

Visualising Lenz's Law with a dynamic diagrammatic representation

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Abstract

The paper aims to document my journey to visualise the scientific principle of Lenz law through the recreation of Faraday's Law of Induction. The paper documents my initial process of selection of topic, classification and study of current visualization methods, and then the finalised approach of visualization. The output was an interactive simulation created for the web, which allows users to interact with

real-world elements and experiment with the values and direction of the current, reinforcing the specification of the phenomenon. Figma and AngularJS were used to build the simulation, which was later deployed to be tested out by the users. The simulation can be tested out at: <https://rishabhkumar.design/lenzlaw/>

Keywords

Information visualization, graphic visualization, interaction design, education

1. Process

1.1 Selection of topic

I attempted to list the scientific principles that I was interested in for visualization. The entire process of finalising a scientific principle and selecting a medium was linear for me, as the medium was highly dependent on my chosen scientific principle. I aimed at selecting in the realm of physics, and something where simulation was involved, to learn new techniques to

render the same. I had finalised to work on the visualization of Lenz's law, supplementing it with visualising principles of Faraday's Law of Induction, as these principles go hand in hand while teaching the concepts.

1.2 Definition of the Scientific Principle

The following excerpt is directly quoted from Britannica's article about Lenz's Law [1] and its workings:

"Lenz's law, in electromagnetism, states that an induced electric current flows in a direction such that the current opposes the change that induced it. This law was deduced in 1834 by the Russian physicist Heinrich Friedrich Emil Lenz (1804–65).

Thrusting a pole of a permanent bar magnet through a coil of wire, for example, induces an electric current in the coil; the current, in turn, sets up a magnetic field around the coil, making it a magnet. Lenz's law indicates the direction of the induced current. (The direction of the induced current from Lenz's law contributes to the minus sign in Faraday's law of induction.) Because like magnetic poles repel each

other, Lenz's law states that when the north pole of the bar magnet is approaching the coil, the induced current flows in such a way as to make the side of the coil nearest the pole of the bar magnet itself a north pole to oppose the approaching bar magnet. Upon withdrawing the bar magnet from the coil, the induced current reverses itself, and the near side of the coil becomes a south pole to produce an attracting force on the receding bar magnet."

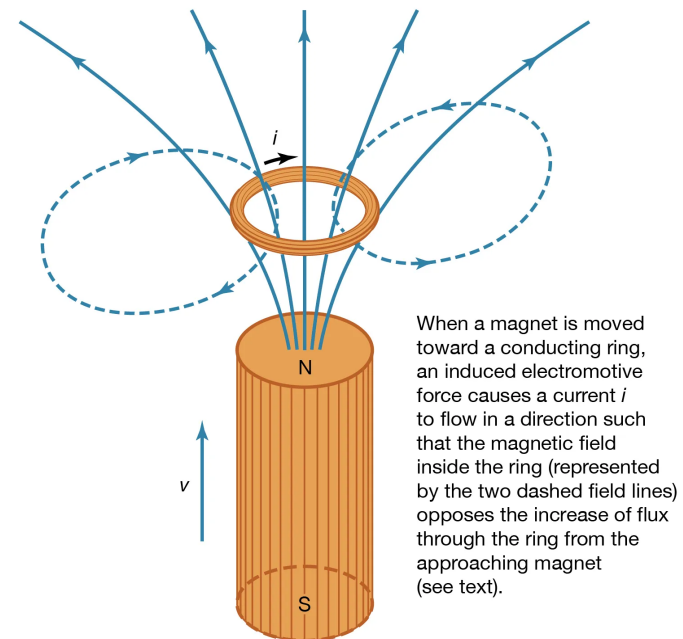


Figure 1: Demonstration of Lenz's Law, courtesy of the Department of Physics and Astronomy, Michigan State University [1]

1.3 Study of current visualization methods

I looked up current methods of teaching the laws. There were two major kinds of static representations of Lenz's Law. School textbooks usually use static diagrams to represent the interaction between coils and the magnet. The change in the direction of the current is represented by arrows in different directions, and sometimes complemented by an attached light bulb and/or galvanometer to show the presence of current through real-world elements. These static diagrams fail to visualise the changing directions of the current, and how the rate of change of magnetic flux is associated with the magnitude of the current produced in the solenoid coil.

