# 24 Magnetic Fields

## 24.1 Current-carrying Conductors in a Magnetic Field

A **magnetic field** is a force field surrounding a **magnet** or **current-carrying wire** which acts on any other magnet or current-carrying wire placed in the field.

- The magnetic field of a bar magnet is **strongest at its ends** - referred to as north-seeking and south-seeking **poles**.
- A **magnetic field line** is a lien along which a north pole would move in the field.

### The Motor Effect

A current-carrying wire placed at a non-zero angle to the field lines of a magnetic field experiences a force due to the field.

- When a current flows, the section of the wire in the magnetic field experiences a force that **pushes it out of the field**.
- The magnitude of the force depends on the **current**, **magnetic field strength**, **length of the wire**, and the **angle between** the field lines and the current direction.

  The force is greatest when the wire is at right angles to the magnetic field.

  The force is zero when the fire is parallel to the magnetic field.

Tests shows that the force $F$ on the wire is proportional to the current $I$, and the length $l$ of the wire.

The **magnetic field strength** is defined as the force per unit length per unit current on a current-carrying conductor.

For a wire carrying current in a uniform magnetic field at 90° to the field lines

$$F = BIl$$

The unit of $B$ is the **tesla**, equal to $1\text{Nm}^{-1}\text{A}^{-1}$.

For a straight wire at angle $\theta$ to the magnetic field lines

$$F = BIl \sin\theta$$

### Couples

Consider a current-carrying coil with $n$ turns, and can rotate about a vertical axis.

1. The long sides of the coil are vertical, each long side experiences a force $F = (BIl)n$ in opposite directions at right angles to the field lines.

2. The **torque of the couple** $= Fd$ where $d$ is the perpendicular distance between the line of action of the forces on each side.
3. If the plane of the coil is at angle $\alpha$ to the field lines, then $d = w \cos \alpha$ where $w$ is the width of the coil.

   Therefore, $\tau = Fw \cos \alpha = BIlnw \cos \alpha = BIAn \cos \alpha$

## 24.2 Moving Charges in a Magnetic Field

For an electric beam in a magnetic field,

- The beam **follows a circular path** because the direction of the force on each electron is perpendicular to the direction of motion of the electrons.
- A current-carrying wire in a magnetic field experiences a force because the electrons moving along the wire are pushed by the force of the field.

Magnetic fields are used in particle physics detectors to **separate different charged particles out**, and **measure their momentum** from the curvature of the tracks they create.

### Force on a Moving Charge

For a particle of charge $Q$ moving through a uniform magnetic field at speed $v$ in a **perpendicular direction** to the field, the force on the particle

$$F = BQv$$

If the direction of motion of a charged particle is at angle $\theta$ to the field lines, then

$$F = BQv \sin \theta$$

## 24.3 Charged Particles in Circular Orbits

- The force of the magnetic field on a moving charge is at **right angles to the direction of the motion** of the particle.
- **No work is done** by the magnetic field on the particle as the force always acts at right angles to the velocity of the particle. The particle's direction change but not its speed - the kinetic energy of the particle is unchanged by the magnetic field.
- The particle therefore moves on a **circular path** with the force always acting towards the centre of curvature of the circular path. The force causes **centripetal acceleration** because it is perpendicular to the velocity.
- The path is a **complete circle** because the magnetic field is uniform and the particle remains in the field.

$$r = \frac{mv}{BQ}$$