Advanced Higher Physics:

ELECTRICAL PHENOMENA

Electron Flow Version

Important note on CURRENT DIRECTION

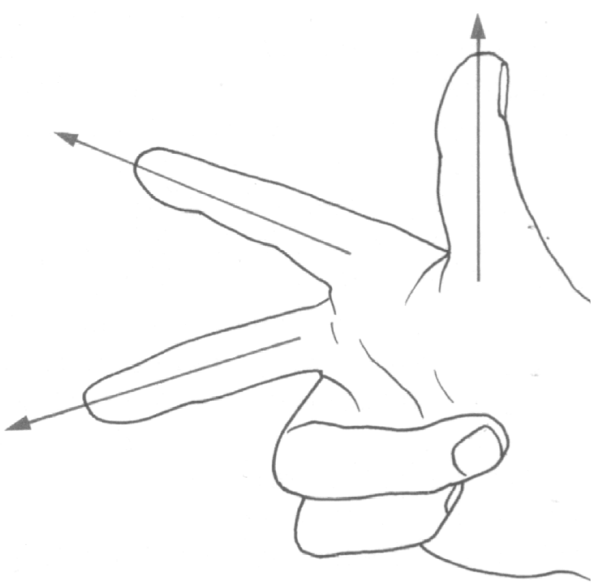
- **State that a magnetic field exists around a moving charge in addition to its electric field.**

- **State that a charged particle moving across a magnetic field experiences a force.**
- **Describe how the concept of a magnetic field is used to explain the magnetic force exerted by current-carrying conductors on each other.**

Currents in same direction

Currents in opposite direction

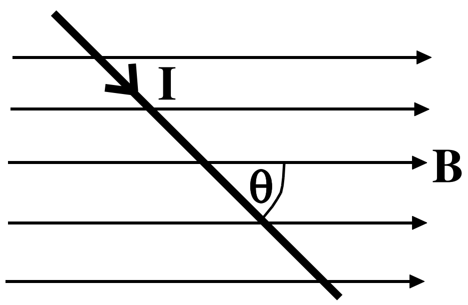
- **State the relative directions of current, magnetic field and force for a current-carrying conductor in a magnetic field.**



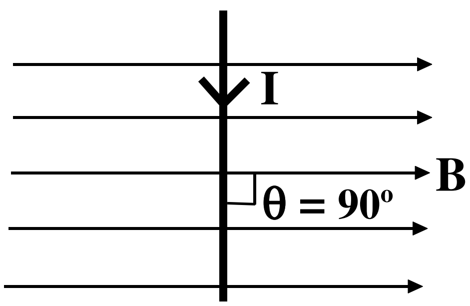
- **State that: "One tesla is the magnetic induction (B) of a magnetic field in which a conductor of length 1 metre, carrying a current of 1 ampere perpendicular to the field, is acted upon by a force of 1 newton."**

- **State the relationship: $F = IlB\sin\theta$.**

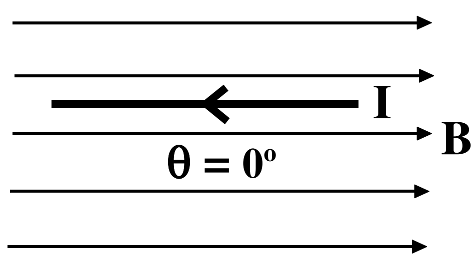
<u>Conductor at angle θ to magnetic field (B)</u>



<u>Conductor perpendicular to magnetic field (B). θ = 90°</u>

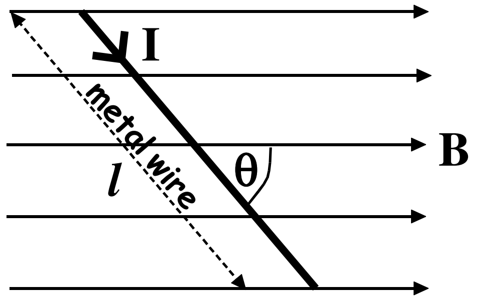


<u>Conductor parallel to magnetic field (B). θ = 0°</u>



● **Carry out calculations using the relationship: $F = IlB\sin\theta$.**

1) The following questions relate to this diagram. The current direction arrow shows the flow of ***electrons*** through the metal wire.



