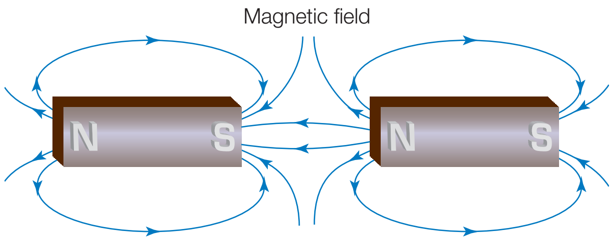
CHAPTER 5

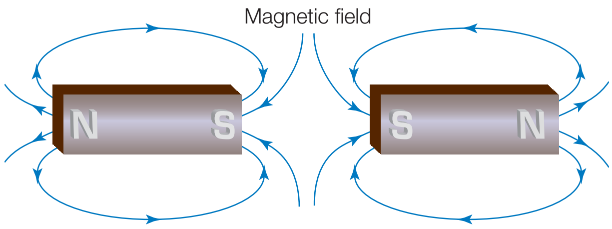
The motor effect

Answers to revision questions

1. (a)



(b)



2. (a) x: right
y: right
z: from right to left

(b) Point $\times$ has the strongest magnetic field.

(c) Two factors:
- the number of loops
- the size of the current.

3. (a) Using the magnetic force equation:

$F_B = \boldsymbol{B}\boldsymbol{I}l \sin\theta$

Known quantities:
$\boldsymbol{B} = 0.5$ T
$\theta = 90°$
$\boldsymbol{I} = 9$ A
$l = 0.5$ m

$F_B = 0.5 \times 9 \times 0.5 \times \sin 90°$
$= 2.25$ N up the page [right-hand palm rule] (2.3 N to two significant figures)

(b) Using the magnetic force equation:
$F_B = \boldsymbol{B}\boldsymbol{I}l \sin\theta$

Known quantities:
$\boldsymbol{B} = 0.5$ T
$\boldsymbol{I} = 2.0$ A
$l = 0.90$ m
$\theta = 45°$

$F_B = 0.05 \times 2.0 \times 0.90 \times \sin 45°$

$= 0.064$ N into the page

(c) Using the magnetic force equation:

$F_B = BIl \sin\theta$

Known quantities:

$B = 0.001$ T

$I = 3.0$ A

$l = 3.5$ m

$\theta = 30°$

$F_B = 0.001 \times 3.0 \times 3.5 \times \sin 30°$

$= 5.25 \times 10^{-3}$ N out of the page

(d) Using the magnetic force equation:

$F_B = BIl \sin\theta$

Known quantities:

$B = 3.4$ T

$I = 0.6$ A

$l = 1.3$ m

$\theta = 90°$

$F_B = 3.4 \times 0.6 \times 1.3 \times \sin 90°$

$= 2.652$ N up the page (2.7 N to two significant figures)

(e) Using the magnetic force equation:

$F_B = BIl \sin\theta$

Known quantities:

$B = 1.0$ T

$I = 5$ mA $= 0.005$ A

$l = 2.8$ m

$\theta = 90°$ (it is perpendicular to the magnetic field)

$F_B = 1.0 \times 0.005 \times 2.8 \times \sin 90°$

$= 1.4 \times 10^{-2}$ N 30° to the left from the vertical

(f)
- On the left half of the semicircle, the current is composed of an upward component and one directed to the right side.
- On the right half of the semicircle, the current is composed of a downward component and also another directed to the right side.
- The upward and downward components of this semicircle exactly cancel each other out.
- The conductor will only experience a force due to the current from left to right as if it's a straight conductor.

Using the magnetic force equation:

$F_B = BIl \sin\theta$

Known quantities:

$B = 0.12$ T

$I = 0.3$ A

$l = 0.02 + 0.05 \times 2 + 0.02$

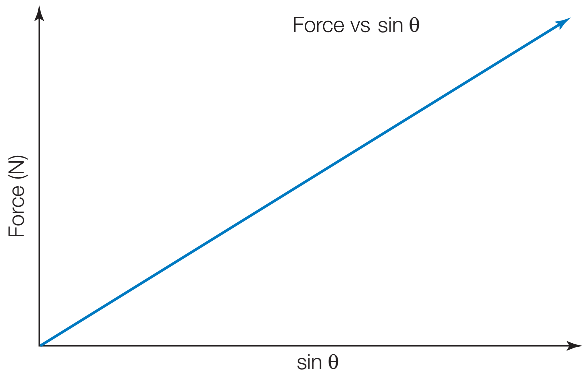
$= 0.14$ m

$\theta = 90°$ (It is perpendicular to the magnetic field)

$F_B = 0.12 \times 0.3 \times 0.14 \times \sin 90°$

$= 5.04 \times 10^{-3}$ N

4. (a)



(b) According to the magnetic force equation:

$F_B = BIl \sin\theta$

The graph has the equation $F = m \sin\theta$ with the gradient m.

