

Magnetism and Electromagnetism Notes

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Magnetism is a hugely interesting area of physics and so much cool stuff involves magnets, big and small. But, before we look at how magnetism works, let's make sure that we know some important definitions. 😊

Magnetism: a non-contact force that results in the attraction or repulsion between objects.

What objects are magnetic? For the GCSE we say the only magnetic materials are **iron (this also includes steel)**, **cobalt** and **nickel**. There are of course others that can be attracted to a magnet for example aluminium and tungsten can both be weakly attracted but we don't count these at GCSE.

Law of magnetic poles: opposite magnetic poles attract each other. Like magnetic poles repel each other. This is very much like the law of electric charges.

Magnetic field: the region around a magnet or a moving electric charge where magnetic forces can be seen.

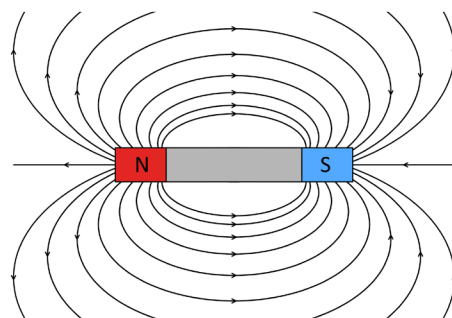
Permanent magnet: a magnet that always has a magnetic field around it. Fridge magnets are a good example of permanent magnets or the needle of a compass.

Induced magnet: a magnet whose magnetic field can be turned on or off, they are also called temporary magnets but you get the idea as to why. Any electromagnets or transformers are great examples of induced magnets.

Magnetic Field

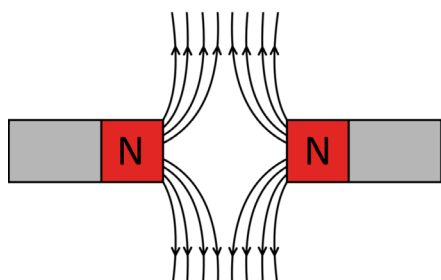
All magnets, whether they are permanent or induced, have two poles, a **north pole** and a **south pole**. Magnetic field lines always go from the north pole to the south pole.

The diagram to the right shows the typical magnetic field for a bar magnet.

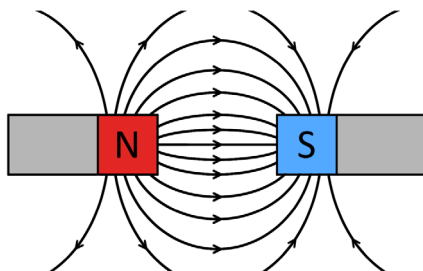


Magnetic field facts 😊

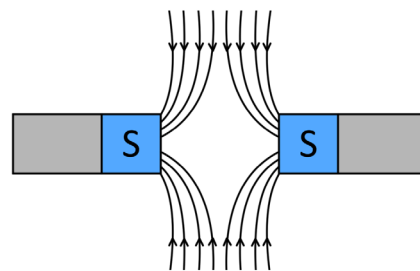
- The magnetic field lines are invisible.
- Magnetic field lines always go from the north pole to the south pole.
- The closer the magnetic field lines are, the stronger the magnet.
- The strength of a magnet is called the magnetic flux density.
- The earth has its own magnetic field. It behaves just like an enormous bar magnet.



Two north poles repel each other



North and south pole attracting



Two south poles repel each other

Electromagnetism

Electromagnetism: the relationship between magnetic fields and electric current.

Magnetic fields and electric current are fairly similar to each other. What is very interesting is how they interact when they meet each other. When magnetic fields are travelling parallel to electric current, nothing happens. But when magnetic fields are travelling perpendicular to electric current they will repel each other. We use this characteristic to either generate a force, which is called motor effect, or to generate electricity, which is called generator effect.

We will look at these in full later for now let's look at electromagnets themselves 😊

Electromagnets

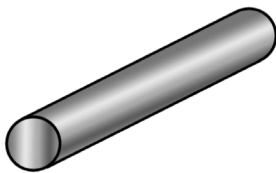
Electromagnet: a magnet created by passing an electric current through a coil of wire, which is wrapped around an iron core.

Note: The magnetic field of an electromagnet only exists while the current flows through the coil of wire.