● (a) Calculate the *size* of the **magnetic** **force** acting on the metal wire when I = 3 A, l = 0.2 m, B = 0.5 T and θ = 20°.

● (b) State the ***direction*** of the force. (Hint: Right-hand rule.)

Answer = 0.1 N vertically down

● Calculate the size of the **magnetic** **force** acting on the metal wire when I = 2.5 A, l = 0.01 m, B = 0.15 T and θ = 30°.

Answer = (1.9×10^{-3}) N

● Calculate the size of the **magnetic** **force** acting on the metal wire when I= 0.75 A, l = 0.025 m, B = 0.02 T and θ = 40°.

Answer = (2.4×10^{-4}) N

● Calculate the size of the **current** passing through the metal wire, which experiences a force of (1.5×10^{-3}) N, when l = 0.04 m, B = 0.2 T and θ = 25°.

Answer = 0.4 A

● Calculate the **length** of metal wire in the magnetic field if the wire experiences a force of (1.25×10^{-3}) N, when I = 0.03 A, B = 0.4 T and θ = 35°.

Answer = 0.18 m

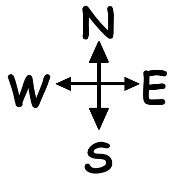
● Calculate the **magnetic** **induction** of the magnetic field if the metal wire experiences a force of (1.75×10^{-3}) N when I = 0.5 A, l = 0.06 m and θ = 45°.

Answer = 0.08 T

● Calculate the **angle** **(θ)** between the metal wire and magnetic field lines if the wire experiences a force of (4.33×10^{-2}) N when I = 0.5 A, l = 0.08 m and B = 0.5 T.

Answer = 60°

2) A 1 m length of straight, horizontal metal wire which carries an ***electron*** current of 50 A from west to east is placed in a horizontal magnetic field (magnetic induction 1.2 T) directed towards the northeast (i.e., 45º east of north).



(a) Draw a labelled sketch to show this situation from **above**.

(b) Calculate the *size* of the **magnetic force** which will act on the metal wire.

Answer = 42.4 N

(c) State the *direction* of the **force**. (Hint: Right-hand rule).

Answer: vertically down

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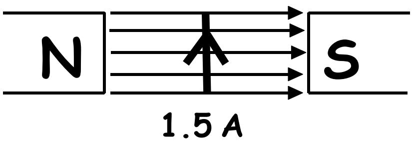
3) A 0.05 m length of straight, horizontal metal wire, carrying an ***electron*** current of 1.5 A is placed at 90º (right-angles) to the magnetic field lines of a horseshoe magnet which has a magnetic induction of 0.25 T. The diagram shows the view from above the magnet.



(a) Calculate the *size* of the **magnetic force** which will act on the metal wire.

Answer = 0.019 N

(b) State the *direction* of the **magnetic force**. (Hint: right-hand rule).

Answer: vertically up

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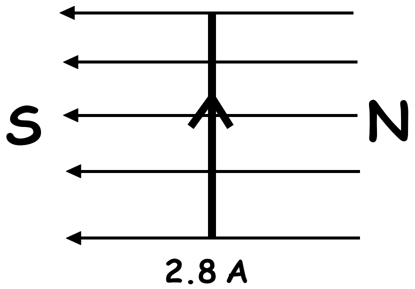
4) The diagram shows from above a 0.1 m straight, horizontal length of metal wire which has been placed perpendicular (at 90º) to a horizontal magnetic field. The wire carries an ***electron*** current of 2.8 A across the magnetic field, which has a magnetic induction of 1.5 T.



