Demonstration Model of Self Inductance Using Relay

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Using an electrical component like a relay, the phenomenon of self inductance can easily be demonstrated to undergraduate students. By wiring simple electrical components like relay, neon bulb and a DC power supply, intermittent back electromotive force (emf) can be generated in the range from 60 to 100 volt. The glowing of neon bulb provides visual evidence for the generation of large back emf due to self inductance.

Introduction

An electrical switch is a device which breaks off the ohmic contacts between two electrically conducting wires. Switches can be classified into two categories: passive switch and active switch. Tap key, toggle switch, slide switch, etc., are few types of switches that we have used in our school and college practical course work. These are passive switches – they do not need any external electrical power to make them work. That is, if we manually simply press the tap key, it will complete an electrical circuit in which it is connected. On the other hand, an active switch requires an electrical supply to change its state from being OFF to ON (or vice versa) to complete or disconnect the electrical circuit in which it is connected.

Demonstration of back emf due to self inductance using relay (active switch) has been shown by the authors of [1]. Their work utilizes manual control and a complex electronic circuit to oscillate the relay. The glow of the neon bulb due to back emf from the coil and transformer was used to demonstrate the concept.

In the present article, we first elaborate on the functioning of the relay (an active switch). Then, we describe our model in which a simple circuit, using a relay and readily available electrical components, was designed to demonstrate the principle of self inductance [2, 3].

Keywords
Electromagnetic switch, inductance, inductor, emf, Lenz's Law.

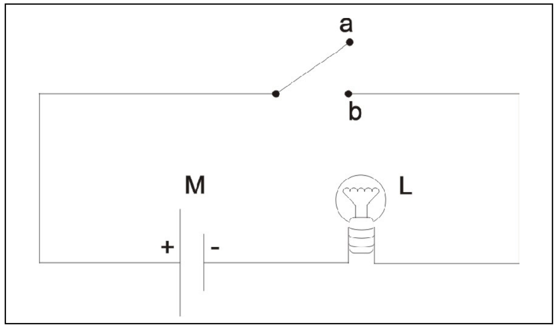


Figure 1. Circuit diagram showing the functioning of an arbitrary passive switch, connected with a power supply and a bulb.

Passive switches are commonly used in day-to-day life in our schools, offices and houses. Examples are tap key, toggle switch, slide switch, switch mounted on an electrical board for switching on power to fans and lights, etc.

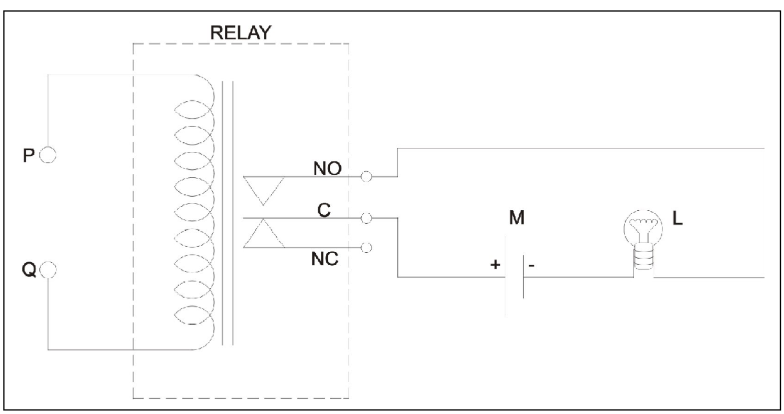
As shown in *Figure* 1, when the part 'a' of the switch is pressed to make a contact with part 'b' of the switch, an electrical circuit gets completed and the current starts flowing through the circuit, which in turn causes a bulb to glow.

On the other hand, if the function of switching the bulb 'ON' and 'OFF' is done by a switch which requires a separate power supply for its functioning, then it is called an active switch.

Relay

One of the examples of an active switch is a relay. *Figure* 2 shows a power supply and a bulb connected with a switch which is called as a relay. The relay contains a coil whose connections are P and Q

Figure 2. Circuit diagram showing the use of a relay as a switch.