$\therefore m = BIl$

Known quantities:

$m = 1.1$ (given)

$I = 0.45$ A

$l = 0.2$ m

$$B = \frac{1.1}{0.2 \times 0.45}$$

$$= 12 \text{ T}$$

5. Using the magnetic force equation:

$F_B = BIl \sin\theta$

Known quantities:

$B = 0.6$ T

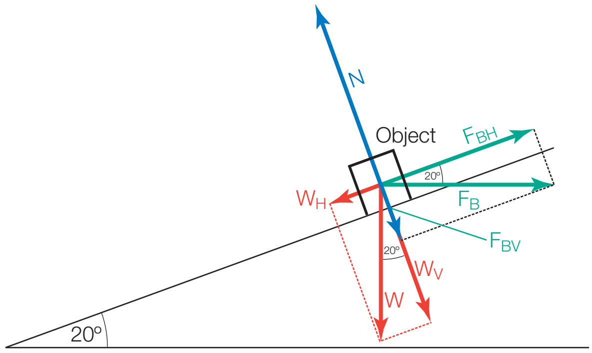
$I = 1.3$ A

$l = 0.25$ m

$\theta = 90°$

$$F_B = 0.6 \times 1.3 \times 0.25 \times \sin 90°$$

$$= 0.195 \text{ N to the right}$$



$W = 0.03 \times 9.8 = 0.294$ N perpendicularly down

When both forces are separated into their components, the components that are directed perpendicularly downwards to the surface of the slope will be cancelled by the normal reaction force.

The component of the force that is up parallel to the plane of the slope (due to F_B) and the component that is down parallel to the slope (due to W) will result in acceleration up the slope.

$$\boldsymbol{F}_{BH} = 0.195 \times \cos 20^\circ$$
$$= 0.183 \text{ N up the slope}$$
$$W_H = 0.294 \times \sin 20^\circ$$
$$= 0.101 \text{ N down the slope}$$
$\therefore$ Net force $= 0.183 - 0.101 = 0.083$ N (up the slope)

$$\boldsymbol{F}_{net} = ma$$
$$0.083 = 0.03 \times a$$
$$a = 2.8 \text{ m s}^{-2} \text{ up the slope}$$

6. (a) XY is responsible because only this side has a current which is travelling at a direction perpendicular to the magnetic field. AX and BY are both parallel to the field.

(b) Out of the page.

(c) Using the magnetic force equation:

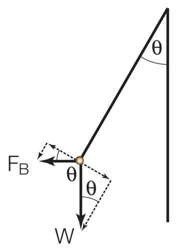
$$\boldsymbol{F}_B = \boldsymbol{BI}l \sin\theta$$

Known quantities:

$\boldsymbol{B} = 0.5$ T
$\boldsymbol{I} = 50$ A
$l = 4$ m
$\theta = 90^\circ$

$$F_B = 0.5 \times 50 \times 4 \times \sin 90^\circ$$
$$= 100 \text{ N out of the page}$$

(d) When the side XY reaches a point where it cannot get any further, the component force which pushes the side XY at the direction it is going will exactly cancel out the resisting (weight) force that is pushing it in the opposite direction, that is, the net force is zero.



$$\boldsymbol{F}_B = 100 \text{ N}$$
$$W = 45 \times 9.8 = 441 \text{ N}$$

$$\therefore F_B \times \cos\theta = W \times \sin\theta$$
$$\frac{\sin\theta}{\cos\theta} = \frac{F_B}{W}$$
$$\tan\theta = \frac{100}{441}$$
$$\theta = 13^\circ$$

(e) Using the equation $T = 2\pi\sqrt{\frac{l}{g}}$ to calculate the period

Known quantities:

$l = 3$ m

$g = 9.8$ m s^{-2}

$$T = 2\pi\sqrt{\frac{3}{9.8}}$$

$$= 3.48 \text{ s}$$

1 min = 60 s

$$\frac{60}{3.48} \approx 17 \text{ cycles}$$

7. The currents in wires A and B are travelling towards opposite directions, thus they will repel each other.

Wire B will be deflected downwards by wire A.

$$\frac{F}{l} = \frac{kI_1I_2}{d}$$

Known quantities:

$k = 2 \times 10^{-7}$

$I_1 = 10$ A

$I_2 = 5$ A

$d = 1$ m

$l = 3.3$ m

$$F = \frac{2 \times 10^{-7} \times 10 \times 5 \times 3.3}{1}$$

$$= 3.3 \times 10^{-5} \text{ N down}$$

The currents in wires B and C are travelling towards opposite directions, thus they will repel each other.