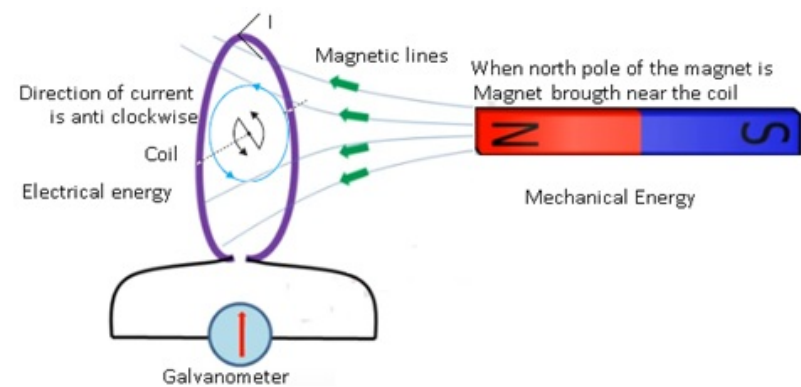


Figure 2: Demonstration of Lenz's Law, NCERT

Another type of diagram that was utilised was stepped static diagrams, where multiple phases of the process, that is the direction of the current with respect to the motion of the magnet, were visualised with separate diagrams. Although the diagram is successful in showing the different phases and directions of current with respect to the coil and movement of the magnet, it is unable to show the transition and the relation between the two phases of the process intuitively.

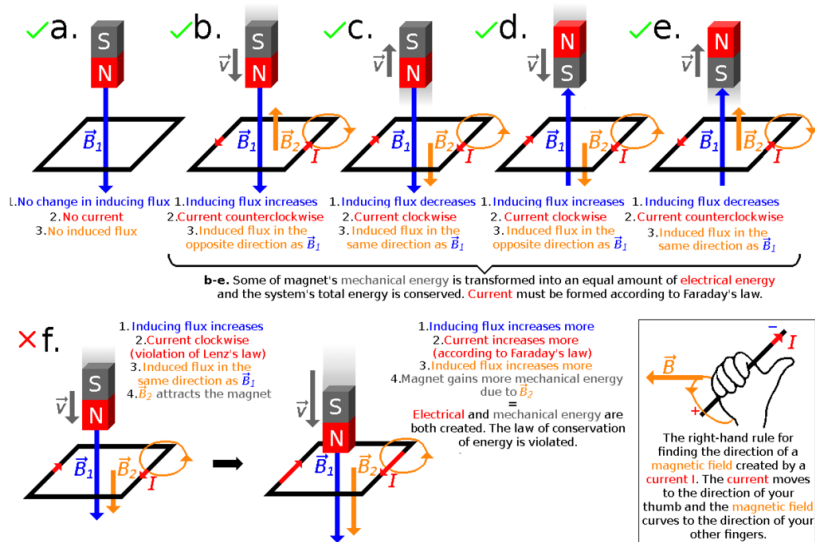


Figure 3: Demonstration of Lenz's Law, Wikipedia, by Keminsti, Lenz's law tells the direction of a current in a conductor loop induced indirectly by the change in magnetic flux through the loop. Scenarios a, b, c, d and e are possible. Scenario f is impossible due to the law of conservation of energy. The charges (electrons) in the conductor are not pushed in motion directly by the change in flux, but by a circular electric field (not pictured) surrounding the total magnetic field of inducing and induced magnetic fields. This total magnetic field induces the electric field. [7]

Real-life experiments seemed to be the most intuitive way to visualise the phenomenon, as videos created by

educators across the world used real-life examples and experiments, the most famous ones being the dropping of a magnet through a hollow metal pipe, where the magnet falls slowly along when it travels along the pipe under the influence of gravity. [2] Experiments representing the conventional setup represented in the above diagrams were also used by educators, which represented all the states and the transition between them.

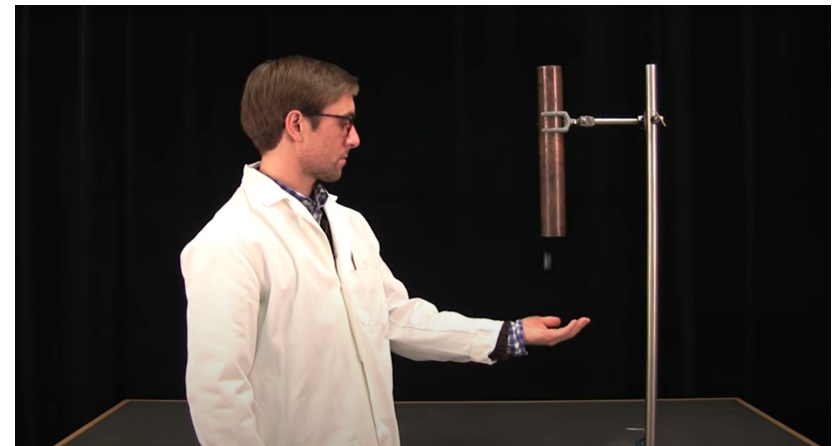


Figure 4: A snapshot from TSG Physics Video, Lenz's Law with copper pipe [2]

