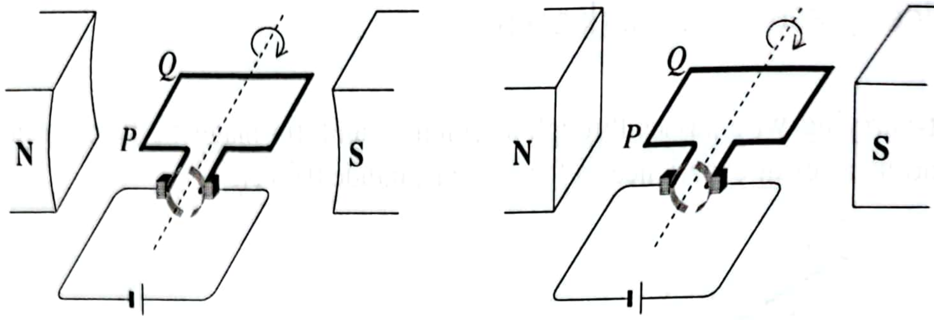
(B) Anticlockwise

(C) Towards the magnet

(D) Away from the magnet

2013 HSC Q3

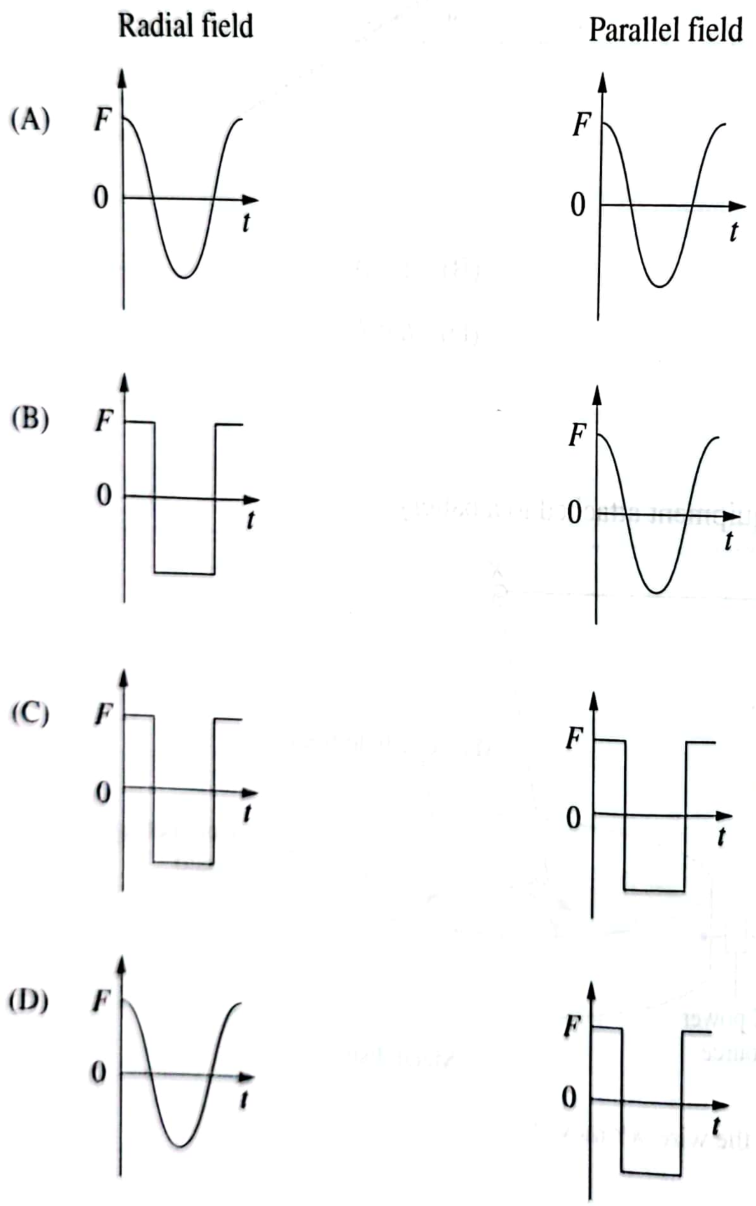
3. The diagrams show a wire loop rotating clockwise in a radial magnetic field and in a parallel magnetic field. There is a constant current in the wire loop.



Radial magnetic field

Parallel magnetic field

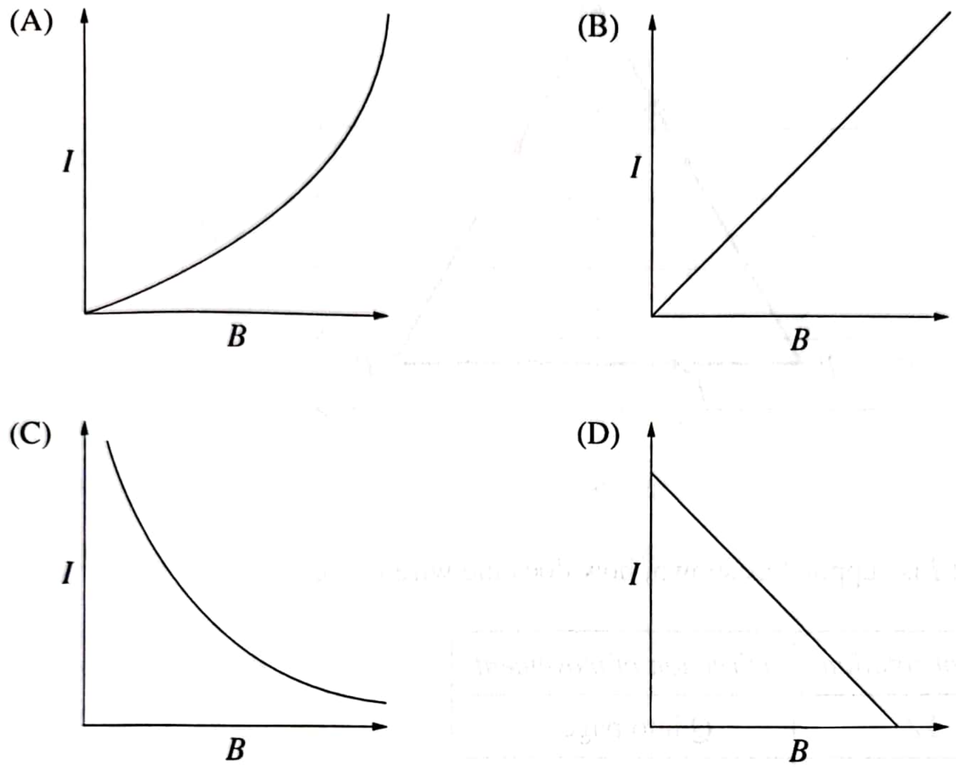
Which pair of graphs best describes the behaviour of the force (F) on the length of wire PQ as a function of time (t) for one revolution of the wire loop?



2014 HSC Q12

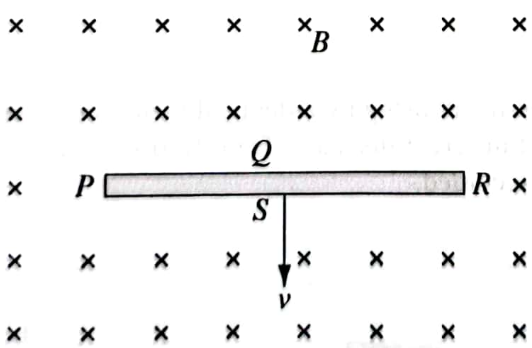
4. A current-carrying wire is placed perpendicular to a magnetic field.

Which graph correctly shows the relationship between magnetic field strength (B) and current (I) if the force is to remain constant?



2015 HSC Q7

5. A thin solid conductor with sides $PQRS$ is moving at constant velocity v, at right angles to a uniform magnetic field B, directed into the page as shown.



Which side of the conductor has the greatest concentration of electrons?

(A) P

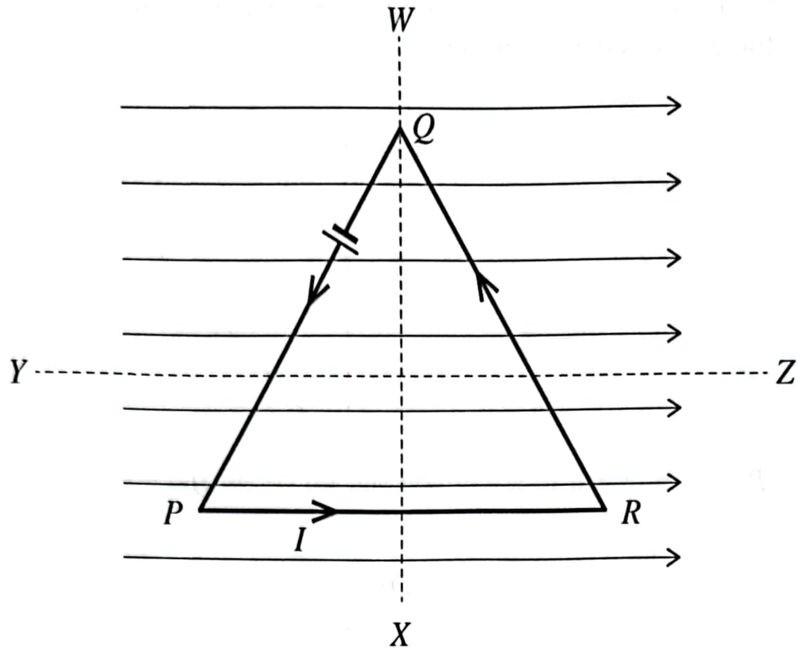
(B) Q

(C) R

(D) S

2009 HSC Q9

6. A triangular piece of wire is placed in a magnetic field as shown.

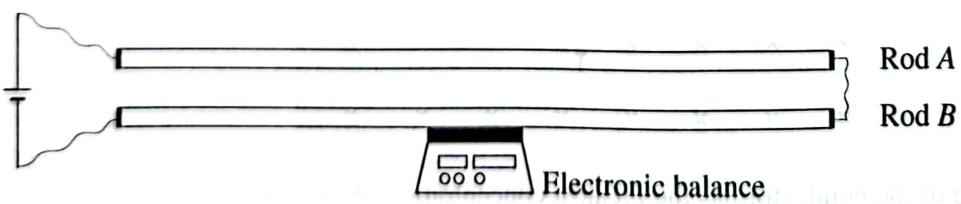


When current I is supplied as shown, how does the wire move?

	Axis of rotation	*Direction of movement*
A.	*YZ*	*Q* into page
B.	*YZ*	*Q* out of page
C.	*WX*	*R* into page
D.	*WX*	*R* out of page

2017 HSC Q13

7. A student performed an experiment using two identical metal rods connected to a power supply. Rod *A* was placed at different distances from Rod *B*, and the measurements on the electronic balance were recorded.



Which is the independent variable?

(A) The length of the rods

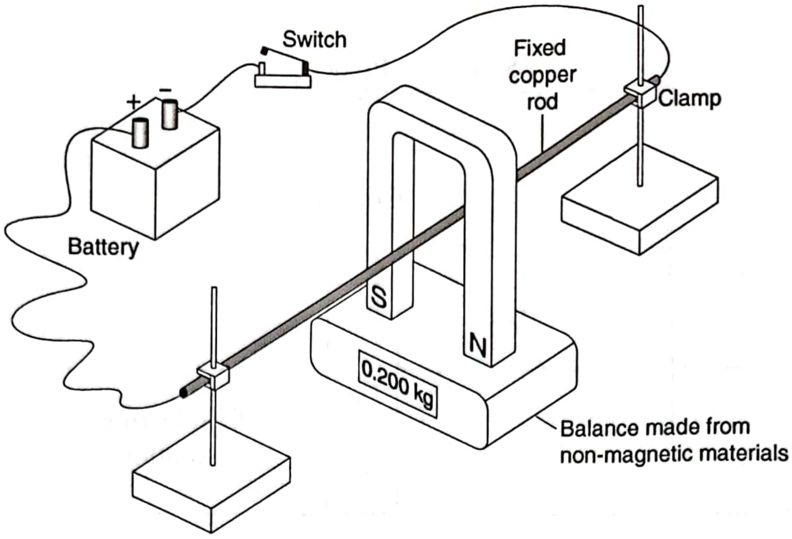
(B) The current in Rod *A*

(C) The mass recorded on the balance

(D) The distance between the two rods

2011 HSC Q10

8. A magnet rests on an electronic balance. A rigid copper rod runs horizontally through the magnet, at right angles to the magnetic field. The rod is anchored so that it cannot move.