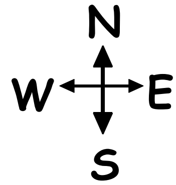
(a) Calculate the *size* of the **magnetic force** which will act on the metal wire.

Answer = 0.4 N

(b) State the *direction* of the **magnetic force**. (Hint: right-hand rule).

Answer: vertically down

5) A 10 cm length of straight, horizontal metal wire is placed in a horizontal magnetic field (magnetic induction 0.75 T) directed from east to west. The wire carries an ***electron*** current of 20 A from south to north.



(a) Draw a labelled sketch to show this situation from **above**.

(b) Calculate the *size* of the **magnetic force** which will act on the metal wire.

Answer = 1.5 N

(c) State the *direction* of the **force**. (Hint: right-hand rule).

Answer: vertically down

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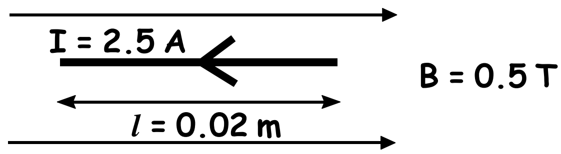
6) A 0.02 m length of straight, horizontal metal wire carries a current of 2.5 A. The wire is placed **parallel** to a horizontal magnetic field which has a magnetic induction of 0.5 T.



(a) State the value of the **magnetic force** which will act on the wire. (b) Explain your answer.

Answer = 0 N

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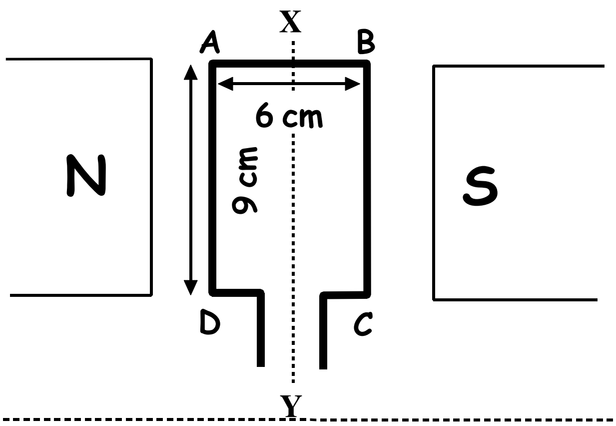
7) A simple, single coil electric motor is shown from above. At the instant shown, the wire coil ABCD is sitting in a horizontal position and is free to rotate about axis XY. An ***electron*** current of 1.5 A is flowing clockwise through the coil. The coil is sitting in a horizontal magnetic field of magnetic induction 0.75 T.



(a) State the value of **magnetic forces** which will act on sides AB and DC of the wire coil at the instant shown.

(b) Explain your answer.

Answer = 0 N

(b) Determine the *size* and *direction* of the **magnetic forces** which will act on sides AD and BC of the wire coil at the instant shown.

Answer: F_{AD} = 0.1 N up, F_{BC} = 0.1 N down

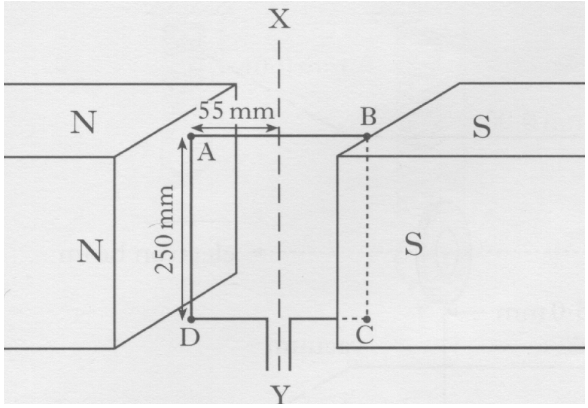
(c) Hence, state the *direction* in which the wire coil will rotate about XY (looking horizontally from Y to X.)

(d) Calculate the *size* of the **total torque** (**turning force**) acting on the wire coil at the instant shown.