1.4 Review of published graphical/data visualizations

I did a short study of various visualizations to draw inspiration to create my visualization. I differentiated these visualizations into two groups: 1. Visualizations focussing on concepts/explanatory method, and 2. Visualizations that are based on the empirical method of representation of data. The former focused on an infographic approach, for example, using 3D animated models to depict the size difference between the parts of an engine in Figure 5 [4], while the latter focused on explaining concepts through the interaction of data points as shown in Figure 6, where time has been taken as a variable to represent the distance travelled by a user during their visit on the website [5].

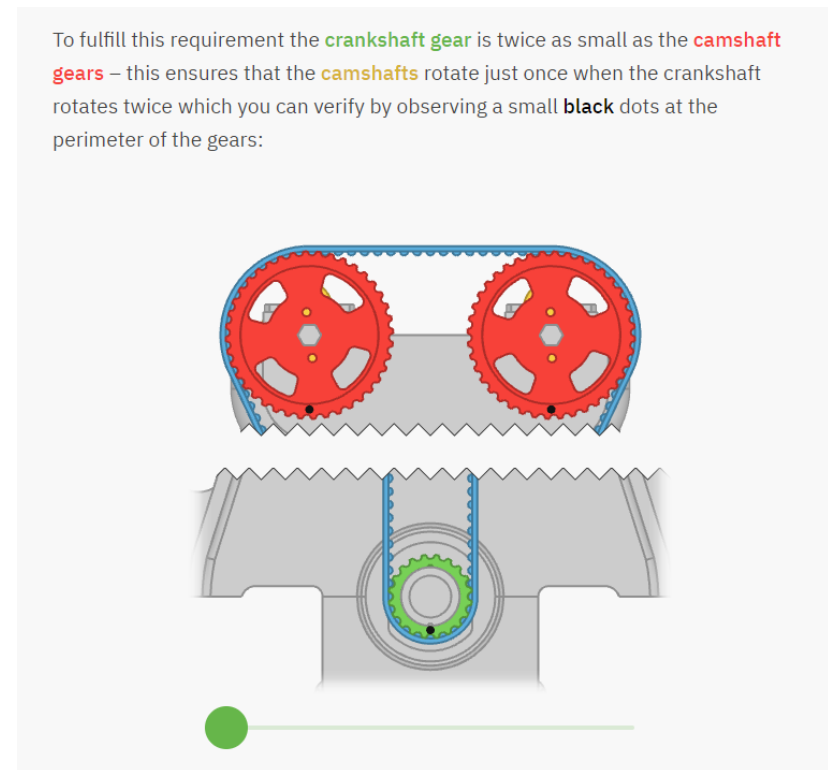


Figure 5: Crankshaft vs Camshaft size comparison, Internal Combustion Engine - Bartosz Ciechanowski [4]

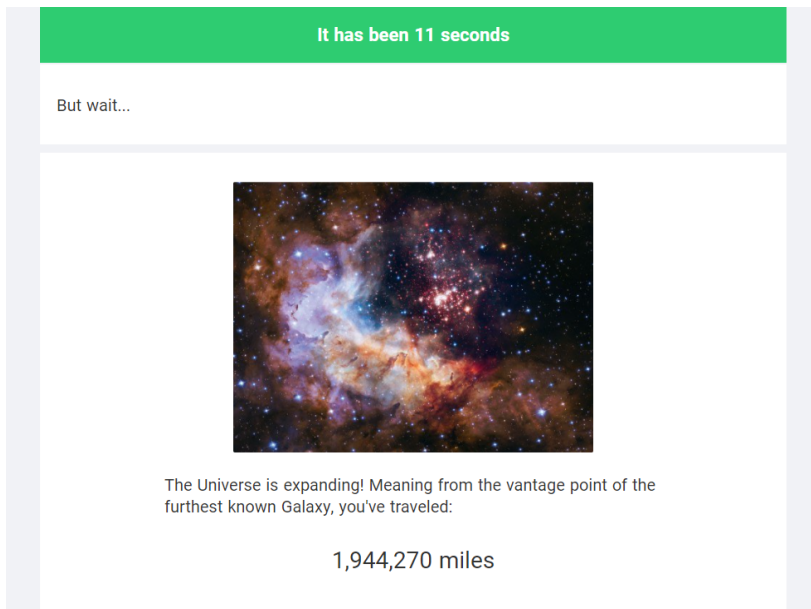


Figure 6: Universal Expansion, How Fast Are You Moving? - Neil Agarwal [5]

Blob Opera by David Li [6] is an artistic interpretation of harmony which allows users to mix and interact with multiple ranges of vocals in an opera. The visualisation used movements of the mouse fixed along the horizontal and vertical axis, which allows the user to control the scale and tonalities of the sound of the individual performer 'blob'. The user can decide to play individual ranges and mute other vocals to create various compositions. These particular visualisations

directed me to make my interpretation of the visualisation of Lenz's Law.