Which expression can be used to calculate the balance reading when the switch is closed?

A. 0.200 kg + BIl

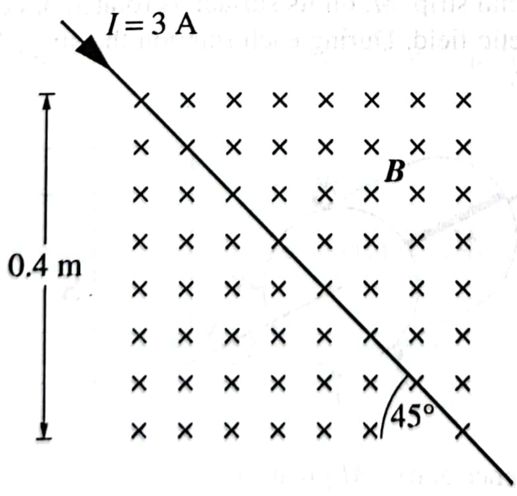
B. 0.200 kg + $\dfrac{BIl}{9.8}$

C. 0.200 kg − BIl

D. 0.200 kg − $\dfrac{BIl}{9.8}$

2017 HSC Q17

9. A current-carrying conductor passes through a square region of magnetic field, magnitude 0.5 T, as shown in the diagram. The magnetic field is directed into the page.



What is the magnitude of the magnetic force on the conductor?

(A) 0.170 N

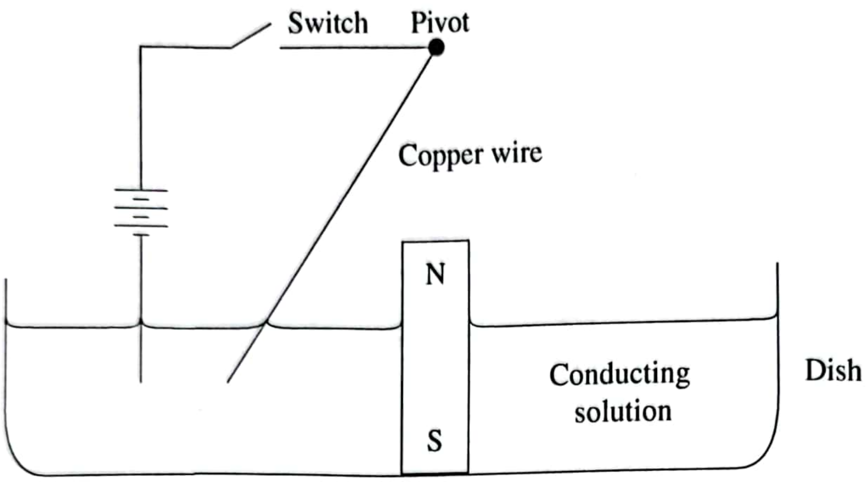
(B) 0.424 N

(C) 0.600 N

(D) 0.849 N

2006 HSC Q7

10. The diagram shows a magnet standing on the bottom of a dish filled with a conducting solution. A copper wire is suspended freely from a point above the magnet with its tip in the conducting solution. It is held in the position shown.



The switch is closed and the wire released.

Which of the following will be observed?

(A) The wire will rotate about the magnet.

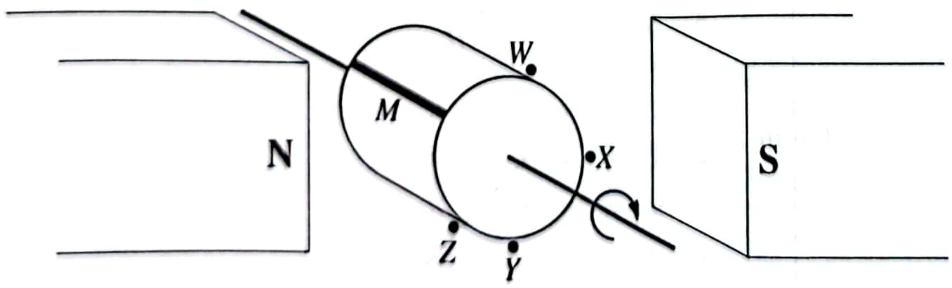
(B) The wire will be attracted to the magnet.

(C) The magnet will rotate about its vertical axis.

(D) The solution in the dish will rotate about the magnet.

2006 HSC Q6

11. A plastic cylinder with a metal strip, M, on its surface is rotated at constant speed about its axis, in a uniform magnetic field. During each rotation the strip, M, passes locations W, X, Y and Z shown below.



When is the potential difference across M greatest?

(A) As M passes W.

(B) As M passes X.

(C) As M passes Y.

(D) As M passes Z.

2008 HSC Q8

12. Two straight metal rods, P and Q, have the same length. They are each pivoted at one end and rotated with the same angular velocity so that they sweep out horizontal circular paths as shown in diagrams X and Y. A constant current I is flowing along each rod, as shown.

In diagram X, a constant magnetic field is applied *at right angles to the plane* of the circular path. In diagram Y, a uniform magnetic field of the same magnitude is applied *in the plane* of the circular path.

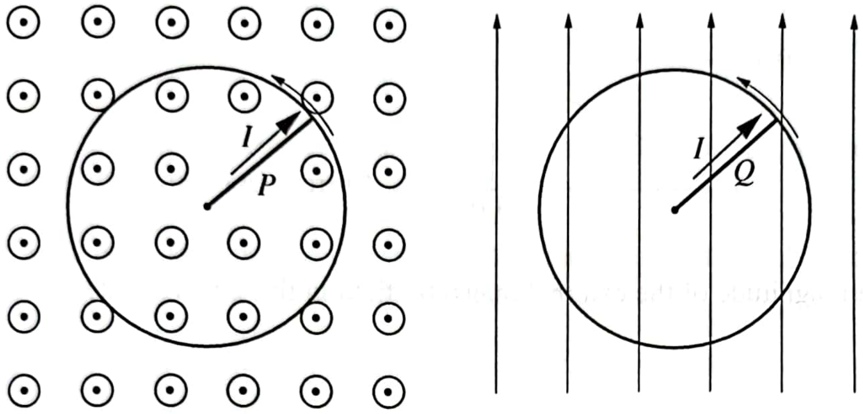


Diagram X Diagram Y

Which of the following statements about the forces acting on rod P and rod Q is correct?

(A) The magnitude of the force on P is exactly the same as the magnitude of the force on Q at all times.

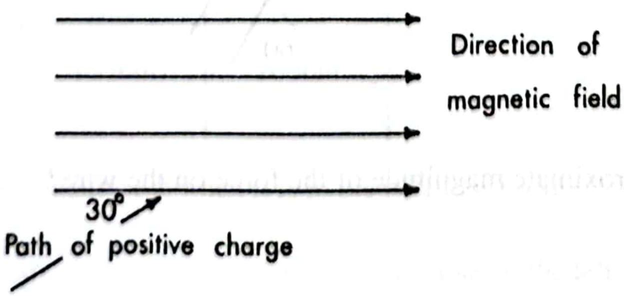
(B) The magnitude of the force on P is constant and the magnitude of the force on Q is zero.

(C) The magnitude of the force on P is constant and the magnitude of the force on Q varies with time.

(D) The magnitude of the force on P varies with time and the magnitude of the force on Q is constant.

2001 HSC Q14

13. The diagram below shows a positive charge entering a magnetic field at an angle of 30° to the field direction.



What is the direction of the magnetic force on this charge?

(A) Out of the page

(B) Into the page

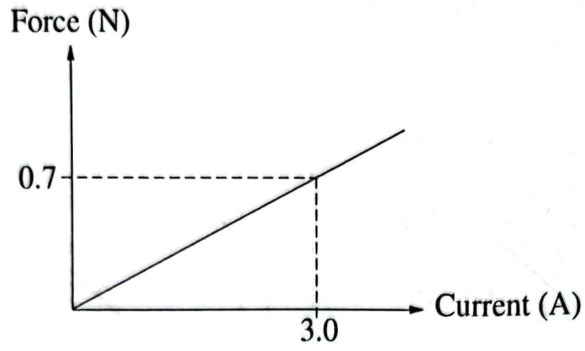
(C) To the left of the page

(D) To the right of the page.

1987 HSC Q8

14. A student performed an experiment to measure the force on a long current-carrying conductor placed perpendicular to an external magnetic field.

The graph shows how the force on a 1.0 m length of the conductor varied as the current through the conductor was changed.



What was the magnitude of the external magnetic field in this experiment?

(A) 0.23 T

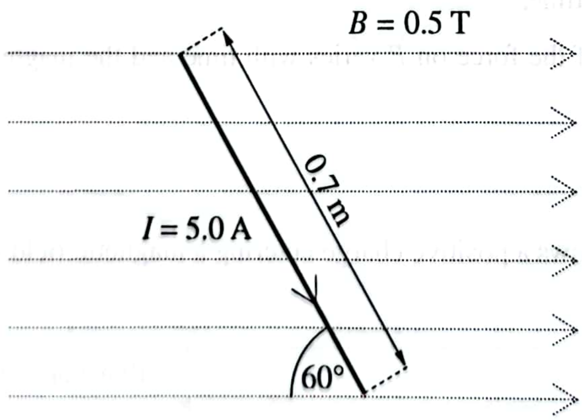
(B) 1.1 T

(C) 2.1 T

(D) 4.3 T

2002 HSC Q7

15. A current of 5.0 A flows in a wire that is placed in a magnetic field of 0.5 T. The wire is 0.7 m long and is at an angle of 60° to the field.



What is the approximate magnitude of the force on the wire?

(A) 0 N

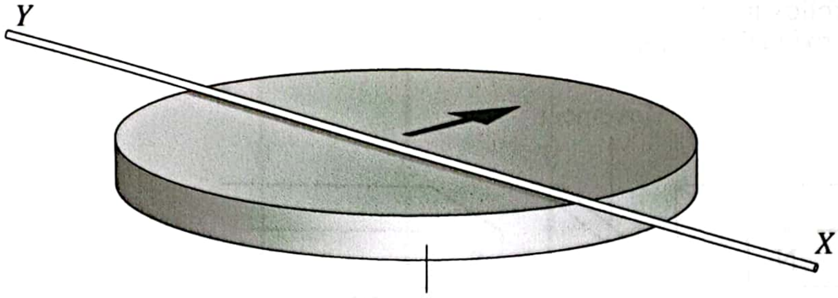
(B) 0.9 N

(C) 1.5 N

(D) 1.8 N

2003 HSC Q9

16. A disc magnet has its poles on its opposing flat surfaces. An insulated copper wire was placed on the disc magnet as shown in the diagram.



The instant the wire was connected to a DC battery, the wire was observed to move in the direction of the arrow.

Which statement describes the direction of the magnet's field and the direction of the current in the wire, consistent with this observation?

(A) The field was vertically upward and the current was from X to Y.

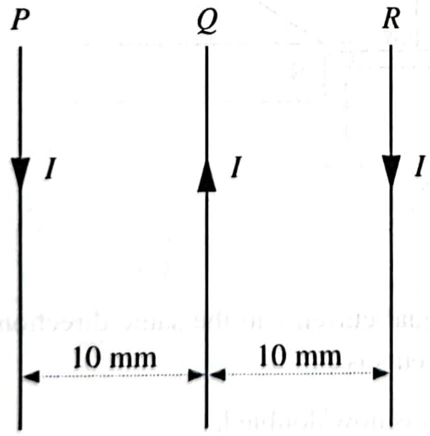
(B) The field was vertically upward and the current was from Y to X.