(Torque = Force x perpendicular distance to pivot point.)

Answer = (6×10^{-3}) N m

8) In a simple design of electric motor, a single rectangular loop of wire is arranged vertically in the uniform magnetic field between the poles of a magnet which has a magnetic induction of 0.6 T. The loop is free to spin about axis XY. An ***electron*** current of 0.4 A flows through the coil in an anti-clockwise direction.



(a) Calculate the *size* and *direction* of the **magnetic force** acting on sides AD and BC of the wire loop at the instant shown.

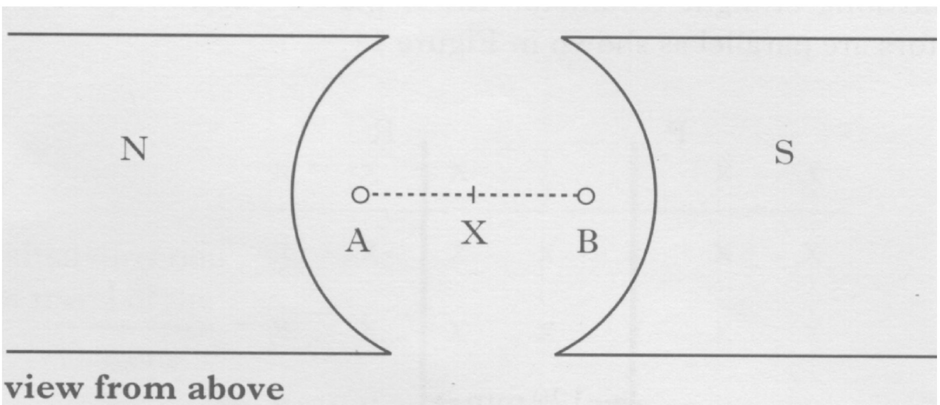
Answer: F_{AD} = 0.06 N away from observer, F_{BC} = 0.06 N towards observer

(b) Hence, state the **direction** in which the wire loop will spin about axis XY.

(c) Calculate the *size* of the **torque** acting on the wire loop at the instant shown.

Answer = (6.6×10^{-3}) N m

(d) The design of the simple motor is improved by using a different design of magnet which produces a **radial** magnetic field - All the magnetic field lines pass through the central axis, i.e., through the line **directly under** point **X** on the diagram below.



Explain how the **radial magnetic field** reduces any change in the ***turning forces*** as the wire loop rotates.

- **State that the magnetic induction (B) at a perpendicular distance (r) from an 'infinite' straight conductor carrying a current (I) is $\frac{\mu_o I}{2\pi r}$**

(μ_o is a constant called the "permeability of free space." $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}.)

- **Derive the following expression for the force (F) per unit length (*l*) between 2 parallel current-carrying wires at a distance r apart where I_1 is the current in the first wire and I_2 is the current in the second wire:**

$$\frac{F}{l} = \frac{\mu_o I_1 I_2}{2\pi r}$$

- **Carry out calculations using the relationships:**

$$B = \frac{\mu_o I}{2\pi r} \quad \text{and} \quad \frac{F}{l} = \frac{\mu_o I_1 I_2}{2\pi r}$$

1) Calculate the *size* of the **magnetic induction** around a long, straight conductor when:

I = 25 A and

r = 0.2 m.

Answer = (2.5×10^{-5}) T

2) Calculate the *size* of the **current** passing through a long straight conductor when:

B = (1.75×10^{-5}) T and

r = 0.35 m.

Answer = 30.6 A

3) Calculate the **perpendicular distance** from a long, straight conductor when:

B = (1.4×10^{-5}) T and

I = 1.5 A.

Answer = 0.02 m

4) Calculate the *size* of the **magnetic induction** at a perpendicular distance of 5 cm from a long, straight metal wire which carries a current of 3 A.

Answer = (1.2×10^{-5}) T

5) Calculate the *size* of the **current** flowing through a long, straight metal wire if the size of the magnetic inductance at a perpendicular distance of 15 cm from the wire is (8×10^{-6}) T.

