Topic: Magnetisation and Magnetic Intensity

Class: CBSE CLASS XII

Subject: Physics

Unit: Unit 5: Magnetism and Matter

1. Why This Topic Matters

In previous topics, we learned that electric currents in wires create magnetic fields around them. But what happens when we place a material, like an iron rod, inside that magnetic field? This topic bridges that exact gap: it connects the external magnetic field (the cause) with how materials internally respond to it (the effect).

Understanding this relationship is crucial for several key reasons:

- **Clarifying Contributions:** It allows us to mathematically separate the magnetic field created by an external source (like the current in a wire) from the additional magnetic field contributed by the material itself.
- **Explaining Strong Magnets:** It explains the fundamental reason why certain materials, like iron, can be turned into powerful magnets, while others, like copper or wood, cannot. The secret lies in their internal response.
- **Practical Engineering:** This concept is essential for designing and building real-world devices. Engineers use these principles to choose the right materials for the cores of powerful electromagnets, transformers, and electric motors.

To make this distinction between the external field and the material's response clear, let's start with a simple analogy.

2. Think of It Like This

The concepts of Magnetisation (M) and Magnetic Intensity (H) can feel abstract. Using analogies can help create a strong mental picture of what's happening inside a material.

The "Crowd Becoming Synchronized" Analogy

Imagine a large crowd of people, each holding a small spinning wheel.

- **No Magnetism:** Initially, everyone is spinning their wheel randomly in different directions. From a distance, there is no overall coordinated motion. This represents an unmagnetised material, where countless atomic magnetic dipoles (the spinning wheels) are oriented randomly, cancelling each other out.

- **Applying an External Field:** Now, a powerful, rhythmic music starts playing. This music acts as an external organizing force. People start to synchronize their spinning wheels with the rhythm, all spinning in the same direction. This external organizing force is like the **Magnetic Intensity (H)**.
- **The Material Responds:** The degree to which the crowd becomes synchronized is a measure of their response. If the music is very effective and everyone aligns perfectly, the collective spinning motion is immense. This collective, synchronized alignment is the **Magnetisation (M)** of the material. A more organized crowd has a higher magnetisation.

Two More Quick Visuals

- **Iron Filings Aligning in a Field:** Think of sprinkling tiny iron filings on paper. Without a magnet, they are scattered randomly. When you bring a magnet nearby (the external field), the filings snap into alignment along the field lines. This alignment is a visual representation of magnetisation.
- **A Crowd Turning to Face the Same Direction:** Imagine a crowd in a field looking in all directions. When a speaker starts talking from a stage, people turn to face the stage. The speaker's voice is the external influence (H), and the degree to which the crowd is uniformly facing the stage is the magnetisation (M).

These intuitive ideas are described by precise definitions and formulas that are very important for your board exams.

****3. Exact NCERT Answer (Learn This for Exams)**

For your exams, it is crucial to know the precise definitions and formulas as given in the NCERT textbook. The following are the key relationships you must learn.

Magnetisation (M):

M = m_net / V

Magnetic Intensity (H):

$H = B/\mu_0 - M$

Total Magnetic Field (B):

$B = \mu_0(H + M)$

Magnetic Susceptibility (χ):

$M = \chi H$

Relative Magnetic Permeability (μ_r):

$\mu_r = 1 + \chi$

Magnetic Permeability (μ):

$\mu = \mu_0 \mu_r$

$B = \mu H$

Definition of Symbols:

- **M:** Magnetisation (in Amperes/meter, A/m)
- **m_net:** Net magnetic moment of the material (in Ampere-meter^2, $A \cdot m^2$)
- **V:** Volume of the material (in cubic meters, m^3)
- **B:** Magnetic field, Magnetic induction, Magnetic flux density (in Tesla, T)
- **H:** Magnetic Intensity (in Amperes/meter, A/m)
- **μ_0:** Permeability of free space (a constant, $4\pi \times 10^{-7}$ T·m/A)
- **χ:** Magnetic Susceptibility (dimensionless)
- **μ_r:** Relative Magnetic Permeability (dimensionless)
- **μ:** Magnetic Permeability of the substance (in Tesla-meter/Ampere, T·m/A)

Now, let's connect our "crowd" analogy directly to the most important formula: $B = \mu_0(H + M)$.

4. Connecting the Idea to the Formula

The central formula, **$B = \mu_0(H + M)$**, is a perfect mathematical description of our "crowd" analogy. Let's break it down.

1. **H is the External Influence** The **Magnetic Intensity (H)** represents the external cause trying to magnetise the material. In our analogy, it's the rhythmic music or the speaker's command trying to organize the crowd. In physics, H is generated by external "free" currents, like the current flowing through the wires of a solenoid. It is the driving force.

2. **M is the Crowd's Response** The **Magnetisation (M)** represents the material's internal response to H. It measures how much the atomic dipoles (the people in the crowd) actually align. A material with atoms that align easily will have a large M for a given H, just like a very responsive crowd becomes highly synchronized.

3. **B is the Total Effect** The formula $B = \mu_0(H + M)$ is the physics version of our analogy. **B** is the total magnetic effect you feel. It's caused by the sum of two things: the external organizing music (**H**) and the crowd's powerful synchronized response (**M**). The constant μ_0 simply translates these factors into the final field strength in Tesla.

With this connection in mind, let's look at the physical process in a more formal, step-by-step manner.

5. Step-by-Step Understanding

Here is a formal breakdown of how a material becomes magnetised when placed in an external magnetic field.