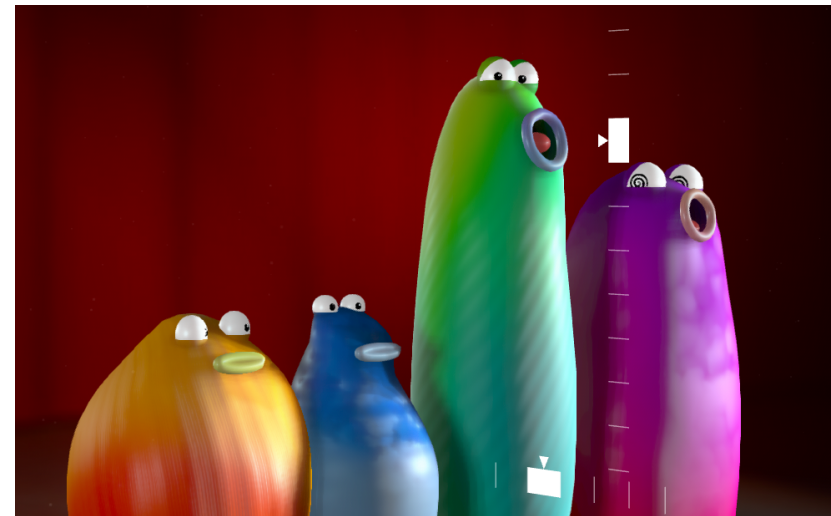


Figure 7: Blob Opera screenshot - David Li in collaboration with Google Arts & Culture [6]

1.5 Review of published graphical/data visualizations

Taking into consideration all the types of visualization, I aimed at using an infographic approach to represent Lenz's law using a dynamic graphical representation, where the user can interact with a virtual representation of real-world elements to create

variations states and phases of the principle. It will be complemented by quantitative simulation, where the rate of input will influence the output of the magnitude of the current induced in the solenoid. The mouse direction and speed of movement will be mapped to the movement of the magnet. The illustration will also be complemented by definitions and descriptions regarding the phenomenon, and real-life examples that utilise the principle for day-to-day use.

The interactive graphic will be deployed on a website that will be accessible to all to test and experiment.

2. Development and Deployment

2.1 Concept Creation

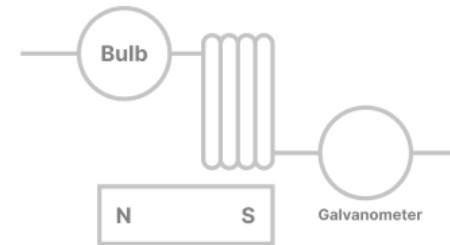
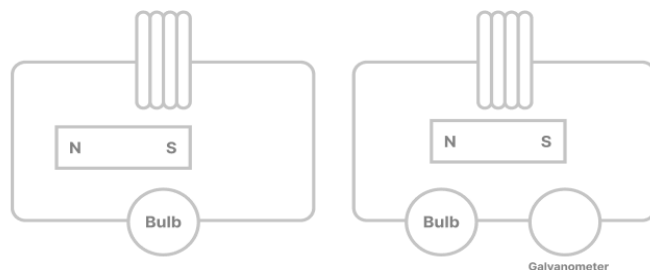


Figure 8: Concept sketches for the visualisation

The development process started with making initial sketches that are a close representation of the conventional static diagram. The aim was to maintain the similarity to utilise the familiarity of users/students with the original concept used to explain the phenomena. After some iterations, the diagram was adjusted to suit the standard proportions of a desktop website. The wires were left open at the end to give the magnet a visually unrestricted free path to move, to convey the depth of the elements in a two-dimensional representation of the experiment. The movement of the magnet was restricted to a single, that is, horizontal axis, to simplify the rate change of magnetic flux with respect to the solenoid, therefore simplifying the calculation.