(C) The field was in the direction of the arrow and the current was from X to Y.

(D) The field was in the direction of the arrow and the current was from Y to X.

2004 HSC Q10

17. P, Q and R are straight, current-carrying conductors. They all carry currents of the same magnitude (I). Conductors P and Q are fixed in place. The magnitude of the force between conductors Q and R is F newtons.



What is the net force on conductor R when it is in the position shown?

(A) $\frac{F}{2}$ newtons to the left

(B) $\frac{F}{2}$ newtons to the right

(C) $\frac{3F}{2}$ newtons to the left

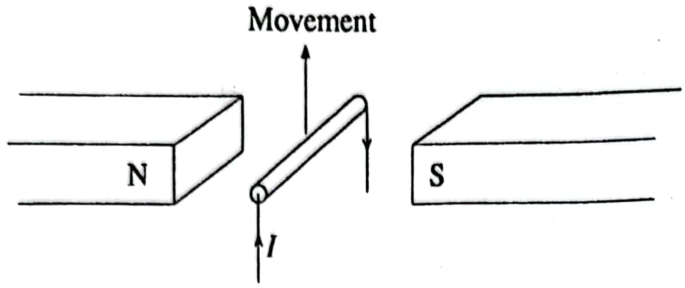
(D) $\frac{3F}{2}$ newtons to the right

2015 HSC Q9

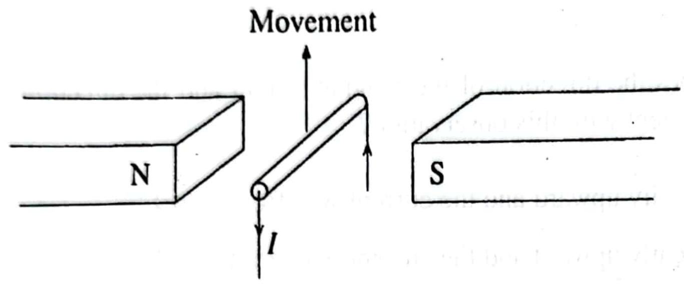
18. A thin metal rod was placed between the poles of a magnet. A current was passed through the rod. This current caused the rod to move vertically upwards.

Which of the following diagrams correctly shows the direction of the current, I, and the position of the rod in the magnetic field?

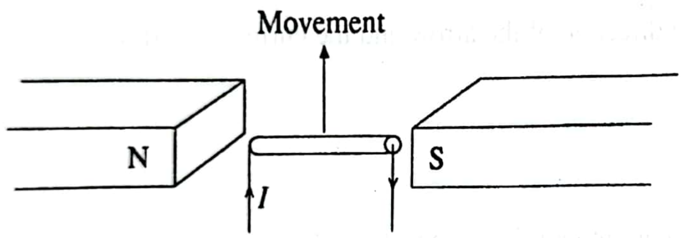
(A)



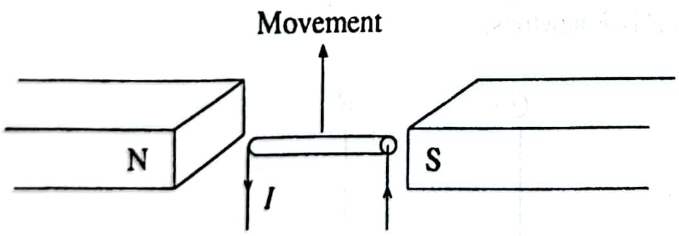
(B)



(C)



(D)



1996 HSC Q12

19. Two long parallel wires carry equal currents in the same direction. The magnitude of the force between the wires due to the currents is F.

The separation between the wires is now doubled.

What is the force now between the wires due to the same current?

(A) Magnitude F/2 and attractive

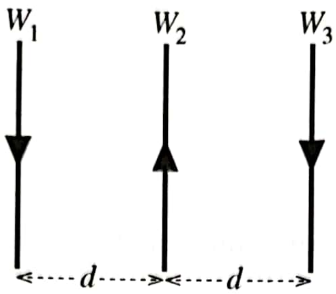
(B) Magnitude F/2 and repulsive

(C) Magnitude F/4 and attractive

(D) Magnitude F/4 and repulsive

1984 HSC Q6 (adapted)

20. Three identical wires W_1, W_2 and W_3 are positioned as shown. Each carries a current of the same magnitude in the direction indicated.



What is the magnitude and direction of the resultant force on W_2?

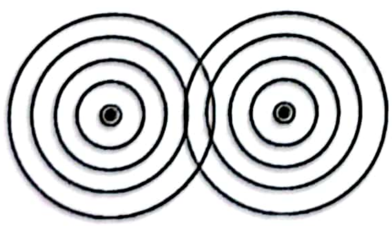
	Magnitude	*Direction*
(A)	Zero	None
(B)	Non zero	To the left
(C)	Non zero	To the right
(D)	Non zero	Out of the page

2008 HSC Q6

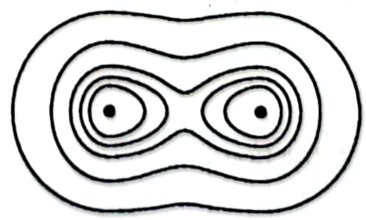
21. Two parallel wires carry currents in the same directions. The wires are viewed from the two ends as shown in the diagram.

Which of the following diagrams best represents the magnetic field in the region near the two wires?

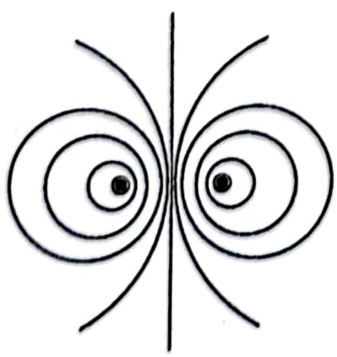
(A)



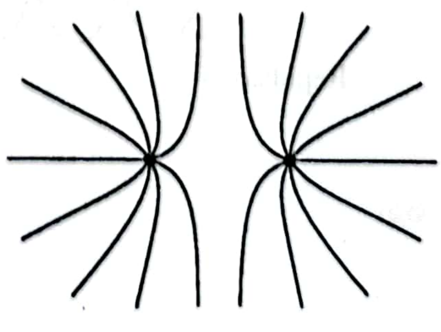
(B)



(C)

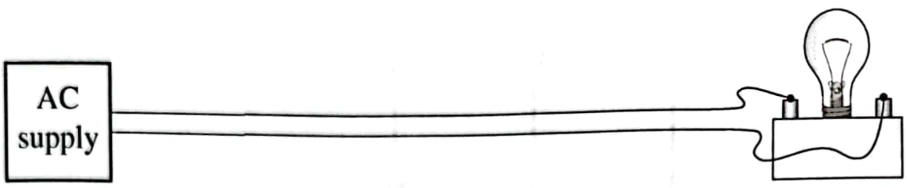


(D)

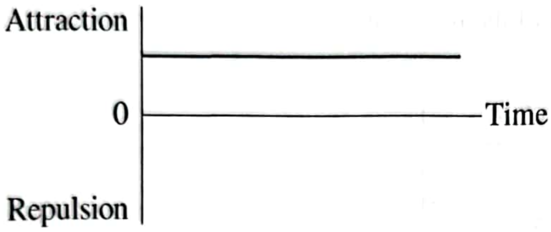


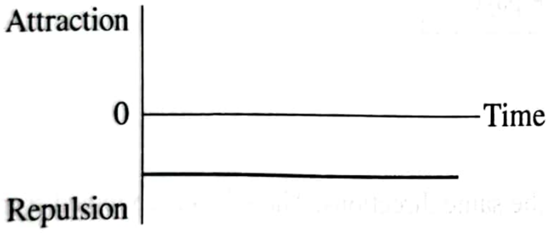
1996 HSC Q11

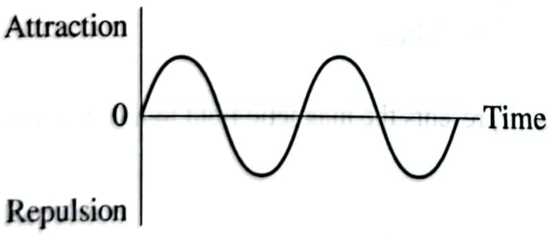
22. An AC supply is connected to a light bulb by two long parallel conductors as shown.

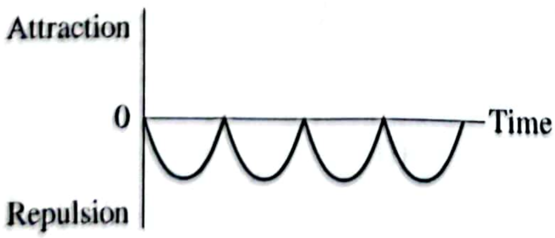


Which graph shows the variation over time of the magnetic force between the two conductors?

A.


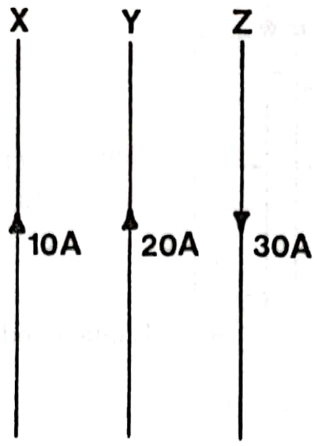
B.


C.


D.


2017 HSC Q16

23. X, Y and Z are three equally spaced long parallel straight wires in air. They carry currents of magnitudes and directions as shown in the diagram below.



What is the direction of the resultant force on Y?

(A) To the right.

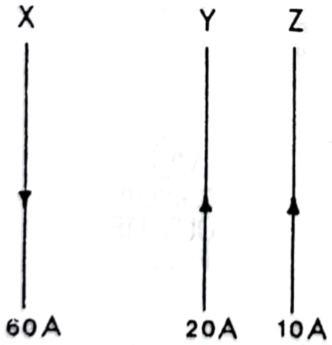
(B) To the left.

(C) Perpendicular to this page.

(D) The same as that of the current in Y.

1988 HSC Q10

24. X, Y and Z are three long parallel straight wires in air, carrying currents, as shown in the diagram below. The distance between X and Y is twice the distance between Y and Z.



What is the direction of the resultant force on Y?

(A) To the right.

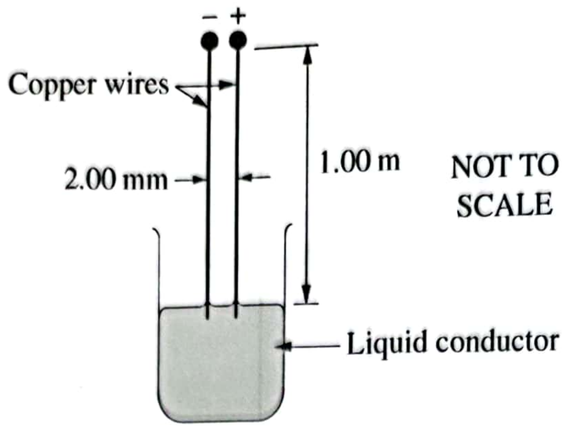
(B) To the left.

(C) Into the page.

(D) Out of the page.

1989 HSC Q10

25. The following equipment is attached to a DC power supply.



What current must be flowing through the wires to result in a force of 2.50×10^{-3} N between them?

(A) 0.224 A

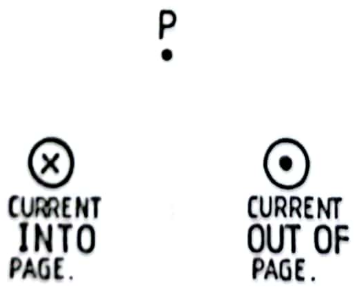
(B) 5.00 A

(C) 12.5 A

(D) 25.0 A

2012 HSC Q17

26. Two parallel conductors carry the same current in opposite directions as shown. A point P is equidistant from both wires.