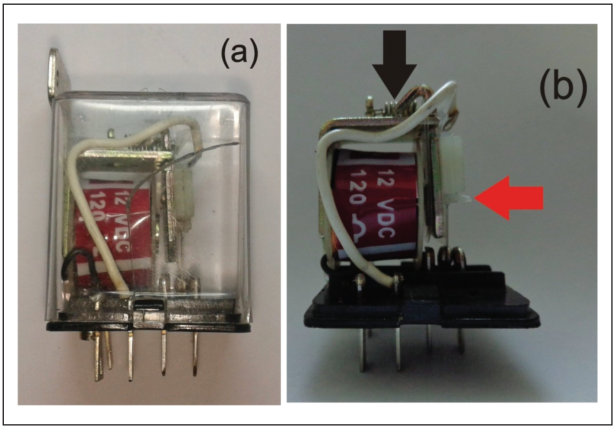


Figure 3.
(a) Image of a relay inside its casing.
(b) Image of the same relay without the casing. The voltage rating to activate the coil is 12V and the coil resistance is 120Ω. The position of armature and the spring are labeled by red and black arrows respectively.

and three terminals namely Normally Open (NO), Common (C) and Normally Closed (NC). In addition, an armature attached to a spring is suspended inside the casing of the relay. The terminal C is attached to this armature. As the spring is kept under tension, the C terminal is always in contact with the NC terminal. Hence the name Normally Connected! *Figure* 3 shows an image of a typical relay with and without its casing.

When the rated DC voltage is applied to the coil across its P and Q terminals, the current flow through the coil produces an electromagnetic field in the vicinity of the armature. This electromagnet attracts the armature towards itself which causes the C terminal to move all the way from its resting position at the NC terminal to its new position at the NO terminal (*Figure* 4). This completes the electrical circuit of the bulb with its power supply M causing the bulb to glow.

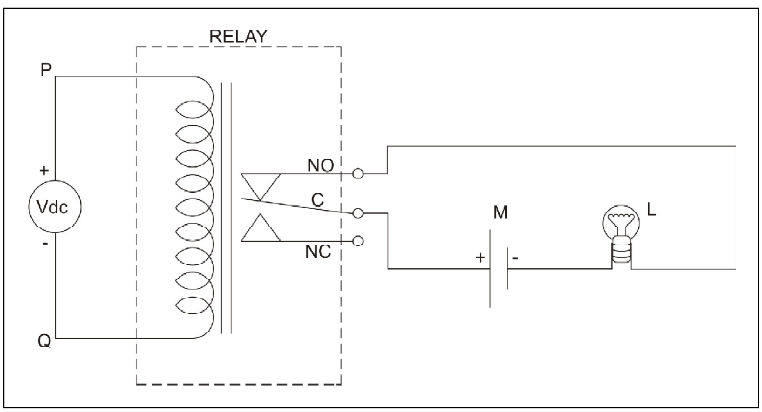


Figure 4. Circuit diagram showing the functioning of relay as a switch to turn ON and OFF a light bulb.

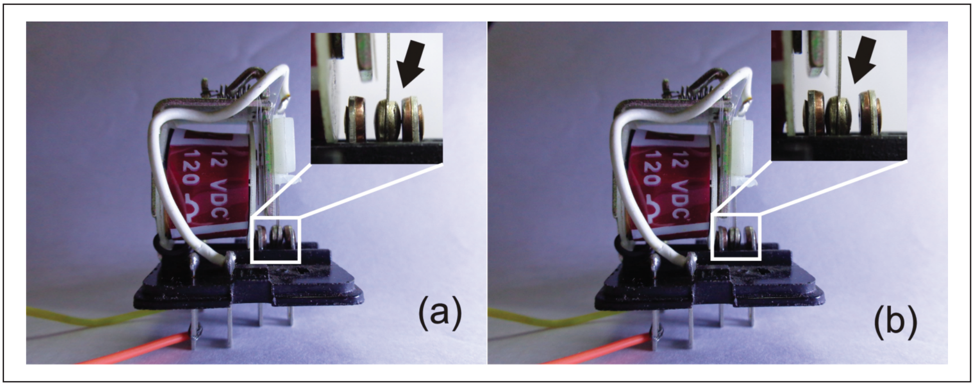


Figure 5. (a) Black arrow in the inset of the image shows close-up view of resting position of the C terminal when the voltage is zero across the coil of the relay. (b) New position of the C terminal when 12V DC voltage is applied across the coil of the relay.

