Physics Factsheet

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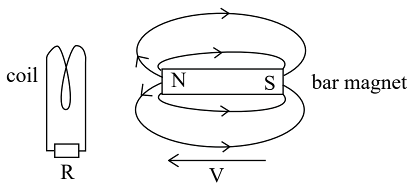
Lenz' Law in Electromagnetic Devices

Faraday's Law of Electromagnetic Induction is a basic law of Physics, explaining an observed Physics phenomenon. Lenz' Law is somewhat different. It says that the Law of Conservation of Energy must be obeyed, and that we can use this to predict the direction of an induced magnetic field. This is very useful in understanding what is happening in electromagnetic devices that make use of e.m. induction. It can also allow us to design devices to do a specific job.

Lenz' Law Theory

A very simple set-up to illustrate this is the motion of a bar magnet at constant speed towards (or away from) a coil connected to an external circuit:



As the magnet approaches the coil, the magnetic field (due to the bar magnet) in the vicinity of the coil will be as shown below, and will be increasing in magnitude.

At the coil

⟵ B

⟵ dB/dt

Faraday tells us that this increasing magnetic field will induce a current in the coil. This induced current will cause the coil to become an electromagnet, with its own magnetic field. But in which direction will this induced magnetic field be directed?

At the coil

⟵ B

⟵ dB/dt

⟵ induced B (a)

Or

At the coil

⟵ B

⟵ dB/dt

⟶ induced B (b)

In (a), the induced magnetic field will cause the magnetic field at the coil to increase faster. This increases the induced current. The electrical energy dissipated in the circuit becomes greater and greater, but there is no source for this increased electrical energy. The Law of Conservation of Energy is violated. So, the induced field cannot add to the increasing magnetic field from the bar magnet.

In (b), the induced magnetic field will oppose the change in applied field and cause the magnetic field at the coil to increase more slowly. This reduces the induced current, etc. So, the Law of Conservation of Energy is not violated. In this set-up, the magnetic field of the induced current opposes the magnetic field caused by the approaching magnet.

However, this is not always the case. If we were to look at the situation when the bar magnet is moving away from the coil, and use similar logic, we would see that the induced magnetic field would be in the same direction as the reducing magnetic field from the departing bar magnet. Otherwise, the Law of Conservation of Energy is violated. The magnetic field of the induced current reinforces the magnetic field of the departing magnet.

In both cases, the induced magnetic field tries to stop the magnetic field at the coil from changing. The increasing magnetic field is opposed; the decreasing magnetic field is reinforced.

This is effectively what Lenz' Law tells us - **an induced magnetic field will be in such a direction as to oppose the change in magnetic field causing the induction effect**.

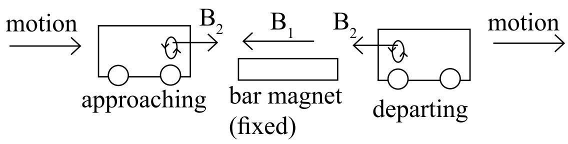
Sometimes this can be useful. We shall look at some examples of Lenz' Law in action.

Electromagnetic (Eddy Current) Braking

This is very similar to the example we used in describing the theory. However, this time let us think of a stationary bar magnet and a metal carriage rolling towards it. As the carriage approaches the magnet, the magnetic field, B_1, at the front of the carriage (due to the bar magnet) will be increasing. Faraday says that this will cause induced eddy currents to flow in circles in the front of the metal carriage, accompanied by an induced magnetic field, B_2. Lenz tells us that B_2 will oppose B_1 (as B_1 is increasing).

Throughout, we will refer to the applied magnetic field as B_1 (which may be as the result of an electric current), and the induced magnetic field as B_2.

Similarly, as the metal carriage passes the bar magnet and starts to depart, the magnetic field, B_1, at the rear of the carriage (due to the bar magnet), will be decreasing. Lenz tells us that the eddy currents must reverse, so that the induced magnetic field, B_2, will now reinforce B_1 (as B_1 is decreasing).

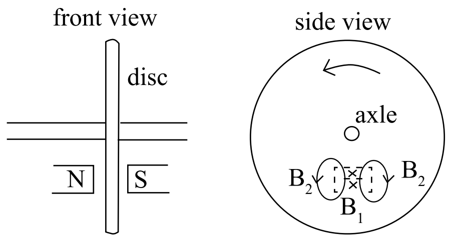


The diagram shows how the magnetic fields repel each other as the carriage approaches and attract each other as the carriage departs. This will result in a braking effect throughout the whole of this motion.

From the energy viewpoint, the loss of kinetic energy as the carriage slows is converted into heat energy in the metal carriage (Joule heating from the eddy currents).

In this example, we have explained the effect of the induced field on forces between the coil and carriage. We have also referred to the energy changes that take place (and we link them to conservation of energy). Lenz' Law can help us explain both energy effects and motion effects.

