Page 403 Test yourself on prior knowledge

1 Gravitational forces affect objects with mass; electrostatic forces affect objects with charge; strong field acts on hadrons.

2 Set up a circuit which includes a coil of wire with many turns. Place an iron bar inside the coil of wire. The electromagnet turns on when the circuit is on.

3 The compass needle lines up with the Earth's magnetic field. The Earth's magnetic core lies with its south pole near the geographic North Pole, and its north pole near the South Pole.

4 Each domain behaves like a mini-magnet. When iron is not magnetized, the domains do not line up in the same direction and their magnetic effects cancel out. When the iron is stroked, the domains line up in the same direction and their magnetic effects reinforce each other.

Pages 408–409 Test yourself

1 a) $F = BIl$

$= 50 \times 10^{-6}$ T × 0.2 A × 0.5 m

$= 5 \times 10^{-6}$ N

b) $F = BIl$

= 1.5 T × 0.2 A × 0.5 m

= 0.15 N

2 a) $I = F/Bl$

$= 0.03$ N / (6×10^{-3} T × 1 m)

= 5 A

b) The force is zero when $\sin\theta = 0$

3 a) mass = density × length × cross-sectional area

$= 8960$ kg m^{-3} × 0.1 m × 2×10^{-6} m^2

$= 1.79 \times 10^{-3}$ kg

b) Change in moment= force × change in distance from pivot = $mg\,\Delta l$

$= 1.79 \times 10^{-3}$ kg × 9.81 N kg^{-1} × 0.025 m

$= 4.4 \times 10^{-4}$ N m

c) When the frame is level, change in clockwise moment equals the change in anti-clockwise moments. Moment on side AB = force on side AB x distance from pivot

Force $= 4.4 \times 10^{-4}$ N m / 0.12 m

$= 3.7 \times 10^{-3}$ N

d) B = F/Il

= 3.7×10^{-3} N / (3.2 A × 0.1 m)

= 0.011 T

4 **a)** Force – direction is parallel to the page, downwards

b) AB – force is upwards; CD – force is downwards

c) The bar will roll towards the terminals

d) The disc will rotate clockwise, when viewed from the north pole of the magnet.

5 **a)** The magnetic field is in direction WV

b) B = F/Il

= 0.241 N/(4.6 A × 0.08 m)

= 0.65 T (2 sf)

c) The force in VW and XY is zero (wire is parallel to the field).
The force is twice as strong in WX as in YV as the current is twice as large.
The force in YV is down (current in opposite direction to WX).

Pages 409–410 Required practical 10

The force on a current-carrying conductor

1

Current /A	Reading from balance /g	Force /N
1.0	0.46	4.5×10^{-3}
2.0	0.91	8.9×10^{-3}
3.0	1.35	13×10^{-3}
4.0	1.83	18×10^{-3}
5.0	2.30	23×10^{-3}

2 Calculations of a quantity, such as force, require a number of significant figures which matches the lowest number of significant figures in the readings taken.

3 The measuring instrument fixes the number of decimal places in raw data (e.g. balance readings). This means raw data may have a different number of significant figures.

4 Either use calculation (B = F/Il) or plot a graph of force (y axis) against current (x axis).
B = F/I x l so B = gradient/l

F = BIl, so B = F/Il = (8.93×10^{-3}) ÷ (2 × 0.045) = 99×10^{-3} T = 100 Mt

Pages 412–413 Test yourself

6 When the charged particle moves parallel to the magnetic flux lines.
When the charged particle is not moving (relative to the field).

7 a) The particle travels parallel to the field, so it experiences no force.

b) The charge of an alpha particle is 2e,

so $F = BQv$

$= 1 \times 10^{-3}\ \text{T} \times 2 \times 1.6 \times 10^{-19}\ \text{C} \times (0.01 \times 3 \times 10^{8})\ \text{m s}^{-1}$

$= 9.6 \times 10^{-16}\ \text{N}$

8 $B = F/Qv$

$= 1 \times 10^{-15}\ \text{N} / (1.6 \times 10^{-19}\ \text{C} \times 1 \times 10^{7}\ \text{m s}^{-1})$

$= 6.25 \times 10^{-4}\ \text{T}$

9 $v = BQr/m$

$= 0.036\ \text{T} \times 1.6 \times 10^{-19}\ \text{C} \times 0.02\ \text{m}/9.11 \times 10^{-31}\ \text{kg}$

$= 1.26 \times 10^{8}\ \text{m s}^{-1}$

10 Particles A and B are both β particles with the same charge.
Particle A is travelling more slowly than particle B – as they both have the same mass, the same charge and are travelling in the same field, $v \propto r$. The deflection of the β particles in the field is consistent with the LHR.