Which arrow best shows the direction at P of the magnetic field resulting from these two currents?

(A) ↑

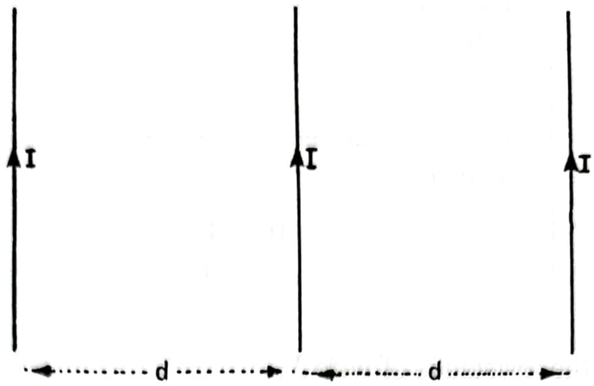
(B) ↓

(C) ←

(D) →

1983 HSC Q9

27. This question refers to the following diagram. Three identical, thin, long parallel wires all carry a current I in the direction shown. The separation between the wires is d.



What is the total magnetic force on the middle wire?

(A) zero

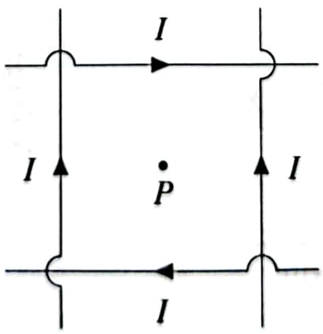
(B) non-zero and directed out of the page

(C) non-zero and directed towards the left of the page

(D) non-zero and directed towards the right of the page.

1982 HSC Q9 (adapted)

28. Four wires in a horizontal plane each carry a current I in the directions shown. They cross each other without touching to form a square as shown in the diagram below. Point P is at the centre of the square.



The strength of the magnetic field at P due to ONE wire only is B. The strength and direction of the magnetic field at P due to all four wires is

(A) $3B$ out of the page.

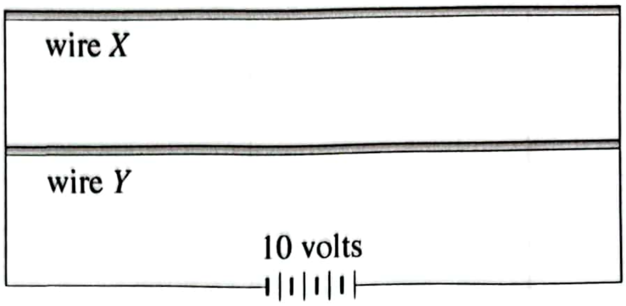
(B) $2B$ out of the page.

(C) $3B$ into the page.

(D) $2B$ into the page.

1995 HSC Q12

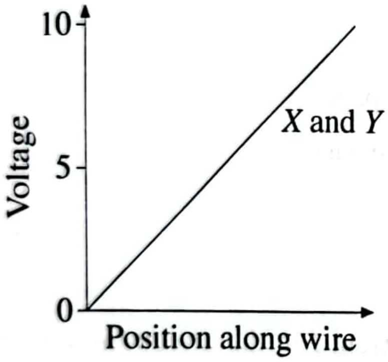
29. A circuit contains two resistance wires in parallel. A 10 V potential difference is applied to it as shown.



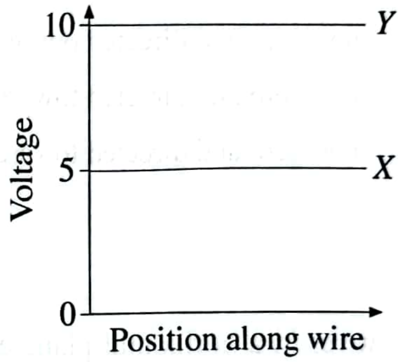
Wire *Y* has twice the resistance of wire *X*.

Which of the following graphs best represents the way the voltage varies along the length of each of the wires?

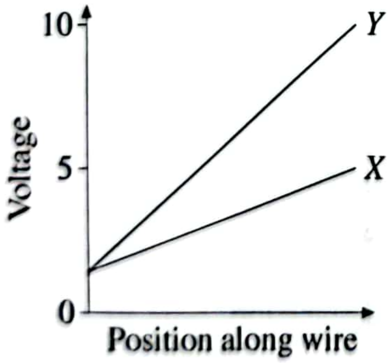
(A)



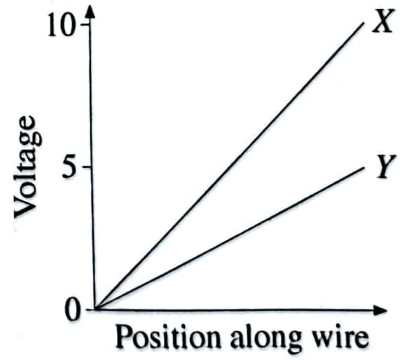
(B)



(C)

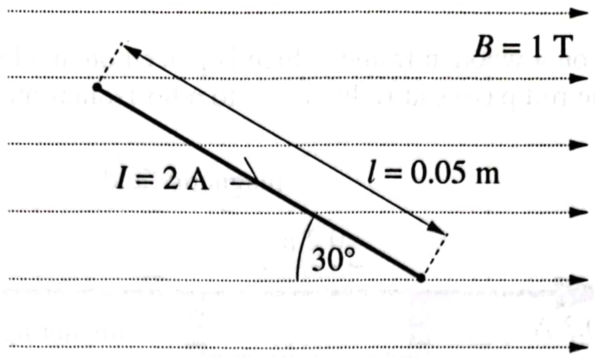


(D)



1995 HSC Q9

30. The diagram shows a current-carrying conductor in a magnetic field.



What is the magnitude of the force on the conductor?

A. 0 N

B. 0.05 N

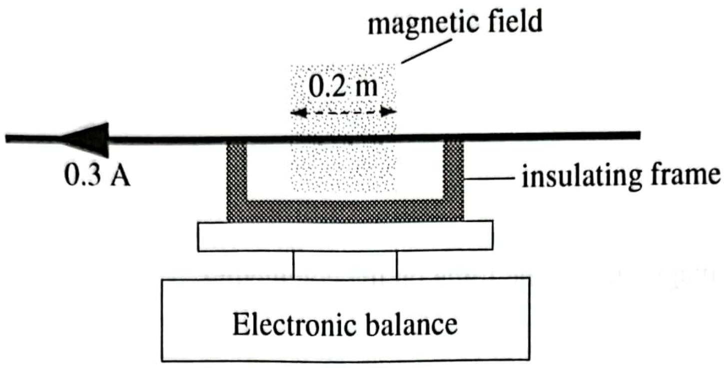
C. 0.09 N

D. 0.10 N

2018 HSC Q5

Short-answer questions

31. A copper rod is placed on a wooden frame, which is placed on an electronic balance. A length of 0.2 m of the rod passes at right angles to a horizontal magnetic field.



When a current of 0.3 A is passed through the rod, the reading on the balance increases by 7.5×10^{-4} kg.

What is the strength and direction of the magnetic field?

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2010 HSC Q28 – 4 marks

32. A straight piece of wire of length 1.5 m has a resistance of 2.5 ohms. The wire is placed in a large uniform magnitude field of strength 4.0×10^{-3} T. The wire is perpendicular to the direction of the field.

If a potential difference of 10 V is applied between the ends of the wire, what is the magnitude of the magnetic force on the wire? Show your working.

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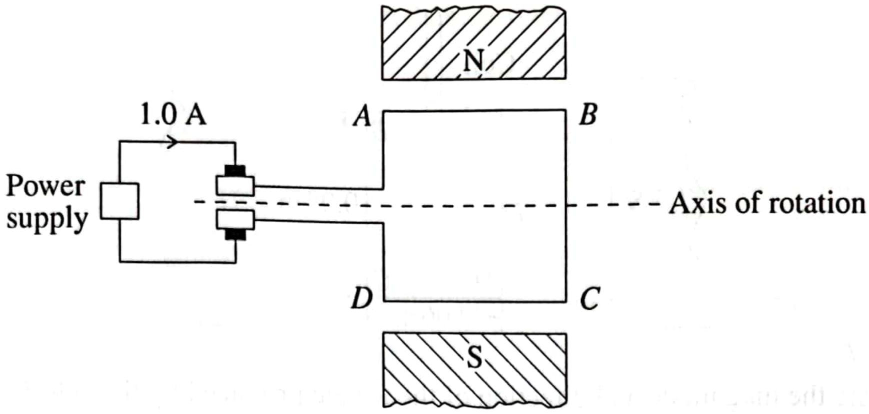
1982 HSC Q17 – 3 marks

33. The diagram represents a simple DC motor. A current of 1.0 A flows through a square loop *ABCD* with 5 cm sides in a magnetic field of 0.01 T.



(a) Determine the force acting on section *AB* and the force acting on section *BC* due to the magnetic field, when the loop is in the position shown.

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(b) How is the direction of the torque maintained as the loop rotates 360° from the position shown?

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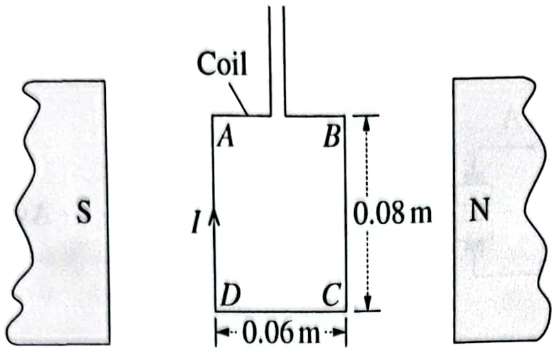
2015 HSC Q22 – 3 + 2 = 5 marks

34. A coil consisting of 15 turns is placed in a uniform 0.2 T magnetic field between two magnets. A current of 7.0 amperes flows in the direction shown.



Calculate the magnitude and direction of the torque produced by the side *BC* of the 15-turn coil.

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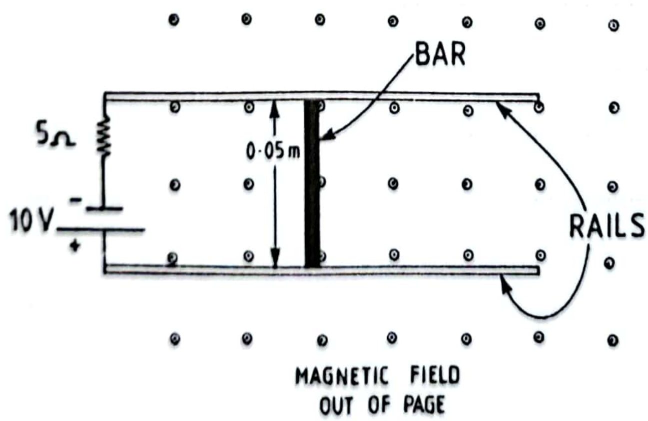
2017 HSC Q22(b) adapted – 3 marks

35. The diagram shows a 10 V battery connected to a 5 Ω resistor and to two parallel metal rails. A metal bar can slide along the rails without friction. There is a current of 2 A in the metal bar. The mass of the bar is 0.01 kg and its length is 0.05 m.

A uniform magnetic field of 0.1 T is directed out of the plane of the paper.



What is the magnitude and direction of the force acting on the bar due to the current?

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1984 HSC Q16 – 3 marks

36. Two very long parallel wires each carry a current of 9.0 A in opposite directions. These wires are separated by a distance of 4.0 cm.

(a) Calculate the force per metre between these two wires, given that ampere's constant, k, is 2×10^{-7} N s^2 C^{-2}.