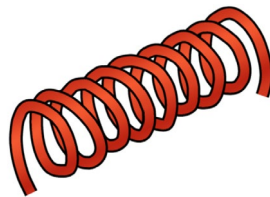
What do we need to make an electromagnet? We need an soft iron core, a solenoid and an electric current.

Soft iron core: "soft" in this case means that it's easily magnetisable. The purer the iron the "softer" it is and this makes it a better magnet. You can still make an electromagnet from steel which is an alloy of iron, but soft (pure) iron is best.

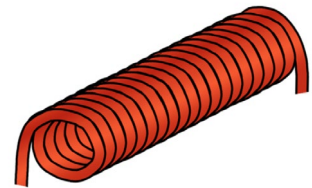
Solenoid: this is a hollow coil of wire. We can have a solenoid with only a few turns of wire or one with many turns of wire. "Turns" means how many times the wire is wrapped around the iron core.



Soft iron core

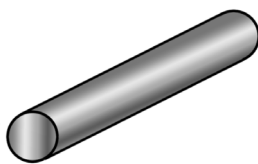


Solenoid with few turns of wire



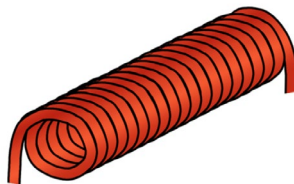
Solenoid with many turns of wire

An electromagnet is then made when you combine an iron core with the solenoid and then pass an electric current through it. The image below shows a simple electromagnet.



Soft iron core

+



Solenoid with current flowing

=



Electromagnet 😊

Electromagnets – how to make them stronger

This is a very popular question in the exams. It's a lovely question to get 😊 So, how can we make an electromagnet stronger? Please learn the following three points.

1. Increase the number of turns of coil.
2. Increase the current.
3. Use a softer iron core.

Electromagnetism – how does it work?

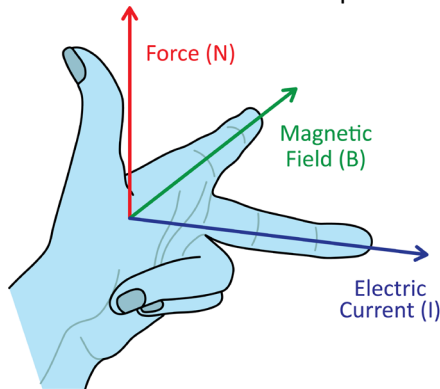
Ok, we have an iron core, a solenoid and we pass a current through it... we have an electromagnet. **But how?**

What actually happens to turn this system into an electromagnet?

Each atom of iron has its own magnetic field. When we pass an electric current near these iron atoms it causes the magnetic fields to change direction and form a domain. A domain is a region where the magnetic fields of many iron atoms have lined up and face the same direction. All of these mini magnetic fields coming together to face the same direction amplifies the effect and makes one big magnetic field around the whole iron bar.

Flemings Left Hand Rule

Flemings left hand rule is a lovely guide to help us understand how magnetic fields and electric current interact with each other and what happens as a result. It does look a bit weird when you first try it but it does work 😊
Let's check it out and see what each part of it means. The figure below shows Flemings left hand rule.



Thumb: refers to the force that the object will experience when the magnetic field and the electric current meet at 90° .

Index finger: represents the direction of the magnetic field from north pole to south pole. Its unit is Tesla (B).

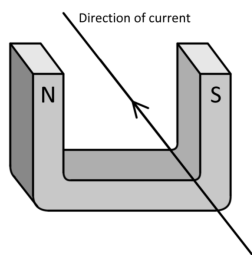
Middle finger: represents the direction of the electric current.

Note: when magnetic fields and electric current meet perpendicularly (at 90°) to each other they repel each other with the greatest force. If they meet at an angle less or greater than 90° they will still repel but not with the greatest force.

If magnet fields and electric current are travelling in the same direction (parallel to each other) then there is no repulsion, it's like they are invisible to each other when they're moving parallel.

How could this come up in an exam style question. Check out the example below 😊

Example 1: A wire is placed between the poles of a magnet, perpendicular to the magnetic field lines as shown in the figure below.