The magnetic flux has been kept constant to simplify the mathematical calculations. The users will be allowed to change the number of turns in the solenoid, therefore allowing the users to experiment with the magnitude of current produced. The current induced is directly proportional to the number of turns in the solenoid. The direction of the current is indicated by the arrows. A galvanometer is added to the circuit to show the direction of the current, to have a real-life representation of the instrument that is used to show the direction of the current. A bulb is also added as a part of the circuit, which lights up when current is induced in the circuit.

Magnetic field lines of the magnet are also visualised, as it is difficult to perceive their presence in reality without assistance. The lines are animated to move from the north to the south pole, to visualise the force as a constant force, and to visualise, to some approximate, the magnetic flux induced in the coil.

2.2 Creation of Assets, Prototyping and Development

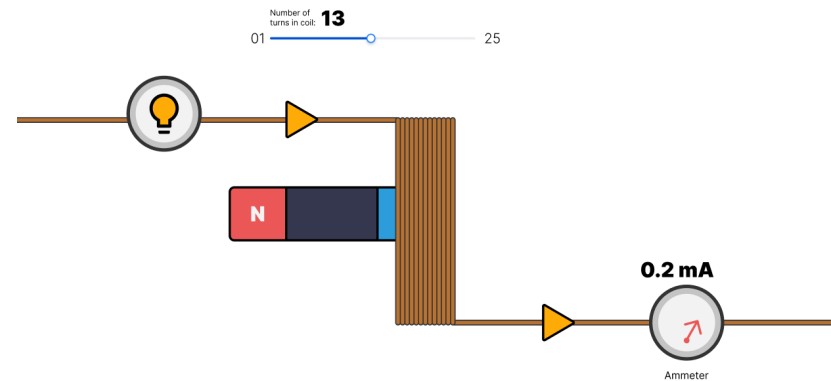


Figure 9: Figma Prototype

The initial prototype was created in Figma, a visual design and prototyping software, where a high fidelity version of the sketch was recreated. The animations for the magnetic field were created using Adobe After Effects and LottieFiles, a JavaScript-based plugin, that allows exporting animations from the AE source file. The simulation was created using AngularJS, a front-end JavaScript library to develop graphical user interfaces. Informal feedback and evaluation were done internally by colleagues and the project guide to creating iterations to fix usability issues. More animations were created to supplement the

visualisation and to show the current as a dynamic variable quantity moving in the circuit.

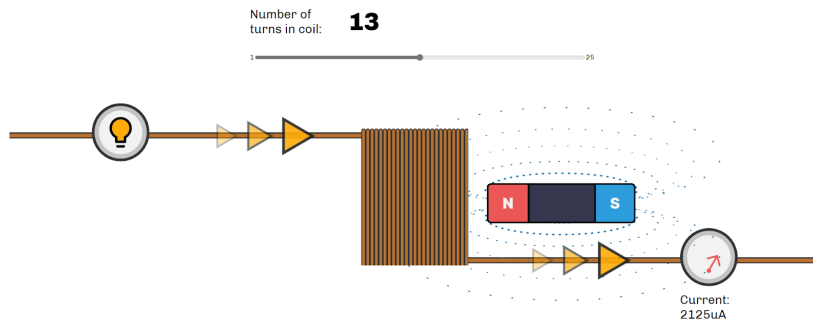


Figure 10: Deployed visualisation
(<https://rishabhkumar.design/lenzlaw/>)

3. Development and Deployment

The simulation/visualisation is a simplification of the original equation, as the change of flux has been kept a constant in the current version to simplify the mathematics required to calculate the current induced. The change of magnetic flux also depends on a spatial quantity, that is, the area of the coil and the angle between a perpendicular vector to the area and the

magnetic field. This requires setting up a scale for the diagrams, therefore making the rendering and visualising it difficult within the time period on the web, as elements will scale differently across devices and web browsers.

The visualisation only works well on a desktop full HD resolution (1920x1080) for the time being and will require optimization to function properly across other platforms.

4. Conclusion and Reflections

The paper aimed to document my journey and process to visualise Lenz's law through Faraday's Law of Induction. I was able to prototype and develop a web-based graphical simulation for the same, which allows users to experiment with representations of real-world elements and the direction and magnitude of the current induced in the representative circuit.

I underestimated the difficulty of creating a realistic emulation for the equation, as it involved working with

spatial variables and varying scales, therefore I had to simplify my process by making the change of flux constant to simplify the equation. More time and iterations are required to allow users to have control over all the variables of the simulation.

The prototyping and development was a great learning experience for me, giving me a lot more confidence in my skills while developing future prototypes, digital and physical alike.

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