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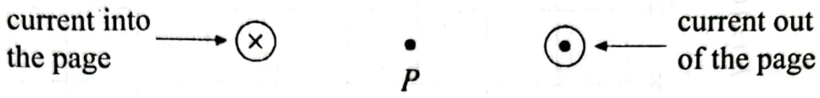
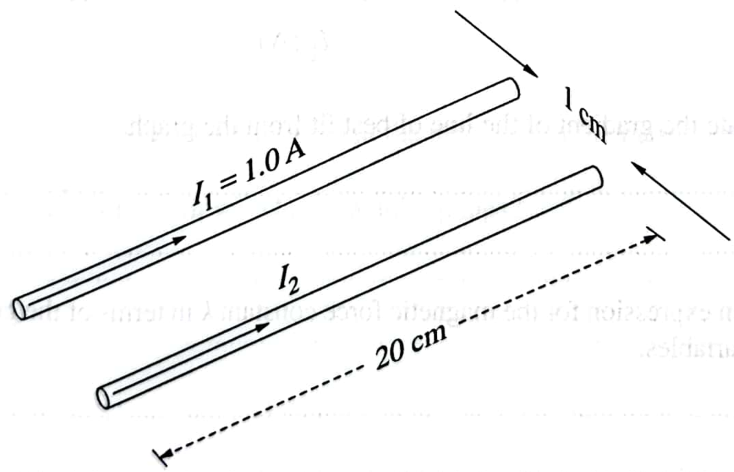
(b) On the diagram below, show the direction of the magnetic flux at a point, P, midway between the two wires.



1995 HSC Q22 – 2 + 1 = 3 marks

37. The diagram shows part of an experiment designed to measure the force between two parallel current-carrying conductors.

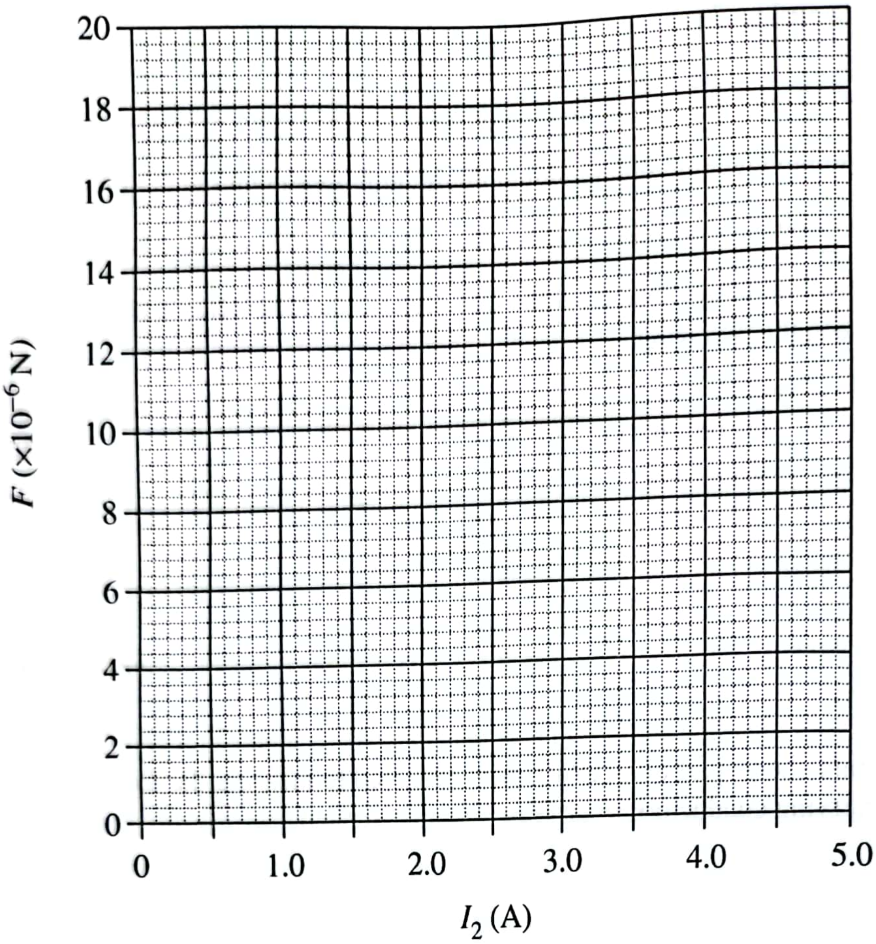


The experimental results are tabulated below.

I_2 (A)	Force ($\times 10^{-6}$ N)
0	0
2.0	7
3.0	11
4.0	14
5.0	18

Question 37 continues

(a) Plot the data and draw the line of best fit.



(b) Calculate the gradient of the line of best fit from the graph.

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(c) Write an expression for the magnetic force constant k in terms of the gradient and other variables.

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(d) Use this expression and the gradient calculated in part (b) to determine the value of the magnetic force constant k.

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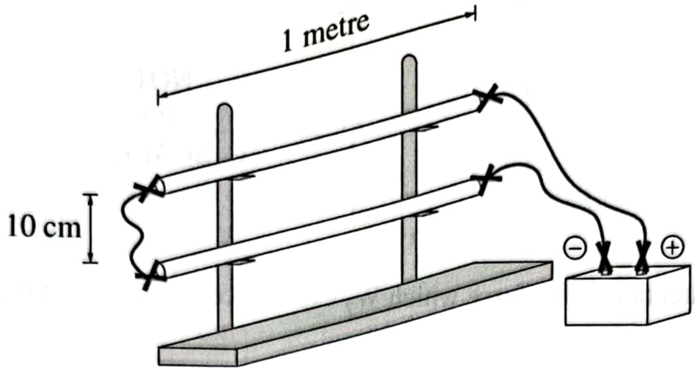
End of Question 37

2004 HSC Q26 – 3 + 1 + 2 + 1 = 7 marks

38. Two thin metal tubes one metre long were supported in a vertical wooden rack as shown in the diagram.



The two ends were connected together, then the other two ends were connected briefly to a car battery as shown in the diagram. It was observed that one of the tubes jumped upward as the connection was made.

(a) Explain why only one tube jumped upward.

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(b) Each tube has a mass of 1×10^{-2} kg, and the tubes lie on the rack 10 cm apart.

What minimum current flows when one tube jumps?

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(c) What is the implication of this result for power distribution networks?

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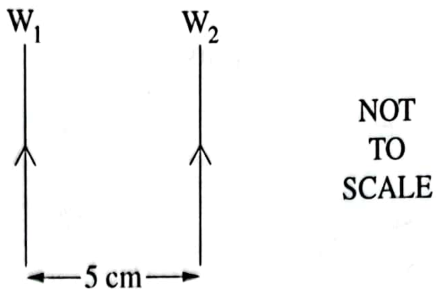
2005 HSC Q21 – 2 + 3 + 1 = 6 marks

39. Two identical wires, W_1 and W_2, each 2.5 m in length, are positioned as shown. They carry identical currents in the direction indicated.



(a) Identify the direction of the force which W_2 experiences as a result of the current in W_1.

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(b) Calculate the current in each wire, given that the two wires experience a force of 6.9×10^{-4} N.

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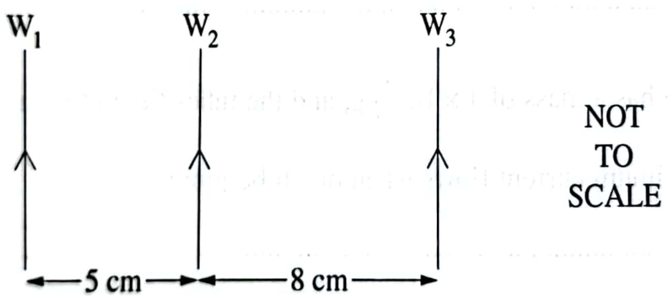
(c) A third wire, W_3, carrying a smaller current, is now placed as shown.



Explain qualitatively the forces on W_2 as a result of the currents in W_1 and W_3.

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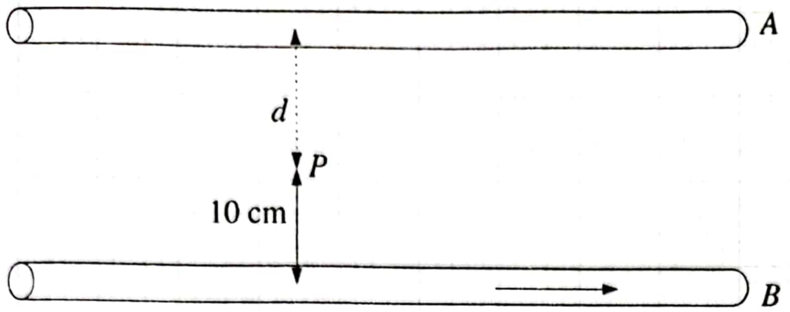
2009 HSC Q23 – 1 + 2 + 3 = 6 marks

40. Two current-carrying wires are placed parallel to each other shown below.

The magnetic field is measured at point P, a perpendicular distance of 10 cm from wire B and a perpendicular distance d from wire A.

(The diagram is not drawn to scale.



Readings are taken of the magnetic field strength and direction at P due to the current in both wires. The current in wire A was varied, as shown in the table below. The current in wire B was kept constant throughout the experiment.

Current in wire A (amperes)	*Field direction at P*	*Field strength at P* (tesla)
0	Out of page	$3{\cdot}4\times10^{-6}$
0·4	Out of page	$4{\cdot}4\times10^{-6}$
0·7	Out of page	$4{\cdot}9\times10^{-6}$
1·5	Out of page	$6{\cdot}7\times10^{-6}$
2·1	Out of page	$8{\cdot}0\times10^{-6}$
2·9	Out of page	$9{\cdot}7\times10^{-6}$

(a) Calculate the magnitude of the current in wire B. Show your working.

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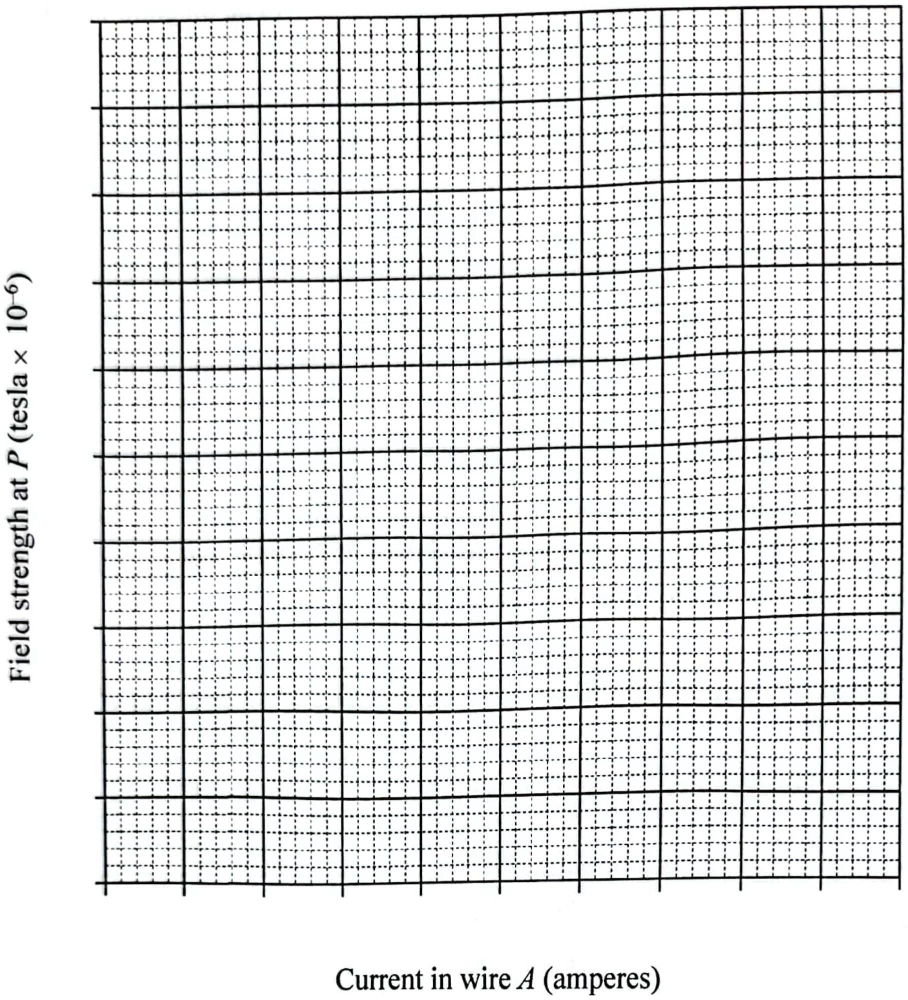
Question 40 continues

Question 40 (continued)

(b) Plot the results on the grid below. Draw a straight line of best fit.