When the voltage across the terminals P and Q is disconnected, the electromagnetic field goes to zero. The tension of the spring pulls back the armature to its original state, where the C terminal was in contact with the NC terminal. As the connection between the NC and the C terminals is broken, the electrical connection of the bulb with its power supply M also gets severed. The bulb switches OFF. *Figure* 5 shows the image of a relay when its coil is connected to the rated voltage supply.

Not only DC voltage but AC voltage can also be used. If the rated voltage of the coil (in this case 12V) is applied across the coil, it will get magnetized. The sine wave has positive and negative voltage peaks at $+V_A$ and $-V_B$ (*Figure* 6). As the voltage increases towards $+V_A$ across the coil, it gets magnetized and changes its position as mentioned above. As the sine wave makes its transition

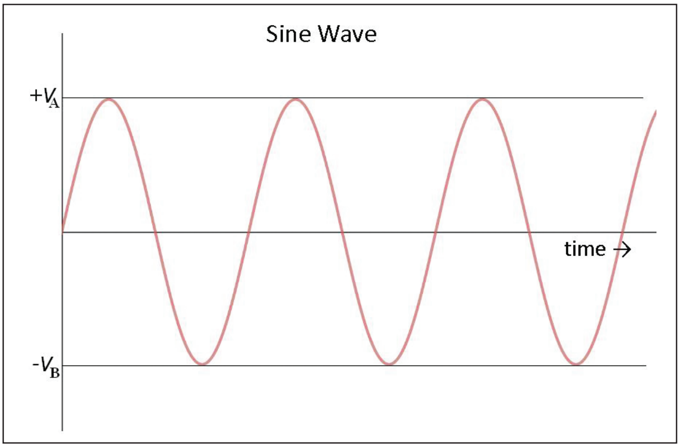


Figure 6. Schematic of a sine wave power supply.

towards $-V_B$ across the coil, it passes through the zero voltage point in the sine wave. For that instant, there is no current in the coil and the armature does not move. As the voltage reaches its peak value of $-V_B$ across the coil, it attracts the armature again towards the magnetized coil. In short, the two peak voltages in the sine wave cause the coil to get magnetized two times in a cycle, i.e., in a single wavelength of the sine wave, the relay activates two times. The armature in the relay shows this oscillatory behavior only up to a frequency of few hundreds of Hertz due to lag caused by the mechanical motion of the armature.

Self Inductance Using Relay

Students come across the concept of inductance [1] in Lenz's law of electromagnetism mostly in higher secondary physics course work.

When a changing current flows through a loop of conducting wire, the magnetic field associated with it is also changing. This changing magnetic field in turn induces an emf in the same wire.

Mathematically, it is written as

$$\mathrm{E} = -L(\mathrm{d}I/\mathrm{d}t) \quad (1)$$

$$\Rightarrow \quad L = -E/(\mathrm{d}I/\mathrm{d}t)$$

Here, E is the induced emf, $(\mathrm{d}I/\mathrm{d}t)$ is the rate of change of current in the conductor, and L is the inductance of the loop.

Inductance of a wire is nothing more than the resistance offered by the magnetic field to the changing current which is responsible for the creation of the same magnetic field. The negative sign in the equation signifies this opposition.

Figure 7 shows a wire twisted in a helical coil structure and connected to a DC power supply having voltage V through a switch S. Initially, when the switch S is closed, the current I_A starts rising in the coil. Due to this current, a magnetic field is generated around the coil. Since the current is rising (changing), the magnetic field is also rising (changing). This changing magnetic

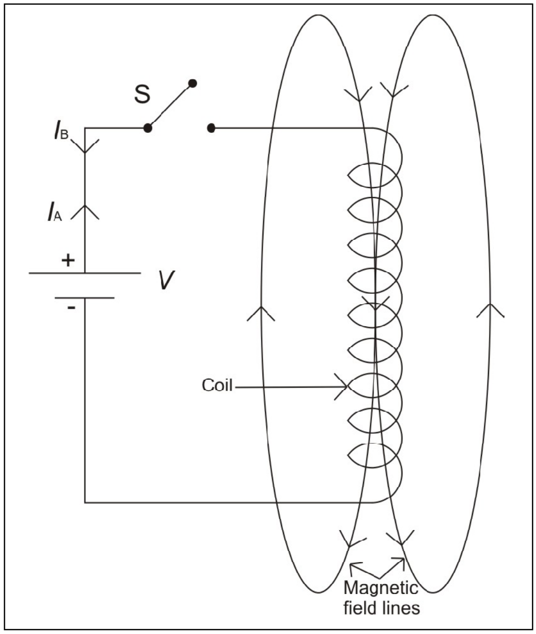


Figure 7. Schematic to show directions of initial rising current I_A, induced current I_B and magnetic field in the coil.

field induces an emf in the coil which sets up its own current flow I_B in the coil but in the opposite direction with respect to current I_A. The changing I_A opposes this induced current I_B. This action suppresses the magnitude of I_B from reaching high values.