Wire B will be deflected upwards by wire C.

Known quantities:

$k = 2 \times 10^{-7}$

$I_1 = 5$ A

$I_2 = 20$ A

$d = 1$ m

$l = 3.3$ m

$$F = \frac{2 \times 10^{-7} \times 5 \times 20 \times 3.3}{1}$$

$$= 6.6 \times 10^{-5} \text{ N up}$$

$\therefore$ The resultant force $= 6.6 \times 10^{-5} - 3.3 \times 10^{-5} = 3.3 \times 10^{-5}$ N up the page

8. The currents in the two wires are travelling towards opposite directions, thus they will repel each other. That is, the one on the left will move to the left, while the one on the right will move to the right. They experience the same magnitude of force.

$$\frac{F}{l} = \frac{kI_1I_2}{d}$$

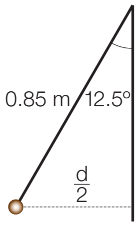
Known quantities:

$k = 2 \times 10^{-7}$

$\boldsymbol{I}_1 = 50\,\text{mA} = 0.05\text{ A}$

$\boldsymbol{I}_2 = 0.05\text{ A}$

$l = 1\text{ m}$



$$\frac{d}{2} = 0.85 \times \sin 12.5°$$

$d \doteqdot 0.37\text{ m}$

$$\boldsymbol{F} = \frac{1 \times 2 \times 10^{-7} \times 0.05 \times 0.05}{0.37}$$

$$= 1.4 \times 10^{-9}\text{ N}$$

9. (a) The vertical component of the force is:

$$\boldsymbol{F}_p = 4 \times \cos(120° - 90°)$$
$$= 3.46\text{ N}$$
$$\therefore \tau = \boldsymbol{F}_p\boldsymbol{d}$$
$$= 3.46 \times 2$$
$$= 6.9\text{ Nm}$$

(b) The vertical component of the force is:

$$\boldsymbol{F}_p = 2.4 \times \sin 40°$$
$$= 1.54\text{ N}$$
$$\therefore \tau = \boldsymbol{F}_p\boldsymbol{d}$$
$$= 1.54 \times 0.6$$
$$= 0.93\text{ Nm}$$

10. (a) Using the torque equation: $\boldsymbol{\tau} = n\boldsymbol{BI}A\cos\theta$

Known quantities:

$n = 40$ turns

$\boldsymbol{B} = 0.2\text{ T}$

$$\boldsymbol{I} = \frac{6}{0.5} = 12\text{ A}$$

$A = 0.2^2\,\pi = 0.126\text{ m}^2$

$\theta = 0°$

$$\tau = 40 \times 0.2 \times 12 \times 0.126 \times \cos 0°$$
$$= 12\text{ Nm}$$

(b) It will make the coil rotate.

(c) Using the torque equation: $\boldsymbol{\tau} = n\boldsymbol{BI}A\cos\theta$

$n = 40$ turns

$\boldsymbol{B} = 0.2$ T

$$\boldsymbol{I} = \frac{6}{0.5} = 12 \text{ A}$$

$A = 0.126 \text{ m}^2$

$\theta = 30°$

$$\tau = 40 \times 0.2 \times 12 \times 0.126 \times \cos 30°$$
$$= 10 \text{ Nm}$$

(d) Using the torque equation: $\boldsymbol{\tau} = n\boldsymbol{BI}A\cos\theta$

$n = 40$ turns

$\boldsymbol{B} = 0.2$ T

$\boldsymbol{I} = 12$ A

$A = 0.126 \text{ m}^2$

$\theta = 90°$

$$\tau = 40 \times 0.2 \times 12 \times 0.126 \times \cos 90°$$
$$= 0 \text{ Nm}$$

(e) Since the speed is constant, there is no acceleration, thus no force. Hence there will be no torque ($\tau = 0$ Nm).