(c) Calculate the slope of your line of best fit.

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(d) Use your answer to part (c) to calculate the value of the distance d.

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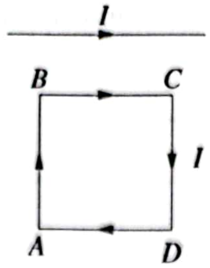
End of Question 40

1997 HSC Q30 – 2 + 2 + 2 + 2 = 8 marks

41. A square current-carrying wire loop is placed near a straight current-carrying conductor, as shown in the diagram.



Explain how the current in the wire loop affects the straight conductor.

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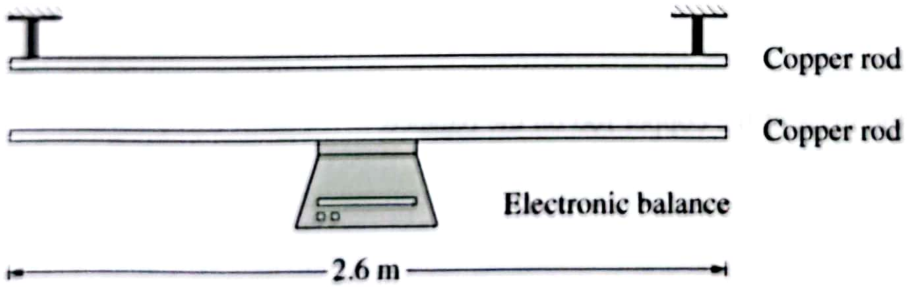
2014 HSC Q23 – 3 marks

42. A balance was used to investigate the relationship between current and force. The balance was set up with one copper rod fixed to it and a second rod fixed above it, as shown in the diagram. Each rod was connected to a source of current. The diagram is not to scale.



The copper rods were rigid, each was 2.6 m long, and they were parallel. The current in the upper rod was kept constant at 50 A. Different currents were passed through the lower rod and the balance reading recorded for each current. The readings are given in the table below.

Current in lower rod (A)	*Balance reading* (kg)
2.8	0.5485
8.0	0.5480
12.2	0.5474
16.8	0.5470
20.0	0.5465

Question 42 continues

Question 42 (continued)

(a) Identify the relative directions of the currents in both rods, and justify your answer.

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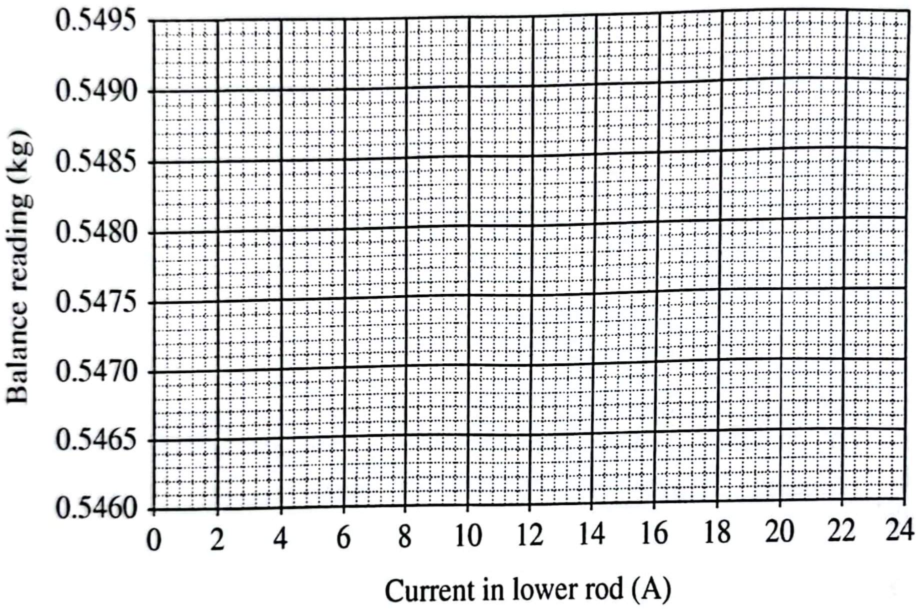
(b) Plot the data from the table onto the graph, using the scales and axes as indicated, and add the line of best fit (trend line).



(c) Find the mass of the copper rod on the balance.

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(d) Calculate the distance between the two copper rods.

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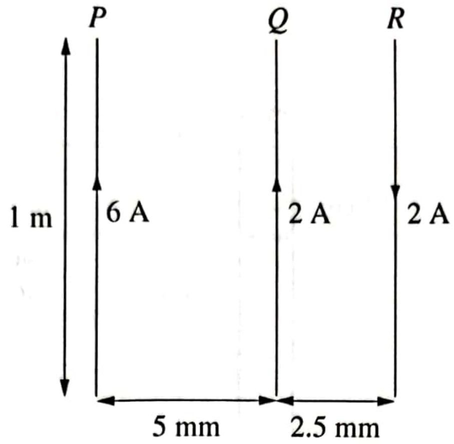
End of Question 42

2006 HSC Q20 – 2 + 2 + 1 + 3 = 8 marks

43. *P*, *Q* and *R* are straight current-carrying conductors.

Conductors *P* and *R* are fixed and unable to move. Conductor *Q* is free to move.



(a) In which direction will the conductor *Q* move as a result of the current flow in *P* and *R*?

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(b) Calculate the magnitude of the force experienced by *Q* as a result of the currents through *P* and *R*.

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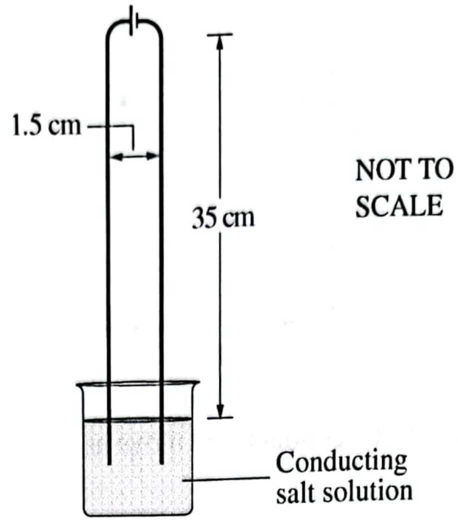
2013 HSC Q25 – 2 + 2 = 4 marks

44. Two straight copper wires are suspended so that their lower ends dip into a conducting salt solution in a beaker as shown. The length of the straight section of each wire above the conducting salt solution is 35 cm and they are placed 1.5 cm apart. The ends of the wire do not touch the bottom of the beaker. The two wires are connected to a DC power supply.



A current of 2 amperes flows from the battery. Calculate the magnitude and direction of the initial force on each wire.

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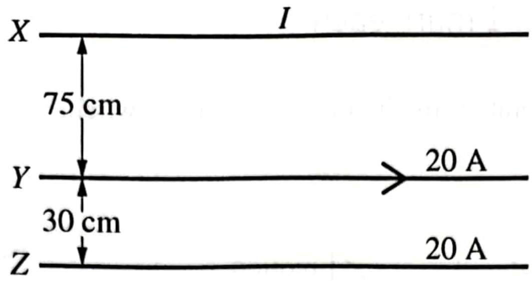
2003 HSC Q19 – 3 marks

45. Three parallel wires X, Y and Z all carry electric currents. A force of attraction is produced between Y and Z. There is zero net force on Y.



What is the magnitude and direction of the current in X?

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2018 HSC Q24 – 3 marks

6.2 The Motor Effect

Multiple choice: 1 mark each

1. A	2. A	3. C	4. C	5. A	6. C	7. D	8. B
9. D	10. A	11. B	12. C	13. B	14. A	15. C	16. A
17. B	18. B	19. A	20. A	21. B	22. D	23. B	24. A
25. B	26. B	27. A	28. D	29. A	30. b		

Explanations:

1. **A** $F = B\,I\,l\sin\theta$

$$0.03 = 0.05 \times I \times \frac{0.2}{\sin 30} \times \sin 90$$

$$\therefore I = \frac{0.03 \times \sin 30}{0.5 \times 0.2} \times \sin 90$$

$= 1.5$ A ... as in (A).

2. **A** This is similar to Faraday's original electric motor. When current flows through the wire from X towards Y, it produces an electromagnetic field that interacts with the magnetic field of the fixed permanent magnet. Looking downward from X, the electromagnetic field will be clockwise around the conductor. The force on the wire will be perpendicular to both the conductor and field lines of the magnet towards the direction where the overall field strength is lowest. So the wire will move in a clockwise direction (as viewed from above this apparatus). So (A) is the answer.

3. **C** Force on PQ, $F = BIl\sin\theta$. In both fields, B, I and l remain constant, while the loop is rotating between the magnetic poles. The angle θ is also constant at 90°. So the force, F, is constant in magnitude. However, F reverses direction twice per revolution as the split ring commutator causes the current in PQ to reverse direction each time the coil turns through the vertical plane. Hence, F as a function of time results in square waveforms for both fields, as shown in (C).

[Note: The purpose of the radial field is to maintain the force at right angles to the plane of the wire loop for a greater portion of each revolution. This makes the torque uniform for a bigger part of each revolution, allowing smoother operation of the motor with a radial magnetic field.]

4. **C** $F = B\,I\,l\,\sin\theta$

Since l is perpendicular to B, $\theta = 90°$ So $F = B\,I\,l$.

$\therefore$ if F remains constant, $I \propto \frac{1}{B}$.

This relationship is only shown in (C).

5. A Since B is directed into the page and v is directed down the page, the force on the electrons will be at right angles to both and will therefore be along the length of the conductor, so neither (B) nor (D) are correct. The induced current will create a magnetic field that opposes the original change of flux (Lenz's Law) – so the induced emf will tend to produce a current from P to R. The electrons will flow from R to P and so will concentrate at P. So (A) is the answer and (B) is incorrect.

6. C For this triangular wire loop, the force on segment QP is up out of the page by the Right Hand Palm Rule (or Fleming's left hand rule.). The force on segment RQ is opposite, and so down into the page. There is no force acting on segment PR as the current in this segment is parallel to the magnetic field. The two opposite forces acting on the triangular loop result in a torque about the WX axis causing point R to move into the page. Only (C) has this combination and so is the answer.

7. D In any experiment, the independent variable is the variable changed by the experimenter. The dependent variable is the variable that changes as a result of this change. In this case, the student changes the distance between rods, so this is the independent variable. So (D) is the answer. Length of rods and current in Rod A are both constants, so (A) and (B) are incorrect. The reading on the electronic balance is the dependent variable, so (C) is incorrect.

8. B There will be an upward force on the copper rod (Right Hand Palm Rule). However, since it is anchored and unable to move, there will be an equal and opposite downward force on the magnet. This will add to the weight of the magnet. Since $F = BIl$ gives this force in Newtons, the value must be converted to kg weight by dividing by g. Hence the balance will read $0.200 \text{ kg} + \dfrac{BIl}{9.8}$ ... as in (B).

9. D To determine the force on a conductor in a magnetic field, use: $F = B\,I\,l\sin\theta$

$B = 0.5\text{ T}, I = 3\text{ A}$ and $\theta = 90°$

To calculate l, use Pythagoras' theorem: $a^2 + b^2 = c^2$, where $c = l$

Hence $l^2 = 0.4^2 + 0.4^2 = 0.32$

$\therefore l = \sqrt{0.32} = 0.5657$

$\therefore F = 0.5 \times 3 \times 0.5657 \times \sin 90 = 0.84855 \approx 0.849\text{ N}$ ... as in (D).