Now, as the switch S is opened, the voltage V starts falling rapidly to zero. As depicted in *Figure* 8, the falling voltage induces an emf V_O across the points 'x' and 'y', but opposite in polarity in the coil. This emf sets up a current I_C in the coil. Since now the circuit

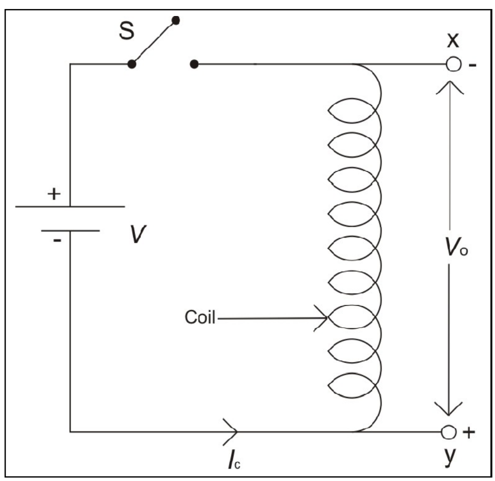


Figure 8. Polarity and the direction of the induced back emf and current in the coil of the relay.

is electrically open, there is no opposing current to suppress I_C. As there is no electrical power available after the switch has opened and due to the presence of the ohmic resistance of the coil, the current I_C in the coil dissipates within a short time. The maximum magnitude that the current I_C can attain depends upon the rate of change of falling voltage and the inductance of the coil. To observe this high voltage generated across any coil, a simple circuit was conceived. The circuit uses nothing more than a relay (which contains the coil), couple of wires, DC power supply and a neon bulb (*Box* 1).

Figures 9 and 10 show a circuit diagram and an image of how the neon bulb is connected in the circuit to make it glow. The bulb is connected in parallel with the coil at the points X and Y. The wiring diagram is trivial; hence it will not be discussed here.

The glowing of the neon bulb from a 9V DC power supply indicates the generation of voltages over 60V due to inductance of the relay coil (see *Box* 2). As the power supply is switched ON,

Box 1.

A neon bulb is a small and low pressure discharge glow bulb. It can be readily found in AC mains tester embedded inside a screw driver. The tester contains a few MegaOhms resistor which is connected from its one end to a flat head long metal rod and the other end is connected to the neon bulb. The remaining open end of the neon bulb is connected to the metal cap on the top portion of the screw driver. *Figure* A depicts an image of the screw driver tester. A hollow green cylinder encompasses all the smaller parts in the same sequence. The long steel rod fits at the end. As labelled in the *Figure* A, the neon bulb can easily be taken out from the tester. Another source to procure the neon bulb and the relay will be at a local electronic market/TV-Radio repairing shop.

Order in which the components are connected inside the screw driver handle to form the tester:
(1) Steel shaft, (2) MegaOhm resistor, (3) Neon bulb, (4) Spring, (5) Head nut, (6) Electrically insulating handle.

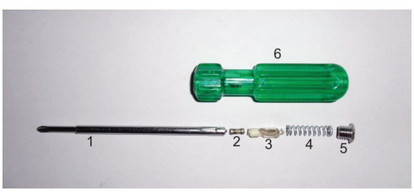


Figure A. The image shows dissembled AC mains line tester. All the components have ohmic contact when they are inside the handle (marked 6) of the screw driver.