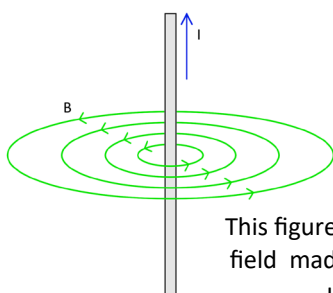


Which direction will the wire move when a current flows?

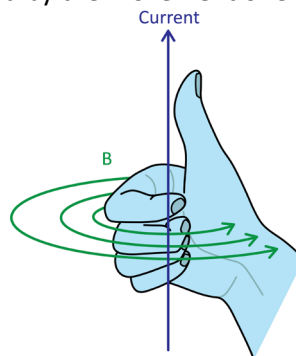
Solution: Using Flemings left hand rule, we point our index finger left to right as the magnetic field lines move from the north pole to the south pole. The current goes back into the page. In order to have our middle finger pointing back we need to turn our left hand upside down. So, now our index finger is still pointing from left to right, our middle finger is pointing back into the page let's extend our thumb. Is it pointing down? It should be 😊. So, the force is moving downwards. The wire will move downwards.

The Right Hand Rule

The right hand rule is a handy (no pun intended) way of understanding the effect of current moving through a wire. When current moves through a wire it creates a magnetic field. But most wires are made of copper and copper isn't a magnetic material so what is creating this field? It's created by the movement of electrons in the wire.



This figure shows the magnetic field made by current moving up the wire.



This figure shows the right hand rule being used to show direction of current.

How does the right hand rule work?

1. Point your right thumb in the direction that the current is moving.
2. Curl your fingers around the wire.
3. The direction in which your fingers curl represents the direction of the magnetic field around the wire.

Motor Effect

This can seem a little bit scary at first and it does scare people but I promise it's absolutely fine once we get used to it! One thing that we really should know to help us understand this is Fleming's left hand rule. So, if you're a bit unsure of that please go back and make sure you know it well before you continue 😊

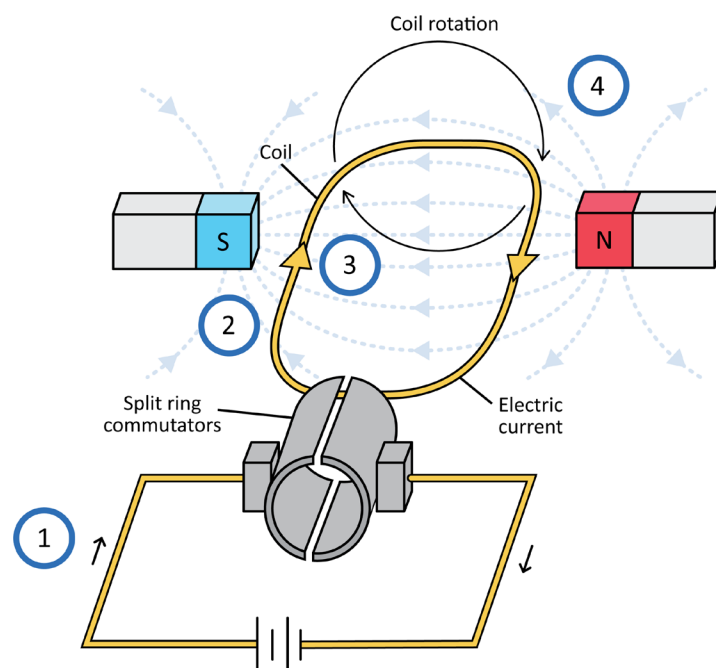
Motor effect: the interaction of a magnetic field and an electric current to produce a force on a wire that is carrying an electric current.

Doesn't sound too bad right? It builds on a lot of the material we already know about electromagnets 😊 and Fleming's left hand rule of course.

Note: we must remember that when a magnetic field and an electric current meet perpendicularly they will repel each other and cause a resultant force on the object in the fields.

Extra note: if we have two aspects of Fleming's left hand rule we can generate the third aspect. In motor effect we have the magnetic field and the electric current so we can generate a force 😊

The diagram below shows motor effect in action using a DC (direct current) motor.



Let's talk through motor effect in a step by step way 😊 When motor effect happens all of the steps happen at once of course but looking at it step by step can help us understand it!

Step 1: current flows into the coil: a direct current passes through the coil of wire.

Step 2: a magnetic field is created: this current creates its own magnetic field around the wire.