11 a) The centripetal force acting on the electron is mv^2/r
where v is its velocity, m is the mass of the electron, and r is the radius of the path.

When it is in a magnetic field of flux density B, this is equal to BQv
where Q is the charge on the electron.

b) $mv^2/r = BQv$

so $v = BQr/m$ $= 0.43\text{x}10^{-3}\ \text{T} \times 1.6\text{x}10^{-19}\ \text{C} \times 74 \times 10^{-3}\ \text{m}/9.11\text{x}10^{-31}\ \text{kg}$

$= 5.6 \times 10^{6}\ \text{m s}^{-1}$.

c) i) Radius is proportional to velocity, and kinetic energy is proportional to velocity^2.
Doubling the kinetic energy increases velocity (and radius) by a factor of √2

ii) The relativistic mass of an electron is greater than its rest mass.
Since r is proportional to m, the radius increases if relativistic effects are allowed for.

12 a) $r = mv/BQ$
In a spectrometer, r is proportional to m since B, Q and v are the same.
If particles of mass M move in an arc of radius r, particles with mass 2M will follow a path of radius 2r and those of 3M one of 3r.

b) r is proportional to m/Q so,
if the radius of particle with mass/charge ratio M/Q is r,
the radius for particles with mass/charge ratio 2M/2Q is also r,
and the radius for 3M/2Q is 3r/2.

Page 415 Test yourself

13 a) The alternating electric field accelerates particles between the dees; the particles gain additional energy QV as they pass through each gap between the dees.
Thus, the particles move faster and follow a path with larger radius as they enter the next dee.

b) The magnetic field applies a centripetal force at right angles to the velocity of the charged particles so that inside the dee they follow a circular path at constant speed.

14 The particles travel in a circular path – they are constantly changing direction.
Acceleration is rate of change of velocity; velocity is speed in a particular direction, so by changing direction the particles are accelerating.

15 $mv^2/r = BQv$, but $v = 2\pi rf$

This means $2\pi f = BQ/m$

so $B = 2\pi mf/Q$

$= 2\pi \times 1.67 \times 10^{-27}\text{ kg} \times 4 \times 10^{6}\text{ Hz}/1.6 \times 10^{-19}\text{ C}$

$= 0.26\text{ T}$

16 The time spent in one dee, $t = \pi r/v = \pi r/(BQr/m) = \pi m/BQ$, so t does not depend on radius or speed. For particles of the same mass and charge travelling in the same field, t will be the same so they will all reach the gaps as the alternating current changes direction.

17 $BQv = mv^2/R$

$BQR = mv$

$\frac{1}{2} mv^2 = \frac{1}{2}(mv)^2/m$

$= \frac{1}{2} (BQR)^2/m$

Pages 416–418 Test yourself

1 B

2 A

3 A

4 D

5 B

6 C

7 C

8 D

9 A

10 D

11 a) downwards [1]

b) B = F/Iℓ [1]
= 2×10^{-3} N/(0.4 A × 0.1 m) [1]
= 0.05 T [1]

c) 10 cm of this wire has a mass 10 g × 0.5 g cm^{-1} = 5 g = 5×10^{-3} kg [1]

F = mg = BIℓ for levitation. [1]

I = mg/Bℓ [1]
= 5×10^{-3} kg × 9.81 N kg^{-1}/(0.05 T × 0.1 m)
= 9.81 A [1]

d) The wire extends beyond the magnetic field and a certain amount of these sections would also need to be lifted. [1]

e) The wire vibrates vertically [1]
as the force is perpendicular to the current and magnetic field. [1]
The direction of the force changes when the current reverses [1]
which happens repeatedly when ac is used. [1]