For electromagnetic (eddy current) braking in practical applications, aluminium discs are mounted on the axles. A strong magnetic field is applied across each disc. As an area of the disc passes through the magnetic field, eddy currents are induced in the disc just in front of the magnet and just behind (regions where the magnetic field on the disc will be changing fastest). These induced eddy currents will cause their own magnetic fields, which can either support or oppose the magnet's field.



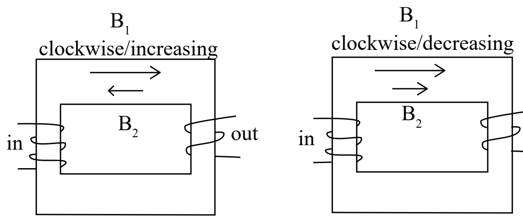
On the portion of the disc approaching the magnet, the induced magnetic fields will oppose the applied magnetic field; on the portion leaving the magnet, the induced magnetic fields will support the applied field. At both edges, the effect will be to slow down the rotation of the disc (and the speed of the vehicle). Again, in energy terms, some of the kinetic energy of the vehicle is turned into Joule heating in the disc.

These eddy current brakes are used in high speed electric trains, and also in devices such as circular saws and rowing machines.

Transformers

Transformers are very common electromagnetic devices. We can see how Lenz' Law helps us explain the energy transfers involved.

A changing input current through the primary coil causes a changing magnetic field around the iron core of the transformer. This induces a changing output current through the secondary coil (and the external circuit). This induced output current will itself be accompanied by a magnetic field. And Lenz tells us that this induced magnetic field will oppose the change occurring in the magnetic field from the input current (at any instant).

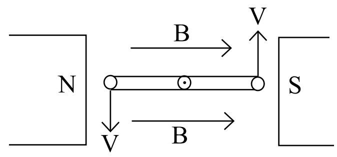


At both instants shown, the applied magnetic field, B_1, is in the clockwise direction. However, in the first diagram, it is increasing; in the second diagram, it is decreasing. In each case the induced magnetic field, B_2, will be in a direction to oppose the change in the applied field.

At both instants, the **resultant** magnetic field in the core will now be changing less quickly than before. This would result in a reduced output. To maintain the output current, a greater input current must be drawn from the supply. So, this extra input energy is the source of the output energy in the secondary coil and circuit.

Back E.M.F. in a Motor

Motors involve a coil spinning through a magnetic field. In a motor, a current is applied through the coil, and motion occurs. However, the motion of the wires of the coil across the magnetic field induces a second current through the coil.



end view of coil

And, as before, Lenz tells us that this induced current will effectively work against the applied current, reducing the speed of the motor.

> *Sometimes we can just talk about currents rather than the further step to magnetic fields. The situation is the same – we are just being a bit lazy.*

The faster the motor is spinning, the greater this"back e.m.f." is, and the greater the braking effect. We must apply an increased current to maintain the motor speed. Again, from an energy viewpoint, we are supplying electrical energy to produce mechanical energy (if the induced current caused the motor to accelerate, we would have a real problem with conservation of energy).

Despite the fact that Lenz has dashed our hopes for a perpetual motion machine based on electromagnetic devices, we should not condemn him too much. In-fact, it is worth trying to answer a few questions about electromagnetism.

Questions

1. Why is the disc used in eddy current braking made of aluminium rather than steel?
2. Why are the iron cores in transformers usually made from many sheets of iron that are glued together?
3. In eddy current braking in a vehicle, how is the amount of braking controlled?
4. Explain the reason for eddy current braking in circular saws and rowing machines.
5. In a vehicle with eddy current braking, the vehicle has a steady speed of 30m/s. The eddy current braking is applied, and causes a total heating effect of 5kW in the discs. What resistive force would be applied to the vehicle?

Answers

1. Aluminium is a much better electrical conductor. The induced eddy currents will be much stronger, causing a greater induced magnetic field and more energy loss to heat (and a greater braking effect). In addition, aluminium is a better thermal conductor, so the heat produced will be more efficiently brought to the surface of the metal and lost to the air.
2. The glue is an insulator. It is very difficult for eddy currents to form in the iron core. This reduces the heating effect and increases the efficiency of the transformer. What we really want is for all of the induced current to be in the secondary coil.
3. Unlike in our diagram, the magnetic field is supplied by an electromagnet. The current to the electromagnet controls the strength of the applied magnetic field. No current – no braking.
4. In circular saws, the braking effect would cause the saw to stop spinning quickly when it is turned off. This is obviously desirable. In rowing machines, the braking effect would provide a means of varying the resistance to motion (and so the effort needed to perform the exercise).
5. Power = Force × Velocity. The force should work out to 167N.

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