- All materials are made of atoms, which contain electrons. The motion of these electrons creates tiny atomic magnetic dipoles.
- When an external magnetic field (represented by **H**) is applied, it exerts a torque on each of these atomic dipoles.
- This aligning torque from the H-field competes with the randomizing effect of thermal energy (heat), which makes the atoms vibrate and resist alignment.
- The result of this competition is a net alignment of some atomic dipoles in the direction of the field. This net alignment is quantified as **Magnetisation (M)**.
- The total magnetic field inside the material, **B**, is the sum of the external field (from H) and the additional field generated by the material's own magnetisation (M).

A simple numerical example will make these relationships perfectly clear.

6. Very Simple Example (Tiny Numbers)

Let's imagine a material with a **magnetic susceptibility (χ) of 49** is placed inside a long solenoid. The current in the solenoid windings produces a **magnetic intensity (H) of 10 A/m**.

Let's calculate the properties of the material.

1. The Magnetisation (M): The magnetisation tells us how strongly the material responded to the external field H.

- **Formula:** $M = \chi H$
- **Calculation:** $M = 49 \times 10$ A/m $= 490$ A/m

2. The Relative Permeability (μ_r): This tells us the factor by which the material enhances the magnetic field compared to a vacuum.

- **Formula:** $\mu_r = 1 + \chi$
- **Calculation:** $\mu_r = 1 + 49 = 50$ This means the material is 50 times more "permeable" to magnetic fields than empty space.

3. The Total Magnetic Field (B): This is the final, total magnetic field inside the material.

- **Formula:** $B = \mu_0(H + M)$
- **Calculation:** $B = (4\pi \times 10^{-7}\ \text{T·m/A}) \times (10\ \text{A/m} + 490\ \text{A/m})$ $B = (4\pi \times 10^{-7}) \times (500)$ $B = 2000\pi \times 10^{-7}\ \text{T} \approx 6.28 \times 10^{-4}\ \text{T}$

This calculation reveals the power of magnetisation: the material itself, by responding to the external field, contributed 490 A/m to H's 10 A/m, amplifying the total magnetic field by a factor of 50 (μ_r). This is why iron cores are used in electromagnets.

7. Common Mistakes to Avoid

This topic can be confusing at first. Here are some common wrong ideas and the correct way to think about them.

- **WRONG IDEA:** "M and B are the same thing; they both measure the magnetic field."
  - **→ why students believe it:** They are both called 'magnetic fields', have similar units, and seem to describe the same effect inside a material.
  - **CORRECT IDEA: M** is the material's internal *response* to an external field. **B** is the *total* field, which includes both the external source (via H) and the material's internal response (M). (In our analogy: M is *how synchronized the crowd becomes*. B is the *total noise* from both the music and the synchronized crowd.)
- **WRONG IDEA:** "H is the magnetic field inside a material, and B is the field outside."
  - **→ why students believe it:** Students try to assign H and B to different locations to simplify things.
  - **CORRECT IDEA:** Both H and B exist everywhere, both inside and outside the material. Their distinction is based on their *source*, not their location. **H** is caused by external free currents, while **B** is the total field from all sources (currents + magnetisation). In a vacuum, M=0, so B becomes directly proportional to H ($B = \mu_0 H$). (In our analogy: The music (H) is heard everywhere, inside and outside the crowd. The total effect (B) is also present everywhere, but it's much stronger inside the crowd where the people (M) are adding their synchronized effort.)

8. Easy Way to Remember

To avoid confusion and keep the relationships straight, use these simple memory anchors.

- **Core Formula:** The entire topic is built around one central equation. Remember it, and you can derive the rest. $\mathbf{B = \mu_0(H + M)}$
- **Simple Phrase:** This phrase summarizes the roles of H, M, and B perfectly. "**H** drives; **M** responds. **B** is the total."

9. Quick Revision Points

- **Magnetisation (M)** is the net magnetic moment developed per unit volume of a material.
- **Magnetic Intensity (H)** is the part of the magnetic field generated only by external, free currents (like in a solenoid's wires).
- The total magnetic field inside a material is the sum of the external influence and the internal response: $\mathbf{B = \mu_0(H + M)}$.
- **Susceptibility (χ)** is a dimensionless number that measures how easily a material can be magnetised ($M = \chi H$).
- Magnetisation can be temporary (induced) or, in some materials, permanent.

10. Advanced Learning (Optional)

For students who want a deeper understanding, here are some key insights that connect these concepts more broadly.

- **Source vs. Response:** The most important conceptual leap in this topic is learning to split the total magnetic field (B) into two parts: a 'driving' or 'cause' component (**H**) from external currents, and a 'response' component (**M**) from the material itself. This separation is key to understanding how different materials behave.
- **Competition in Matter:** The final magnetisation of any material is the result of a constant battle at the atomic level. The aligning torque from the external **H-field** is always competing against the randomizing effect of **thermal energy** (heat).
- **The Limit of Magnetisation:** You cannot magnetise a material infinitely. There is a physical limit called **saturation magnetisation**. This occurs when all the atomic dipoles inside the material have been perfectly aligned with the external field. At this point, increasing H further will not increase M.
- **The Role of Susceptibility:** The value of **χ (susceptibility)** is a powerful label that tells you about a material's magnetic nature. A small positive χ indicates paramagnetism, a large positive χ indicates ferromagnetism, and a small negative χ indicates diamagnetism.

- **H and B Outside the Material:** In a vacuum or empty space, there is no material to be magnetised, so **M = 0**. The core formula $B = \mu_0(H + M)$ simplifies to $\mathbf{B = \mu_0 H}$. This shows that outside a magnetic material, B and H are simply proportional to each other.
- **Unlocking Material Science:** Understanding M and H is the essential foundation for the next topic: classifying all materials as diamagnetic, paramagnetic, and ferromagnetic based on their unique response to magnetic fields.