12 a) The magnetic field is applied perpendicular to the path of the protons. [1]
The force acts in a direction perpendicular to the field and the path of the protons [1]
The force depends on the speed v (F = BQv) [1]
and supplies the centripetal force needed to keep the protons moving in a circle [1]

b) F = mv^2/r [1]

= 1.67×10^{-27} kg × $(6 \times 10^7)^2$ m s^{-1}/(0.5 × 2 m) [1]

= 6.01×10^{-12} N [1]

c) The flux density, B is given by B = F/Qv [1]

B = 6.01×10^{-12} N/1.6×10^{-19} C × 6×10^7 m s^{-1} [1]

= 0.63 T [1]

d) Applying the potential difference gives protons an additional QV J of energy at each gap [1]
which is additional KE [1]
so the protons speed up/accelerate [1]
the protons travel in opposite directions through each of the gaps, so the alternating pd means the protons always accelerate rather than alternately speed up/slow down [1]

13 a) The force, field and velocity of electrons are perpendicular to each other. The force is into the centre of the circle and electrons have a negative charge, so the current is anticlockwise. [1] Therefore the field acts into the page. [1]

b) $F = BQv = mv^2/r$ [1]

so $v = BQr/m$ [1]

$= 0.3 \times 10^{-3}$ T $\times 1.6 \times 10^{-19}$ C $\times 0.15$ m$/9.11 \times 10^{-31}$ kg [1]

$= 7.9 \times 10^6$ m s^{-1}

c) The electrons are changing direction [1]
so they are changing velocity. [1]

d) Since the proton has the same charge as the electron, for r to remain the same for given B, mv must be constant. [1]
Since the mass of a proton is about 2000 times the mass of an electron, [1]
the velocity of the proton would be 2000 times less [1].

14 Any 8 from points below. Must include at least three from each section

- Charged particles moving perpendicular to a uniform magnetic field follow a circular path.
- The direction of the path is found using Fleming's left hand rule.
- Positively charged particles (protons and alpha particles) are deflected upwards on the 'page.'
- Negatively charged particles (electrons) are deflected downwards.
- Neutrons are not deflected.

- The radius of the orbit is proportional to momentum/charge.
- If all the particles are travelling at the same speed the radius is proportional to m/Q.
- The proton's path has a larger radius than for electrons. Since protons have the same magnitude of charge, this shows they have much greater mass.
- The radius for an alpha particle is double that for a proton so m/Q must be double that of the proton.
- Since the alpha particle's charge is double that of the proton m must be four times that of the proton (to make m/Q double).

Pages 418–419 Stretch and challenge

15 a) $r = mv/BQ$ so when the magnetic field gets weaker, the radius of the particle's path increases and it spirals outwards. When the field gets stronger the radius gets smaller and the charged particle spirals inwards.

b) i) Spiral motion is a combination of circular motion and linear motion – as the particle moves forwards it also circles around a central axis.

ii) The field does not affect the component of velocity which is parallel to it. It does affect the component of velocity parallel to it, causing circular motion in this plane.

iii) As the particle circles an axis, its parallel component of velocity causes it to move linearly along this axis, which when combined creates a spiral path.

c) i) Component of velocity perpendicular to the field (in the *x*–*y* plane) is v sinθ

Component of velocity parallel to the field (v_z) is v cosθ

ii) Centripetal force F = BQv sinθ = m(v sinθ)^2/r

So $r = \frac{mv \sin\theta}{BQ}$

If T is the time to circle the field line once, distance travelled parallel to field, d = v cosθ T,

The particle travels 2πr in time T, so

T = $\frac{2\pi r}{v \sin\theta}$

Substituting for r gives

T = $\frac{2\pi}{v \sin\theta} \times \frac{mv \sin\theta}{BQ} = \frac{2\pi m}{BQ}$

Substituting for T in d = v cosθ T gives

d = (v cosθ) × (2πm/BQ) = 2πmv cosθ/BQ

iii) tanθ = sinθ/cosθ

The expression for r, derived above, gives: $\sin\theta = \frac{rBQ}{mv}$

and that for d gives: $\cos\theta = \frac{dBQ}{2\pi mv}$

so tanθ = $\frac{rBQ}{mv} \times \frac{2\pi mv}{dBQ} = \frac{2\pi r}{d}$