Answer = 6 A

6) Calculate the **perpendicular distance** from a long, straight length of extension socket flex carrying a current of 3 A if the magnetic induction at this distance is (2×10^{-5}) T.

Answer = 0.03 m

7) An overhead power line runs parallel with the ground at a height of 5 m. A current of 400 A flows through the power line. Calculate the *size* of the **magnetic induction** at a point on the ground directly underneath the power line.

Answer = (1.6×10^{-5}) T

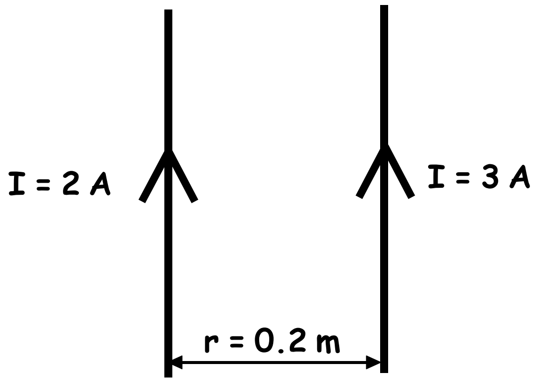
8) At a perpendicular distance of 10 cm from a long, straight metal cable, the size of the magnetic induction is (1.5×10^{-5}) T. Calculate the *size* of the **current** flowing through the cable.

Answer = 7.5 A

9) A current of 1.8 A flows through a long, straight telephone wire. The magnetic induction at a distance directly above the wire has a size of (5.5×10^{-6}) T. Calculate this **perpendicular distance**.

Answer = 0.07 m

10) Calculate the <u>*size*</u> of the <u>***resultant***</u> <u>**magnetic induction**</u> midway between these two long, parallel, current-carrying metal wires:



Answer = (2×10^{-6}) T

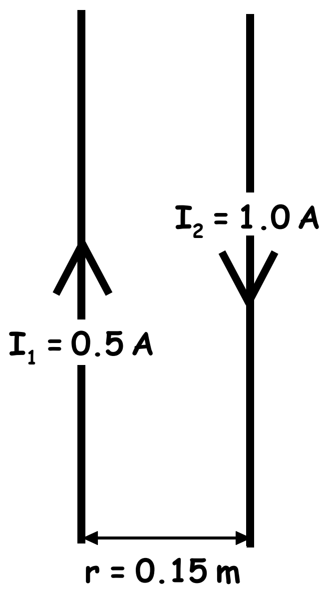
11) Two long, straight metal wires are lined up horizontally, 10 cm apart, parallel to each other. A direct current of 3 A passes through the top wire and a current of 5 A passes through the bottom wire in the opposite direction.

(a) Sketch this situation.

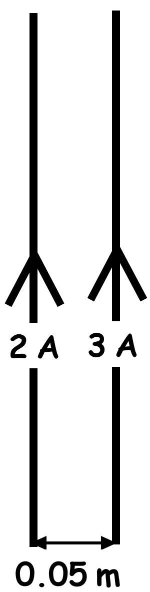
(b) Calculate the <u>*size*</u> of the <u>**magnetic induction**</u> due to both wires on the mid-line between them.

Answer = (3.2×10^{-5}) T

12) In each case, calculate the <u>*size*</u> and <u>*direction*</u> of the <u>**magnetic force per unit length**</u> exerted on the right-hand wire by the left-hand wire.



Answer = (6.7×10^{-7}) N m^{-1} to the right



Answer = (2.4×10^{-5}) N m^{-1} to the left

13) Two long metal wires are placed vertically parallel to one another, 5cm apart. The wires exert an attractive force per unit length on each other of (6×10^{-7}) N m^{-1}. A current of 0.40 A flows upwards through the left-hand wire. A current also flows through the right-hand wire, but its *size* and *direction* are unknown.