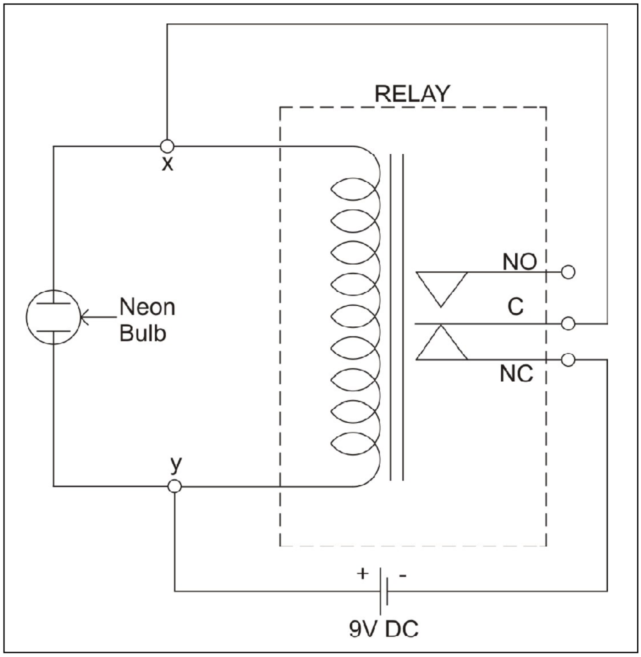


Figure 9. Circuit diagram showing the electrical connections between neon bulb, power supply and the coil and terminals of the relay.

the coil in the relay generates an electromagnetic field. This magnetic field attracts the armature towards itself, simultaneously disconnecting the electrical contacts between the terminals C and NC. The instant this happens, the electromagnetic field starts collapsing due to which the armature returns to its resting position and the electrical connection which was severed between the terminals C and NC, now gets connected. As the DC supply is still kept ON, once again the electromagnetic field gets generated and the system goes through the same cycle. These mechanical oscillations are sustained as long as the DC power is supplied to the system. The mechanical oscillation of the terminal C generates

Box 2.

A neon bulb is a low pressure discharge (electrical conduction through gases) bulb. The magnitude of the voltage required to cause a discharge inside the neon bulb largely depends upon the pressure of the gas and the distance between the electrodes. As the neon bulb is connected across the coil of the relay, due to small distance between the electrodes and the low pressure inside the bulb, the high voltage delivered by the coil causes ionization in the neon gas. When this ionized neon gas reverts back to its neutral state, it emits the light which we perceive as the glow of the neon bulb. The voltage provided by the relay coil is used to trigger the discharge glow in the neon bulb. This voltage is in the range of 60V, as observed on an oscilloscope.

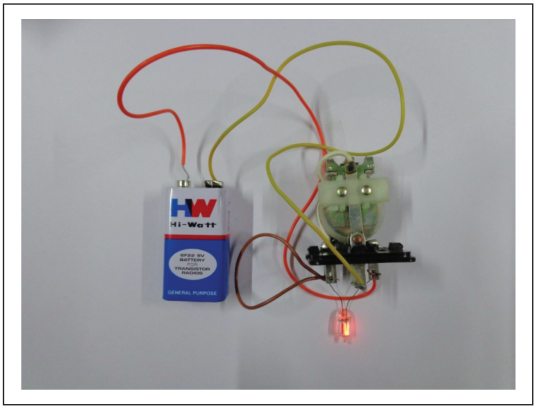


Figure 10. Image of a glowing neon bulb as the 9V battery is connected across the circuit. Even if the relay rating is given to be 12V, it can be easily operated from 9V onwards upto 13V.

a typical 'chattering' sound. The most important thing to observe is the glow of the neon bulb. As discussed above, the make and break action of the C terminal provides the intermittent DC supply to the relay's coil. This intermittent current supply causes time-changing magnetic field in the coil which in turn induces large voltages in the coil. These large voltages are known as 'back emf'. Hence, any electrical device which contains inductive components for its working will always produce back emf across its terminals whenever the current flowing through it changes with respect to time.

Conclusion

Thus, the concept of self inductance can be easily demonstrated to undergraduate students using readily available electrical components like relay, neon bulb, wires and a DC power supply.

Discussing the theory along with designing, fabricating and experimenting with the concepts of physics in the class, will help to stimulate the curiosity in the students and carry them in the realm of scientific exploration.

Suggested Reading

[1] https://www.youtube. com/watch?v=r2guJD9-RLk

[2] Sears and Zemansky, *University Physics with Modern Physics*, 13th Edition, ISBN 13: 978-0-321-69686-1; ISBN 10: 0-321-69686-7, Addison-Wesley publisher, pp 1598, 2011.

[3] http://web.mit.edu/viz/EM/visualizations/course notes/modules/induct-ance.pdf