10. A The magnetic field spreads out three-dimensionally from the north pole of the magnet, so it is approximately at right angles to the direction of current in the wire. The force on the wire will be at right angles to the plane containing the current and the magnetic field and in this case will be into the page. As soon as the wire has moved, the force will continue to be at right angles to the wire, so the wire will display circular motion around the magnet (i.e. clockwise motion, as viewed from above). The only possible answer is therefore (A).

11. B Faraday's Law of Induction states that the induced emf (potential difference) in a conductor depends on the rate of change of magnetic flux ($\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$). The induced potential difference in the metal strip, M will be greatest when M is moving at right angles to the magnetic field. This occurs at point X, so (B) is the answer. At W and Y, the metal strip is moving parallel to the magnetic field so the potential difference across M will be zero. So (A) and (C) are incorrect. At point Z, the metal strip is moving at about 45° to the magnetic field, so there will be a potential across M but it will be less than at W, so (D) is incorrect.

12. C The force on a constant current in a uniform magnetic field depends on the angle between the current and the field (a factor of $\sin\theta$). In Diagram X, angle θ is always 90° so the magnitude of the force on P is constant as in (B) and (C), and so (A) and (D) are incorrect. In Diagram Y, angle θ varies periodically from 0° to 90°, so the magnitude of the force on Q varies with time. Only (C) has the correct combination, and so (B) is incorrect.

13. B The direction of the magnetic force will be perpendicular to the direction of the magnetic field, as well as perpendicular to the velocity of the charged particle. The Right Hand Palm Rule indicates that this force is into the page … as in (B).

14. A The force, F, on a conductor of length, l, carrying a current, i, in a magnetic field, B, is given by: $F = B\,I\,l$

From the graph: force, $0.7\text{ N} = B \times 1.0\text{ m} \times 3.0\text{ A}$

$\therefore B = \frac{0.7}{3} = 0.23\text{ T}$ … as in (A).

15. C Force, F, on a conductor of length, l, carrying a current, i, in a magnetic field, B, is given by $F = B\,I\,l\sin\theta$

$\therefore F = 0.5\text{ T} \times 5.0\text{ A} \times 0.7\text{ m} \times \sin 60 = 1.52\text{ N} \approx 1.5\text{ N}$ So (C) is the answer.

16. A The field cannot be in the direction of the arrow, since the disc magnet has its poles on its opposite flat surfaces, so (C) and (D) are incorrect. The field can only be vertically up or down. Using the Right Hand Palm Rule (or the appropriate rule that you use), with the field as upwards, the force causing the motion is in the direction of the arrow, and so the current is from X to Y, as in (A). It does not go from Y to X, as in (B).

17. B Currents in P and R are equal in magnitude and in the same direction, downwards. Attractive force between P and R means that R experiences a force to the left. Currents in Q and in R are equal in magnitude, but in opposite directions. So there is a repulsive force between Q and R, which means R experiences a force to the right, given as F newton. Now $F = k\frac{I_1 I_2}{B}$, so since the separation of P and R is double that of Q and R, the force caused by P on R will be $\frac{F}{2}$ newtons to the left. Hence the net force will be $\frac{F}{2}$ =newtons to the right, as in (B).

18. B The right hand rule is used to find (B) is correct and not (A). Both (C) and (D) are incorrect as the current is parallel to the field and there will be no force.

19. A The force between two parallel conductors is given by $\frac{F}{l} = k\frac{I_1 I_2}{d}$. Therefore, if d is doubled with I_1 and I_2 unchanged, the force is halved. If the currents are in the same direction, the force is attractive. This combination is only given in (A).

20. A The current in W_2 is equal in magnitude, but in the opposite direction to the current in both W_1 and W_3. The distance of separation of wire W_2 from each of the other two wires is equal. As a result, W_2 will experience equal forces of repulsion due to each of the other two wires. These two forces will negate one another giving zero net force, so (A) is the answer, and both (B) and (C) are incorrect. Wires carrying a current either attract one another or repel one another so the net force, if any, must be in the plane of the page, so (D) is incorrect.

21. B (B) is the resultant of combining the fields in (A) and so (B) is the answer. (A) is a typical diagram representing two individual wires carrying currents in the same direction and the magnetic fields caused around each wire, before vectorially adding the fields. (C) is typical of wires with opposite currents repelling. (D) is the typical diagram of the electrostatic field around two like charges.

22. D The long conductors carry current to and from the light bulb. At every instant of time, whatever direction that the instantaneous current has in one wire, it will have the opposite direction in the second wire. So the force between the wires will always be one of repulsion and will fluctuate between a maximum repulsion and zero each half of the AC cycle. Only the graph in (D) shows this. So (D) is the answer.

23. B Parallel currents result in attraction, so Y will be attracted towards X. Opposite currents result in repulsion, so Y will be repelled away from Z. The net force on Y will be towards the left, as in (B).

24. A Force on Y due to Z is attraction (as currents are parallel).
Force on Y due to X is repulsion (as currents are opposite).
Both the force due to Z and due to X are towards the right, so the net force of both is towards the right, as in (A).

25. B $\frac{F}{l} = k\frac{I_1 I_2}{d}$ So $\frac{2.50\times10^{-3}}{1.00} = 2.0\times10^{-7}\frac{I^2}{2.00\times10^{-3}}$

$$\therefore I = \sqrt{\frac{2.50\times10^{-3}\times2.00\times10^{-3}}{1.00\times2.0\times10^{-7}}} = 5.00\text{ A}$$ ... as in (B)

26. **B** The current into the page results in a magnetic field that is clockwise around the conductor. The current coming out of the page results in a magnetic field that is anticlockwise around the conductor. The vector sum of these two fields will be down the page, as in (B).

27. **A** The three conductors all carry equal parallel currents, so the middle wire is attracted equally towards each of the equidistant outside wires. Therefore, the net force is zero, as in (A).

28. **D** Fields due to the two wires up and down the page cancel one another out because the currents are in the same direction (up page). Fields due to the two wires across the page add together (2B) as currents are opposite. Both produce a field into the page at P. So (D) is the answer.

29. **A** Voltage varies uniformly along both wires from 0 V to 10 V. Only (A) shows this.

30. **B** $F = BIl\sin\theta$

$= 1 \times 2 \times 0.05 \times \sin 30$

$= 0.05$ N ... as in (B)

31. $F = mg = BIl\sin\theta$ $\theta = 90°$, so $\sin\theta = 1$

$7.5 \times 10^{-4} \times 9.8 = B \times 0.3 \times 0.2 \times 1$

$\therefore B = \frac{7.5\times10^{-4}\times9.8}{0.3\times0.2} = 0.1225\ T$ directed into the page

32. $F = BIl$

Using $V = IR$, so $I = \frac{V}{R}$

$\therefore F = B.\frac{V}{R}.l$

$= (4.0 \times 10^{-3}) \times \frac{10}{2.5} \times 1.5$

$= 2.4 \times 10^{-2}$ N

33. (a) $F_{AB} = BIl\sin\theta$

$= 0.01\ T \times 1.0\ A \times 0.5\ m \times \sin 90°$

$= 5 \times 10^{-4}$ N into the page

(as θ is the angle of a current-carrying wire to the magnetic field through which it passes)

$F_{BC} = 0.01\ T \times 1.0\ A \times 0.5\ m \times \sin 0° = 0$ N (current is parallel to BC, so $\theta = 0°$)

$\therefore$ force acting on section AB is 5×10^{-4} N into the page, and there is no force on section BC.

(b) The commutator has a split ring that causes the current in the loop to reverse direction each 180° rotation of the loop (where $\tau = 0$). This reverses the direction of the force and so maintains the torque in one direction.

34. Force due to current flowing in side BC: $F = nBIl\sin\theta$

where $\theta = 90°$, so $\sin\theta = 1$

$F = nBIl = 15 \times 0.2 \times 7.0 \times 0.08 = 1.68$ N

$\therefore$ Torque, $\tau = Fd = 1.68 \times \frac{0.06}{2} = 0.0504$ N m ≈ 0.05 N m

The force is into the page at BC [using Right Hand Palm Rule]

$\therefore$ torque is anticlockwise as viewed from the top of the page.

[OR $\therefore$ Torque is clockwise, as viewed from the bottom of the page.]

35. $F = BIl\sin\theta$

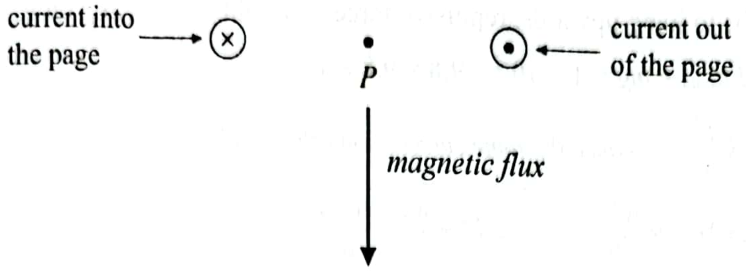
$= 0.1 \times 2 \times 0.05 \times 1$ (as $\sin 90° = 1$)

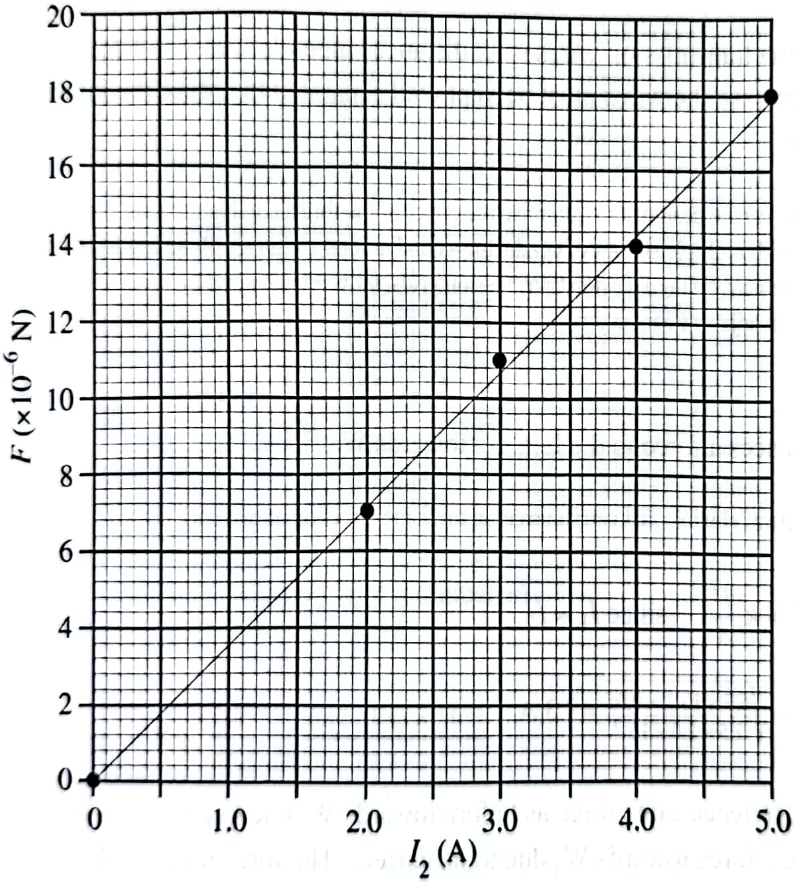
$= 0.01$ N ... towards the right *[using the Right Hand Palm Rule]*

36. (a) $\frac{F}{l} = \frac{u_0 I_1 I_2}{2\pi r} = \frac{k I_1 I_2}{r}$

$= \frac{2 \times 10^{-7} \times 9 \times 9}{4 \times 10^{-2}}$

$= 4.05 \times 10^{-4}\ \text{N m}^{-1}$

(b) 

37. (a) 

(b) Gradient of the line of best fit = $\frac{\text{rise}}{\text{run}} = \frac{(13.2 - 0) \times 10^{-6}}{3.7 - 0} = 3.57 \times 10^{-6}\ \text{N A}^{-1}$

(c) For the magnetic force between two wires: $\frac{F}{l} = k\frac{I_1 I_2}{d}$ $\quad \therefore k = \frac{Fd}{l \times I_1 I_2}$

In a graph: $y = mx + b$, so gradient $= m = \frac{F}{I_2}$ $\quad \therefore k = m\frac{d}{l \times I_1}$

(d) $k = m\frac{d}{l \times I_1} = 3.57 \times 10^{-6} \times \frac{1.0 \times 10^{-2}}{(2.0 \times 10^{-1}) \times 1.0} = 1.785 \times 10^{-7} = 1.79 \times 10^{-7}\ \text{N A}^{-2}$

38. (a) The current flowed in opposite directions through the rods, causing them to repel each other. So, force on lower rod was downwards, and force on upper rod was upwards. The lower rod could not move due to the supports, but the upper rod was free to jump upwards.