(a) Draw a diagram to show this information.

(b) Determine the *size* and *direction* of the **current** flowing through the right-hand wire.

Answer = 0.38 A upwards

14) Two long, vertically parallel metal cables are separated by a distance of 3 cm. A current of 0.80 A flows upwards through the right-hand cable. An current also flows through the left-hand cable - *size* and *direction* unknown. The two cables exert a repulsive force per unit length on each other of 8.5×10^{-7} N m^{-1}.

(a) Draw a diagram to show this information.

(b) Determine the *size* and *direction* of the **current** flowing through the left-hand cable.

Answer = 0.16 A downwards

15) Two long, parallel, horizontal telephone wires both carry a direct current of 1.5 A in the same direction. As a result, a force per unit length of (9×10^{-7}) N m^{-1} acts between the wires.

(a) Draw a diagram to show this information.

(b) Explain whether the telephone wires will attract or repel.

Answer: attract

(c) Calculate the **perpendicular distance** between the two telephone wires.

Answer = 0.5 m

16) An electrician lays two lengths of electrical cable parallel to each other under a floor. Both cables are designed to carry a maximum current of 5 A, in which case they will repel each other with a force per unit length of (4×10^{-7}) N m^{-1}.

(a) Explain whether the currents flow in the same or opposite directions.

Answer: opposite directions

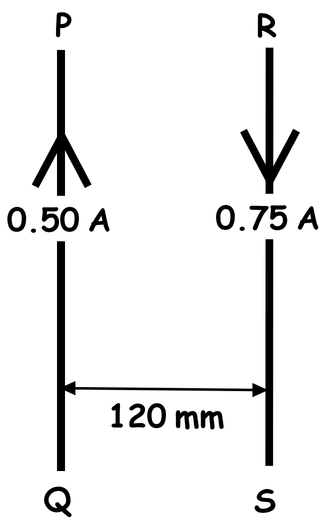
(b) Calculate the **perpendicular distance** between the two lengths of cable.

Answer = 12.5 m

17) (a) A long, straight conductor **PQ** carries a current of 0.50 A. Calculate the *size* of the **magnetic induction** at a point 120 mm perpendicular to the conductor.

Answer = (8.3×10^{-7}) T

(b) A second long, straight conductor **RS** is placed parallel with **PQ**, 120 mm away. **RS** carries a current of 0.75 A in the opposite direction to the current flow in **PQ**.



Calculate the *size* and *direction* of the **force per unit length** exerted on conductor **RS** by conductor **PQ**.

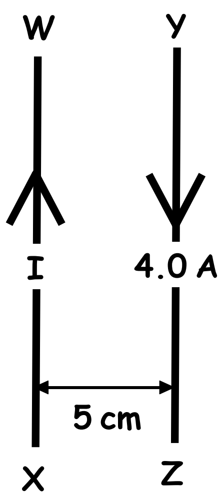
Answer = (6.3×10^{-7}) N m^{-1} to the right

18) (a) The magnetic field surrounding a long, straight, current-carrying conductor **WX** has a magnetic induction of (2.0×10^{-5}) T at a perpendicular distance of 5 cm.

Calculate the *size* of the **current (I)** flowing through **WX**.

Answer = 5 A

(b) A second long, straight conductor **YZ**, carrying a current of 4.0 A, is placed 5 cm from conductor **WX**, as shown below:



(i) Determine the *size* and *direction* of the **magnetic force per unit length** exerted on conductor **YZ** by conductor **WX**.