Step 3: the fields interact: the magnetic field of the wire interacts with the magnetic field of the permanent magnets. This creates a force on the wire.

Step 4: the coil starts to spin: because the current travels in opposite directions on each side of the coil, one side is pushed upwards and the other side is pushed downwards. This makes the coil rotate.

The split ring commutators (these are the clever part): to stop it from just flipping halfway and getting stuck, the split ring commutator swaps the contacts every half turn. This keeps the forces pushing in the same rotational direction, allowing it to spin continuously.

A question could ask how could we increase the speed of the motors. We could do the following to increase the speed.

1. Increase the current flowing through the wire.
2. Increase the strength of the magnetic field of the permanent magnets.
3. Increase the number of turns on the coil.

Induced Potential and the Generator Effect

What is induced potential? Well, induced means to “bring about” and potential in this case is referring to potential difference. Let’s remind ourselves here what the potential difference is.

Potential difference: a difference in electrical potential between two components or objects. It is measured in volts (V). A potential difference produces an electric current, this will then produce a force on the charged particles in the field. The bigger the potential difference the bigger the force on the particles 😊

Induced potential is the potential difference that is made in a conductor when it experiences a changing magnetic field.

How does induced potential work? When a magnetic field changes around a conductor, like a wire for example. It causes electrons in the conductor to move, creating a current. This movement of electrons results in a potential difference across the conductor.

There are two ways of inducing this potential difference across the conductor and it depends on who is moving 😊

1. The magnet moves and the conductor stays stationary.
2. The conductor moves and the magnet stays stationary.

Either way, the result will be the same. We induce a potential difference, we made a voltage. This potential difference will now cause a current to flow and we now have electricity. This whole process is called generator effect.

What is the generator effect? It is the process of generating an electric current in a conductor when it moves through a magnetic field or when the magnetic field moves around the conductor.

Note: induced potential leads to the generator effect.

How does the generator effect work? First, induced potential is used to create a potential difference across the conductor and if the conductor is part of a complete circuit then that potential difference causes a current to flow.

Where is the generator effect used to produce current? It is used in electric generators in power stations as well as in alternators and dynamos. We need to understand how the generator effect is used in an alternator and a dynamo.

Alternators

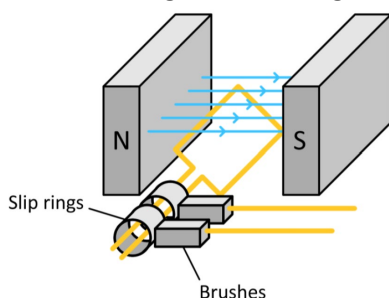
An alternator: a component that generates alternating current (AC).

What is alternating current? It is a type of electric current in which the direction of flow of electrons reverses periodically. So, its current can change direction to go forwards and then change to go backwards.

Exam note: The number of times the current changes direction per second is called its frequency, measured in hertz (Hz). In the UK and Europe, the frequency of the mains electricity is 50 Hz, meaning the current changes direction 50 times per second. This is a very popular multiple choice or short answer question in the GCSEs.

How does an alternator produce AC? The alternator produces alternating current (AC) because the magnetic field reverses as the conductor spins. This naturally causes the direction of the current in the conductor to alternate its direction.

Where are they used? They’re commonly used in cars to charge the battery and supply the electrical systems like the air conditioning while the engine is running. The figure below shows a simplified alternator.



How does it work? Step by step

Step 1: The coil of wire is rotated mechanically within the magnetic field. This could be done using a turbine.

Step 2: As the coil spins, the wires cut through the magnetic field lines.

Step 3: This induces a potential difference across the ends of the coil.

Step 4: This potential difference causes an alternating current to flow.

What do the slip rings actually do? They allow the conductor to spin freely within the magnetic fields.

What are the carbon brushes for? They ensure an electrical connection with the slip rings even when the conductor is spinning. Carbon is used because it’s a good conductor, it’s tough and it’s cheap.

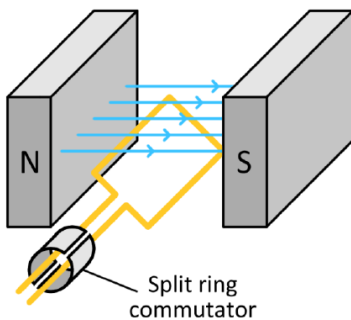
Dynos

A dynamo: a component that uses the generator effect to convert kinetic energy into direct current (DC).