(b) For upper tube to jump upwards, repulsive force > weight force acting on it:

$$F_{weight} = mg = 1 \times 10^{-2} \times 9.8 = 9.8 \times 10^{-2}\ \text{N}$$

$$\frac{F}{l} = k\frac{I_1 I_2}{d} = k\frac{I^2}{d}$$ *(since the same current flows through both tubes)*

$$\frac{9.8 \times 10^{-2}}{1} = 2\times10^{-7} \times \frac{I^2}{0.10} \qquad \therefore\ I^2 = \frac{9.8 \times 10^{-2} \times 0.1}{2 \times 10^{-7}} = 4.9\times10^{4} \quad \text{so } I = 221.36\ \text{A}$$

At $I = 221.36$ A, repulsive force equals weight force.

$\therefore$ for upper tube to jump, $I > 221.36$ A

(c) High tension transmission wires span distances much longer than 1 m and carry quite high currents, so the wires must be kept well separated to reduce the forces they have on each other.

[Note: Cables can be designed to minimise the effect of the force, e.g. high tension conductors can be constructed with multiple strands of conductor wound around a high tensile strength steel core to minimise possible movement. In high tension transmission grids, movement caused by wind is more of a problem than forces between adjacent conductors.]

39. (a) W_2 experiences a force to the left, i.e. towards W_1.

[Note: Two parallel wires that carry current in the same direction attract each other.]

(b) $$\frac{F}{l} = k\frac{I_1 I_2}{d} = k\frac{I^2}{d} \quad \text{since } I_1 = I_2$$

$$\therefore I = \sqrt{\frac{Fd}{lk}} = \sqrt{\frac{6.9 \times 10^{-4} \times 0.05}{2.5 \times 2.0 \times 10^{-7}}} = 8.3\ \text{A}$$

(c) W_2 will experience same force as before towards W_1 due to current in W_1. W_2 will also experience a force towards W_3 due to its current. The force towards W_3 will be smaller than towards W_1 because current in W_3 is less than in W_1 and W_2, and distance between W_2 and W_3 is greater than between W_1 and W_2. There will still be a net force on W_2 towards W_1.

40. (a) I_A = variable current in wire A. I_B = constant current in wire B.

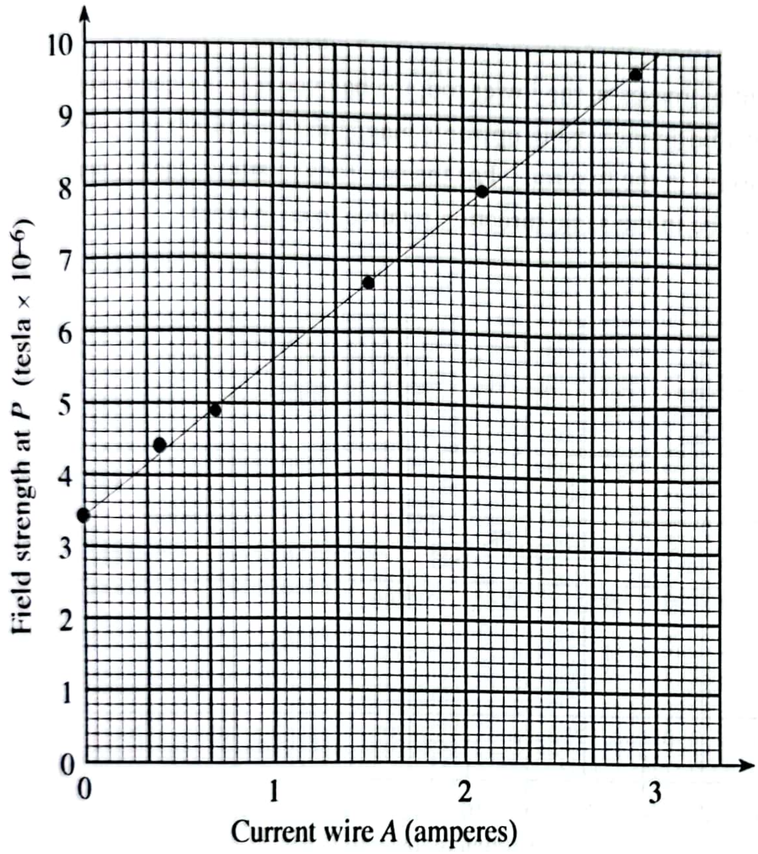
When $I_A = 0$ amp, field at P is due totally to I_B.

$$B = \frac{u_0 I_1 I_2}{2\pi r} = k \times \frac{I_B}{r}$$

$$3.4 \times 10^{-6} = 2 \times 10^{-7} \times \frac{I_B}{10^{-1}} = 2.0 \times 10^{-6} \times I_B$$

$$\therefore I_B = \frac{3.4}{2} = 1.7 \text{ A}$$

(b)



(c) Gradient of line, $\frac{dB}{dI_A} = \frac{(9.7 - 3.4) \times 10^{-6}}{(2.9 - 0)}$

$$= 2.17 \times 10^{-6} \text{ T A}^{-1}$$

(d) $B = \frac{u_0 I_A}{2\pi r} = k \times \frac{I_A}{r}$

$$\frac{dB}{dI_A} = \frac{k}{r} = \frac{2 \times 10^{-7}}{r}$$

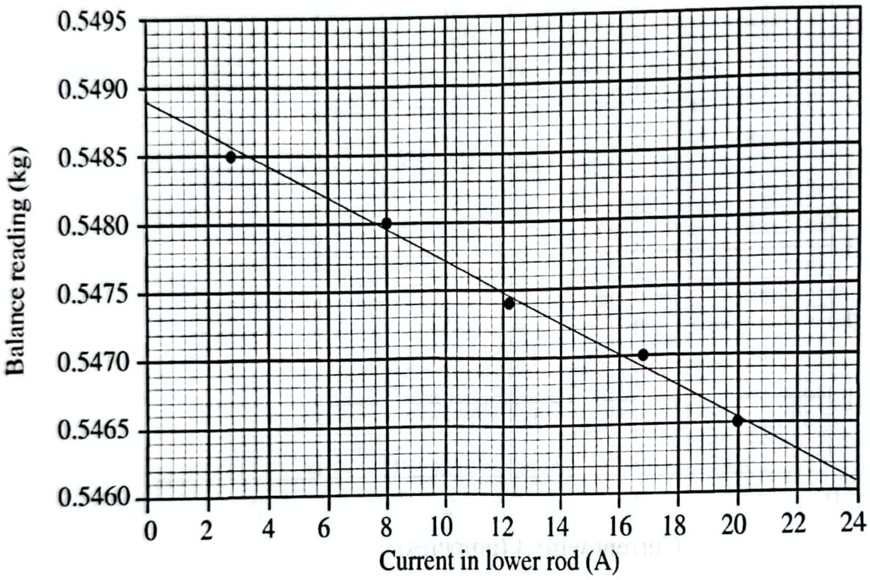
$$\therefore r = \frac{2 \times 10^{-7}}{2.17 \times 10^{-6}} = 9.2 \text{ cm}$$

41. The straight conductor and BC are parallel conductors carrying currents in the same direction. So the straight conductor will be attracted towards the wire loop. Currents in the straight conductor and AD are in opposite directions, resulting in a repulsive force between them. This repulsive force due to AD will be weaker than the attractive force due to BC, as AD is further from the straight conductor. Hence the current causes the straight conductor to experience a net force towards the square wire loop.

[Note: The currents in elements AB and CD are perpendicular to the current in the straight conductor, so there is no net force between the straight conductor and these two elements.]

42. (a) As the current increases in the lower rod, the balance reading decreases. This indicates that there must be an increasing upwards magnetic force of attraction on the lower rod due to the current in the two rods. For the two rods to attract each other, the current in both rods must be in the same direction relative to each other.

(b)



(c) The copper rod's true mass is found at 0 A when no other forces are acting. By extrapolating the line of best fit to $I = 0$ A, the copper rod's mass is 0.5489 kg.

(d) $\frac{F}{l} = k\frac{I_1 I_2}{d}$ $\quad I_1 = 50$ A $\quad l = 2.6$ m $\quad k = 2.0 \times 10^{-7}$ N A^{-2}

Balance reading (kg) $= F = mg -$ magnetic force (F_M)

At $I_2 = 16$ A, $F = 0.5470$ kg

$\therefore F_M = 0.5489 - 0.5470 = 0.0019$ kg $= 0.0019 \times 9.8$ N

Since $\frac{F}{l} = k\frac{I_1 I_2}{d}$

$$d = kl\frac{I_1 I_2}{F} = \frac{2.0 \times 10^{-7} \times 2.6 \times 50 \times 16}{0.0019 \times 9.8} = 2.23 \times 10^{-2} \text{ m} = 2.23 \text{ cm}$$

$\therefore$ Distance between the two copper rods $= 2.23 \times 10^{-2}$ m $= 2.23$ cm

43. (a) Q will move to the left.

[Note: Currents in P and Q are in the same direction, so P and Q attract one another. Currents in Q and R are in opposite directions, so they will repel one another.]

(b) $$\frac{F_{PQ}}{l} = k\frac{I_P I_Q}{d}$$

$$\therefore F_{PQ} = k\frac{I_P I_Q}{d}.l = 2.0\times10^{-7}\times\frac{6\times2}{5\times10^{-3}}\times1 = 4.8\times10^{-4}\text{ N to the left}$$

$$\text{and } F_{QR} = k\frac{I_Q I_R}{d}.l = 2.0\times10^{-7}\times\frac{2\times2}{2.5\times10^{-3}}\times1 = 3.2\times10^{-4}\text{ N to the left}$$

$\therefore$ total magnitude of force = $(3.2 + 4.8)\times10^{-4} = 8.0\times10^{-4}$ N to the left

44. Using Ampere's Law, $\frac{F}{l} = k\frac{I_1 I_2}{d}$

$$\therefore F = k\frac{I_1 I_2}{d}l = 2\times10^{-7}\times\frac{2\times2}{0.015}\times0.35$$

$$= 1.867\times10^{-5}$$

$$\approx 1.9\times10^{-5}\text{ N}$$

The current in the two wires travels in opposite directions, so the direction of the force is outwards. So the two wires *repel* one another, with an initial force of 1.9×10^{-5} N.

45. Current wire Z: $I_Z = 20$ A Between Z and Y: $d_1 = 0.3$ m

Current wire Y: $I_Y = 20$ A Between Y and X: $d_2 = 0.75$ m

Current wire X: $I_X = ?$ A

As the net force is zerio, $\frac{F_Z}{l} = \frac{F_Y}{l}$ So: $\frac{k\, I_Z I_Y}{d_1} = \frac{k\, I_Y I_X}{d_2}$

So, $\frac{20\times20}{0.3} = \frac{20\times I_X}{0.75}$

$\therefore$ current in X, $I_X = 50$ A ... this will be moving in the same direction as I_Y.