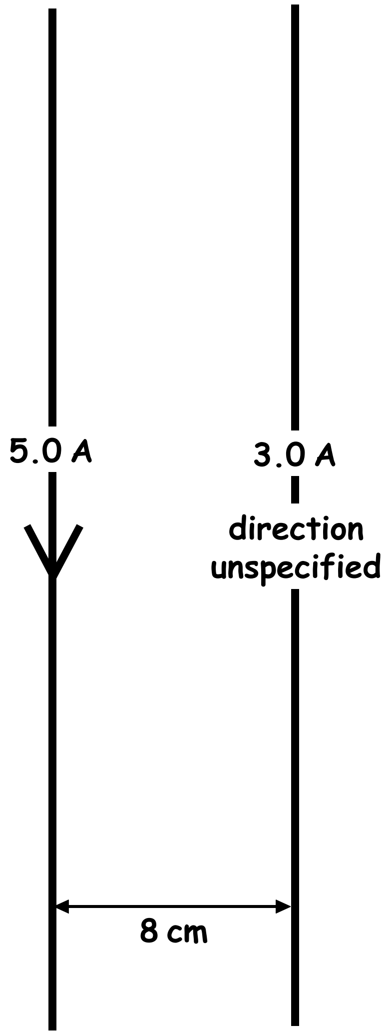
Answer = (8×10^{-5}) N m^{-1} to the right

(ii) The distance between the conductors is **doubled**.

What effect does this have on the *size* of the **magnetic force per unit length** exerted on conductor **YZ** by conductor **WX**?

Answer: value halves

19) Two long, straight, parallel conducors both carry a direct current. The conductors attract.



(a) In which **direction** does current flow through the **right-hand** conductor?

Answer: downwards

(b) Determine the *size* of the **magnetic force per unit length** acting on the **left-hand** conductor as a result of the magnetic field exerted by the **right-hand** conductor.

Answer = (3.8×10^{-5}) N m^{-1}

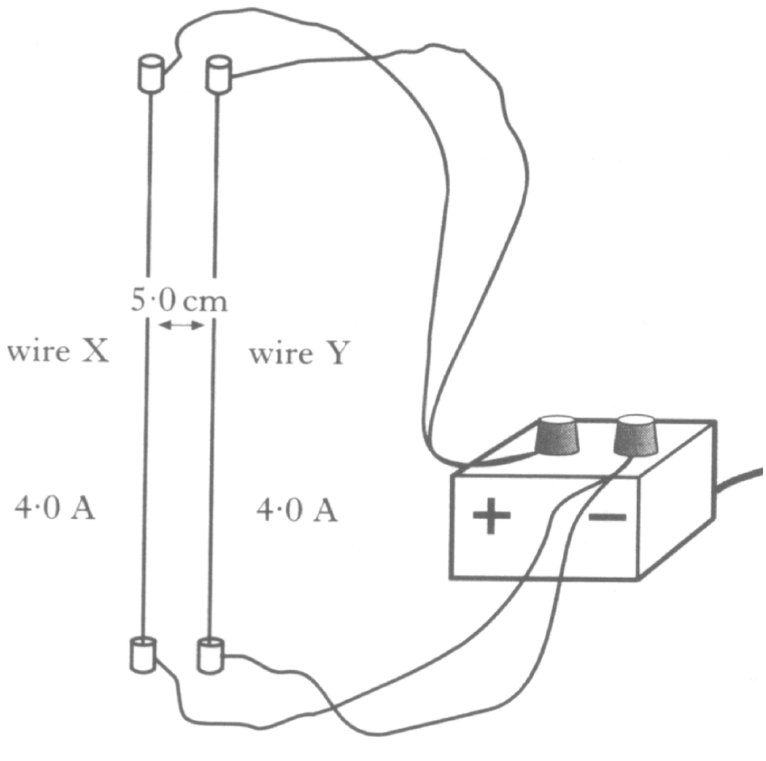
(c) Calculate the *size* of the **resultant magnetic induction** at a point perpendicular to both of the conductors and midway between them.

Answer = (1×10^{-5}) T

20) (a) Calculate the *size* of the **magnetic induction** due to wire Y at wire X.

Answer = (1.6×10^{-5}) T

(b) Determine the *size* and *direction* of the **force per unit length** acting on wire X due to the magnetic induction of wire **Y**.



Answer = (6.4×10^{-5}) N m^{-1} to the right