What is direct current? It is a type of electric current where the current does not change direction. It only travels in one direction.

How does a dynamo produce direct current? The conductor spins in a magnetic field, that should produce an alternating current right? It does indeed 😊 The split ring commutator ensures that the direction of the current moves in only one direction. Without the split ring commutator, the current would move in two directions just like in an AC generator.

Where are they used? They don't have many uses. Mostly they have been replaced by more efficient electric motors. They can be used for lights on bicycles. The wheel of the bike turns, turning the conductor of the dynamo which interacts with the magnetic field of the permanent magnets, generating a direct current which turns on the light. The figure below shows a simplified dynamo.



How does it work? Step by step

Step 1: kinetic energy from a moving object turns the conductor inside the magnetic field.

Step 2: As the conductor spins, it cuts through the magnetic field lines, which induces a potential difference across the coil.

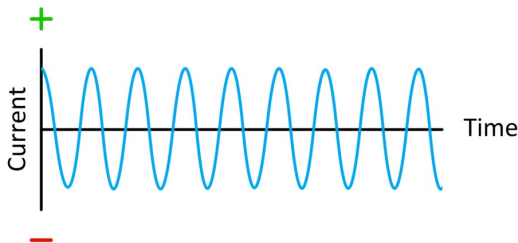
Step 3: The current flows through the brushes and out to the circuit, powering devices such as lights etc.

Could we be asked anything else about alternators and dynamos?

Yes, we could be asked what the current they produce looks like on a graph. This mostly tends to come up as a multiple choice question but it could appear as a match up activity.

Alternator

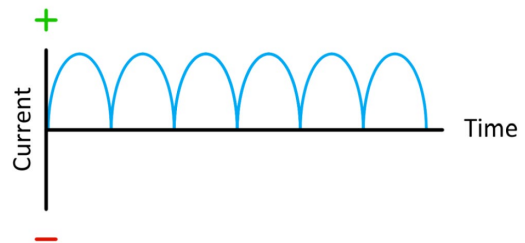
An alternator produces an alternating current which typically looks like the figure below.



Note: we can see it crosses the x axis showing the current can move in two directions.

Dynamo

A dynamo produces a direct current which typically looks like the figure below.



Note: we can see that the current does not cross the x axis, showing it can only move in one direction.

Sound Speakers

Sound speakers are an good example of motor effect. They can look a bit confusing at first but they're actually really straightforward. As the cone moves in and out it moves the air in front of it creating sounds.

How does it work? Step by step

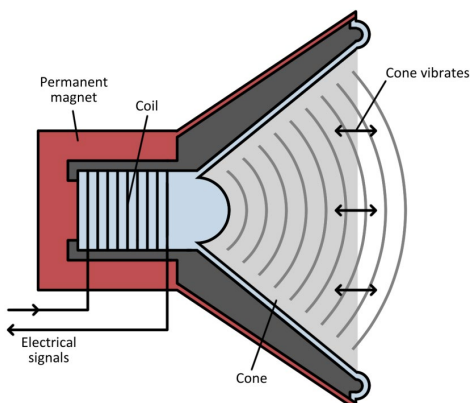
Step 1: an alternating current comes to the speaker.

Step 2: this generates a magnetic field around the coil.

Step 3: the magnetic field interacts with the magnetic field of the permanent magnet.

Step 4: this interaction causes a resultant force which moves the cone.