11. Using the torque equation: $\tau = \boldsymbol{nB}I\,A\cos\theta$

When $\theta = 30°$

$$\tau = nBIA\left(\frac{\sqrt{3}}{2}\right)$$

When $\theta = 45$, $I_{new} = 3I$

$$\tau_{new} = nB(3I)A\left(\frac{1}{\sqrt{2}}\right)$$
$$= \left(\frac{3}{\sqrt{2}}\right)nBIA$$

$$\frac{\tau_{new}}{\tau} = \frac{\left(\frac{3}{\sqrt{2}}\right)nBIA}{\left(\frac{\sqrt{3}}{2}\right)nBIA} = \frac{3}{\sqrt{2}} \times \frac{2}{\sqrt{3}} = \frac{6}{\sqrt{6}} = \sqrt{6}$$

Since $\tau = 3.2$

$$\tau_{new} = 3.2 \times \left(\sqrt{6}\right)$$
$$= 7.8 \text{ Nm}$$

12. The magnetic force should equal to the weight force.
Using the magnetic force equation:

$$\boldsymbol{F}_B = \boldsymbol{BI}l\sin\theta$$

Known quantities:

$\boldsymbol{B} = 2.0\ T$

$\boldsymbol{I} = 40\ A$

$l = 2.4$ m

$\theta = 90°$

$$\boldsymbol{F}_B = 2.0 \times 40 \times 2.4 \times \sin 90°$$
$$= 192\text{ N upwards (on the right-hand side)}$$
$$\boldsymbol{F}_B = W$$
$$W = mg\,(\text{downwards})$$
$$192 = m \times 9.8$$

Maximum $m = 20$ kg

13. See Chapter 5.

14. Advantages:
- it is cheaper
- it is malleable and elastic, thus no spring is needed.

Disadvantages:
- extra lubrication needed
- does not withstand heat as well as graphite.

15. (a) The role of this spring is to provide a restoring torque to rest the armature so a reading can be made. For details see Chapter 5.

(b) See Chapter 5.

(c) Using the torque equation: $\tau = n\boldsymbol{BI}A\cos\theta$

Known quantities:

$n = 30$ turns

$\boldsymbol{B} = 0.2$ T

$\boldsymbol{I} = 0.2$ A

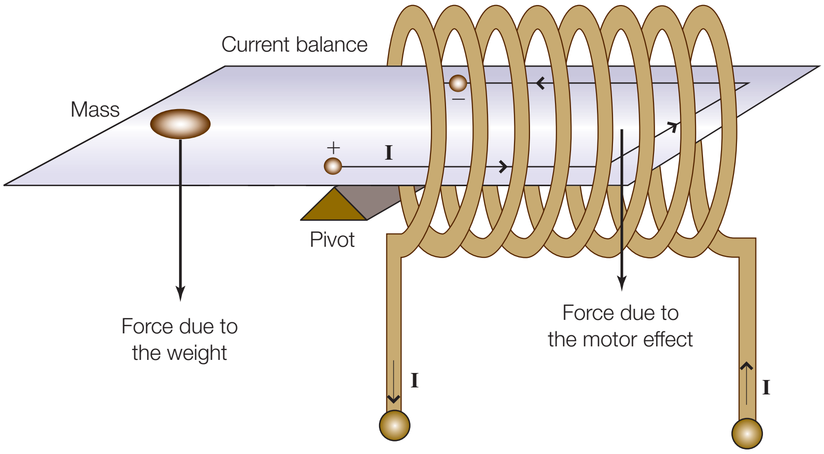
$A = 0.02 \times 0.02 = 4 \times 10^{-4}$ m^2

$\theta = 0°$

$$\tau = 30 \times 0.2 \times 0.2 \times 4 \times 10^{-4} \times \cos 0°$$
$$= 4.8 \times 10^{-4}\text{ Nm}$$

16. See Chapter 5. The motor effect is to vibrate the coil wound around on the core.

17. One way of doing this experiment is to use a device called a current balance. A current balance consists of a rectangular piece that is centred on a pivot, much like a seesaw. On one side of the current balance, there is a rectangular loop of conductor, as shown in the diagram on the following page. Current can be passed through this conductor. The conductor is placed inside the solenoid, which provides a uniform magnetic field inside it. As explained already, when a current-carrying conductor is placed inside a magnetic field, it experiences a force–motor effect. This force will push the current balance down on the side that is inside the solenoid, as shown in the diagram on the next page. To counter the force, a mass object is placed on the other side of the current balance. The mass object is just heavy enough to balance the force experienced by the conductor inside the solenoid. The mass object can be weighed to have its mass, hence its weight force, determined. The weight force then should equal the force experienced by the conductor inside the solenoid, hence allow the motor effect to be quantitatively examined. Also note that the sides that are parallel to the current balance do not exert any force since they are also parallel to the magnetic field; only the portion that is perpendicular to the current balance will experience the force.



For the purpose of this investigation, pass different sizes of current through the current balance and assess the size of the forces this conductor experiences by measuring the mass. The forces can then be plotted versus the current sizes. A linear relationship should be obtained that agrees with the formula $\boldsymbol{F} = \boldsymbol{B}I\boldsymbol{l} \sin \theta$, where the force is proportional to the current size.