

Quantum Mechanics_ Lenz's law

Lenz's law [/]ˈlɛntsɪz lɔː is a common way of understanding how electromagnetic circuits obey Newton's third law and the conservation of energy.^[1] Lenz's law is named after Heinrich Lenz, and it says:

An induced Electromotive force (emf) always gives rise to a current whose magnetic field opposes the original change in Magnetic flux.

Lenz's law is shown with the negative sign in Faraday's law of induction:

$$\mathcal{E} = -\frac{\partial\Phi_B}{\partial t},$$

which indicates that the induced emf (\mathcal{E}) and the change in magnetic flux ($\partial\Phi_B$) have opposite signs.^[2]

For a rigorous mathematical treatment, see Electromagnetic induction and Maxwell's equations.

Opposing currents

If a change in the magnetic field of current i_1 induces another Electric current, i_2 , the direction of i_2 is opposite that of the change in i_1 . If these currents are in two coaxial circular conductors ℓ_1 and ℓ_2 respectively, and both are initially 0, then the currents i_1 and i_2 must counter-rotate. The opposing currents will repel each other as a result.

Lenz's law states that the current induced in a circuit due to a change or a motion in a magnetic field is so directed as to oppose the change in flux or to exert a mechanical force opposing the motion.

Example

Currents bound inside the atoms of strong magnets can create counter-rotating currents in a copper or aluminum pipe. This is shown by dropping the magnet through the pipe. The descent of the magnet inside the pipe is observably slower than when dropped outside the pipe.

When an emf is generated by a change in magnetic flux according to Faraday's Law, the polarity of the induced emf is such that it produces a current whose magnetic field opposes the change which produces it. The induced magnetic field inside any loop of

wire always acts to keep the magnetic flux in the loop constant. In the examples below, if the B field is increasing, the induced field acts in opposition to it. If it is decreasing, the induced field acts in the direction of the applied field to try to keep it constant.

Detailed interaction of charges in these currents

In electromagnetism, when charges change positions along electric field lines, work is done on them, whether it involves storing potential energy (negative work) or increasing kinetic energy (positive work).

When net positive work is applied to a charge q_1 , it gains momentum. The net work on q_1 thereby generates a magnetic field whose strength (in units of magnetic flux density (1 tesla = 1 volt-second per square meter)) is proportional to the speed increase of q_1 . This magnetic field can interact with a neighboring charge q_2 , passing on this momentum to it, and in return, q_1 loses momentum.

The charge q_2 can also act on q_1 in a similar manner, by which it returns some of the emf that it received from q_1 . This back-and-forth component of emf contributes to magnetic Inductance. The closer that q_1 and q_2 are, the greater the effect. When q_2 is inside a conductive medium such as a thick slab made of copper or aluminum, it more readily reacts to the emf sent to it by q_1 . The energy of q_1 is not "instantly" consumed only as heat generated by the current of q_2 but is also stored in *two* opposing magnetic fields. The energy density of magnetic fields tends to vary by the square of the magnetic field's intensity; however, in the case of magnetically non-linear materials such as ferromagnets and superconductors, this relationship breaks down.

Field energy

The electric field stores energy. The energy density of the electric field is given by:

$$u = \frac{1}{2}\epsilon|\mathbf{E}|^2,$$

In general the incremental amount of work per unit volume δW needed to cause a small change of magnetic field $\delta\mathbf{B}$ is:

$$\delta W = \mathbf{H} \cdot \delta\mathbf{B}.$$

Conservation of momentum

Momentum must be conserved in the process, so if q_1 is pushed in one direction, then q_2 ought to be pushed in the other direction by the same force at the same time. However, the situation becomes more complicated when the finite speed of electromagnetic wave propagation is introduced (see retarded potential). This means that for a brief period of time, the total momentum of the two charges is not

conserved, implying that the difference should be accounted for by momentum in the fields, as asserted by Richard P. Feynman.^[3] Famous 19th century electrodynamicist James Clerk Maxwell called this the "electromagnetic momentum".^[4] Yet, such a treatment of fields may be necessary in the case of applying Lenz's law to opposite charges. It is normally assumed that the charges in question have the same sign. If they are not, such as a proton and an electron, the interaction is different. An electron generating a magnetic field would generate an emf that causes a proton to change its motion in the same direction as the electron. At first, this might seem to violate the law of conservation of momentum, but of course, such an interaction indeed conserves momentum once taking into account the momentum of electromagnetic fields.

References

1. [^] Schmitt, Ron. *Electromagnetics explained*. 2002. Retrieved 16 July 2010.
2. [^] Giancoli, Douglas C. (1998). *Physics: principles with applications* (5th ed.). p. 624.
3. [^] *The Feynman Lectures on Physics*: Volume I, Chapter 10, Page 9.
4. [^] Maxwell, James C. *A treatise on electricity and magnetism, Volume 2*. Retrieved 16 July 2010.

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