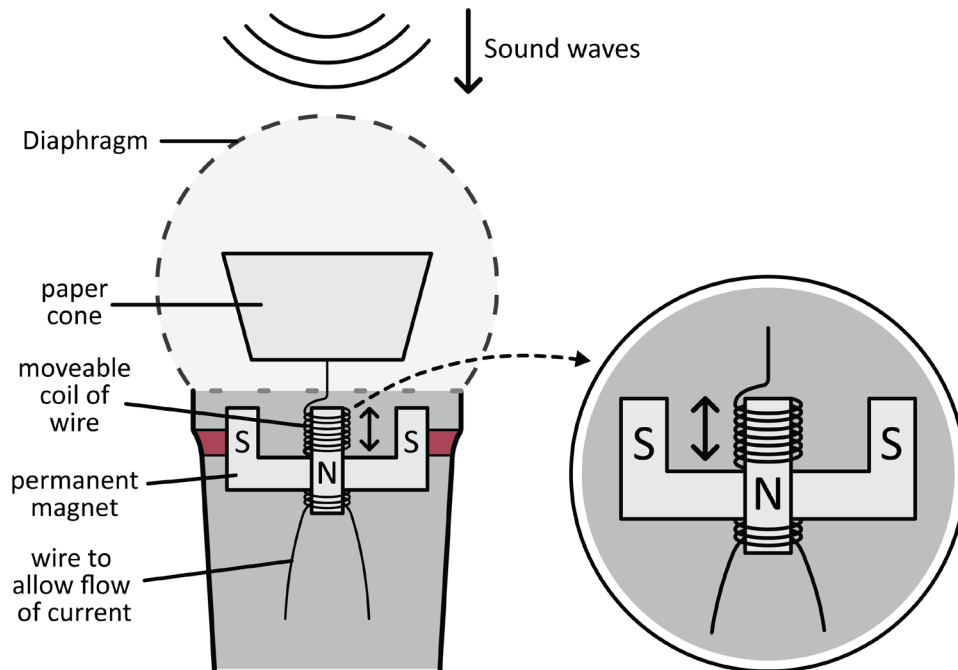
As the current is alternating(moving in different directions) the cone moves up and down as the current changes. That's it 😊



Microphones

Microphones are devices that convert sound waves into electrical signals. They work using generator effect. We provide the motion when we speak as the sound waves cause the cone to vibrate. There is already a permanent magnet in the microphone and of course when a moving coil and a magnetic field meet we generate a current.

They are pretty much the opposite of speakers 😊 The figure below shows a simplified microphone.



Step 1: a person speaks into a microphone.

Sound waves cause the diaphragm to vibrate back and forth. Since the coil is attached to the diaphragm, the coil also vibrates.

Step 2: as the coil vibrates, it cuts through the magnetic field lines of the permanent magnet.

Step 3: This process induces a potential difference across the ends of the coil.

Yes, this is the generator effect at work 😊 .

Step 4: Because the vibrations are back and forth, the direction of the induced potential difference and current constantly reverses.

This creates an alternating current that has the same frequency as the original sound waves.

This alternating current travels to an amplifier where the size of the current is increased and it is then sent to a speaker and converted to sound waves.

Magnetic Flux Density

Magnetic flux density: a measure of the strength of a magnetic field at a particular point. Magnets are always strongest at their poles.

The more lines there are around a bar magnet, the greater the **density** of the magnetic field, the stronger the magnetic field and therefore the stronger the magnet is.

Magnetic flux density is measured in Tesla (B). This has nothing to do with the car maker Tesla.

Magnetic flux density can be calculated using the following equation:

Force = magnetic flux density × current × length in meters

$$F = B \times I \times L \quad \text{or} \quad B = \frac{F}{I \times L}$$

Check out the following examples of this equation at work 😊

Example 1: A 2.5 m length of wire is placed at a right angle to a magnetic field. The wire carries a current of 3.0 A and experiences a magnetic force of 1.5 N.

Calculate the magnetic flux density of the field.

Step 1: state the equation.

$$F = B \times I \times L$$

Step 2: substitute the values into the equation.

$$1.5 = B \times 3.0 \times 2.5$$

Step 3: rearrange the equation and solve for B.

$$B = 1.5 \div (3.0 \times 2.5)$$

$$B = 1.5 \div (7.5)$$

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

Example 2: A small copper rod of length 4.0 cm carries a current of 250 mA. It is placed perpendicular to a uniform magnetic field and experiences a force of 0.012 N.

Calculate the magnetic flux density of the field.

Step 1: do the unit conversions.

There has been a big move in the recent years to have lots of unit conversions in calculations in the GCSE exams.

$$\text{Convert mA to A: } 250 \text{ mA} = 0.25 \text{ A}$$

$$\text{Convert cm to m: } 4 \text{ cm} = 0.04 \text{ m}$$

Step 2: rearrange the equation and solve for B.

$$B = \frac{F}{I \times l}$$

$$B = \frac{0.012}{0.25 \times 0.04}$$

$$B = 1.2 \text{ T}$$