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Transformer Kit
#TRSFRKT

Warning:

- **Not a toy; use only in a laboratory or educational setting.**
- **California Proposition 65 Warning: This product can expose you to chemicals including styrene, nickel, and lead, which are known to the State of California to cause cancer, birth defects, or other reproductive harm. For more information go to www.P65Warnings.ca.gov**

Introduction

This kit will provide you with the tools to investigate step-up and step-down transformers, motors, brakes, Eddy current, and shaded-pole motors.

In the following pages you will find instructions on how to preform experiments that elaborate on the concepts listed above.

Components

1. U&I Core
2. 5 Coils (one 300 turns, one 600 turns, one 1,200 turns, one 3600 turns, one 12,000 turns)
3. Multimeters (x2)
4. Pair of connecting leads with banana jacks
5. Vertical Support Rod
6. Clamping Screw
7. Plain Quadrant-Shaped Plate
8. Slotted Quadrant-Shaped Plate
9. Pair of Test Leads for Multimeter (x2)
10. Aluminum Motor Disk

Experiments

1. To study the working of step-down transformer.
2. To study the working of step-up transformer.
3. To demonstrate motor and braking.
4. Effect of Eddy current.
5. Principles of the shaded pole motor.

Theory

Hans Christian Oersted discovered that the flow of current in a conductor produces magnetic field. Ampere studied the relationship between the two and derived the expression for the intensity of magnetic field so produced. Transformers work on the principle of electromagnetic induction. The phenomenon of electromagnetic induction was discovered by Michael Faraday in England in the year 1831 and by Joseph Henry in United States at about the same time. This phenomenon pertains to the production of electric currents with the help of magnetic fields. Faraday's experiments in the electromagnetic induction propounded following results.

1. Whenever, there is a change in the magnetic flux crossing a conducting circuit, an induced EMF (Electro-motive force) is set-up in the circuit and induced current begins to flow if the circuit is closed.

2. The induced EMF is produced only for the period during which the magnetic flux across the conducting circuit is actually changing.

3. An increase in the number of lines of force (magnetic flux) produces current in one direction, while decrease of these lines produces a current in the other direction.

4. Magnitude of the induced EMF is directly proportional to the rate at which the magnetic flux crossing the circuit changes.

The above results were expressed by Michael Faraday and are thus referred to as Faraday's Law of Electromagnetic Induction. It states that

"The induced EMF in a closed loop equals the negative of the time rate of change of magnetic flux through the loop."

Mathematically, the magnetic flux crossing through the loop of conductor placed in magnetic field is

$$\Phi = \int B \cdot dA \qquad \text{.......... (1)}$$

Hence, it is scalar product (or dot product) of vector **B** (magnetic field) and vector **dA** having magnitude that is perpendicular to a differential area **dA**.

According to Faraday's law of electromagnetic induction, the Induced EMF in the loop at any instant is given as

$$e = -\frac{d\Phi}{dt} \qquad \text{.......... (2)}$$

The negative sign in equation (2) implies that at any instant, induced EMF **e** and the rate of change of magnetic flux $\frac{d\Phi}{dt}$ are always opposite to each other. According to Right Hand Screw Convention, if we face the circuit, an EMF **e** is considered positive if it causes a conventional current in the clockwise direction **(PICTURE 3)** and is considered positive if there is an increase in the magnetic flux directed away from the observer. The equation (2) is applicable to any circuit through which the magnetic flux is made to vary through any means, even when there is no motion of any part of the circuit.

In case of coil having **n** number of loops or turns in such a way that the magnetic flux crossing through each loop can be approximated as having the same magnitude, the EMF is induced in each turn and the total EMF induced in the coil is sum of these individual induced EMFs (since, all the induced EMFs are in series). Thus, the total EMF induced in the coil becomes

$$e = -n\frac{d\Phi}{dt} \quad \text{.........} \ (3)$$

Lenz's Law: Lenz's law gives a useful and convenient method to determine the sign or direction of induced current or EMF. It was deduced in 1834 by a German scientist H. F. E. Lenz. According to Lenz's law.

"The direction of any magnetic induction effect (viz., induced current or EMF) is always such that it opposes the cause producing it."

The cause, as mentioned in the above statement, may be **(a)** a changing magnetic flux through stationary circuit due to a varying magnetic field, **(b)** a changing flux due to motion of the conductors that constitute the circuit, or any combination of the two.

Lenz's law is not an independent principle, it can be derived from Faraday's law. It always gives the same results as that of various sign conventions used in Faraday's law, but it is more convenient to use. It helps in understanding of various induction effects and is also directly related to the energy conservation.

Transformer: Transformer is an electric device that works on the principle of mutual induction. When two coils of wires are placed near each other and electric current is made to flow in one of them (say primary coil), it is observed that the induced current starts flowing in the other coil (say secondary coil). This flow of current in secondary coil due to change in current in the primary coil is the result of electromagnetic induction and is called mutual induction. The flow of electric current in primary coil produces magnetic field whose lines of force (magnetic flux) also pass through the secondary coil (as propounded by Oersted and Ampere). The change in flow of electric current in primary coil results in the variation of magnetic flux through secondary coil, which in turn, induces EMF in the secondary coil in accordance with Faraday's law of electromagnetic induction and the direction of flow of current is explained by Lenz's law.

Just as change in electric current through the primary circuit (containing primary coil) produces induced EMF in the secondary circuit (containing secondary coil), in the same way secondary circuit also induces an EMF in the primary coil. Hence, the total induction through the secondary, during the time induced current lasts in it, is the difference between the inductions due to the primary and the secondary circuits. Any two circuits, in which there is mutual induction are said to be magnetically or inductively coupled.

Let $\mathbf{N_1}$ and $\mathbf{N_2}$ be the number of turns in the primary and secondary coils and let φ be the magnetic flux of first coil that links with the second coil when a current $\mathbf{I_1}$ flows through the primary, then the induced EMF $\mathbf{e_2}$ in the secondary is given as {from equation (3)}

$$e_2 = -N_2 \frac{d\Phi}{dt}$$

$$= -M \frac{dI_1}{dt}$$

$$\Rightarrow N_2\Phi = MI_1 \quad \text{.......... (4)}$$

Where, M is a constant for the two circuits and is known as the coefficient of mutual induction or mutual inductance of the two circuits.

If there is no flux leakage, $M = \sqrt{L_1 L_2}$ **.......... (5)**

Where $\mathbf{L_1}$ and $\mathbf{L_2}$ are self-inductances of the primary and secondary coil, respectively.

The coupling between the coils is never perfect and some leakage of flux always takes place. As such the equation (4) does not hold true. The ratio $\frac{M}{\sqrt{L_1 L_2}}$ is called coefficient of coupling and is the ratio of mutual inductance when the coupling is perfect. From equation (4), coefficient of mutual inductance can be defined as

"Coefficient of mutual induction is the flux linked with a circuit due to unit current flowing through the other circuit positioned close to it" i.e., $M = \frac{N_2\Phi}{I_1}$

In its most basic form, a transformer consists of a closed soft iron ring called core, over which two separate coils are wound (as shown in Diagram 1). Out of the two, input of electric current is given to one coil, which is called primary coil. Other coil through which output is obtained is called secondary coil of the transformer. Both the coils are well insulated from the soft iron core as well as from each other. The circular ring, being closed, minimizes the leakage of magnetic flux through it.

Basic characteristics of material required for a good quality core are
(a) High permeability
(b) Low hysteresis loss
(c) Large specific resistance

Usually the core is laminated to minimize the loss of energy due to eddy currents.

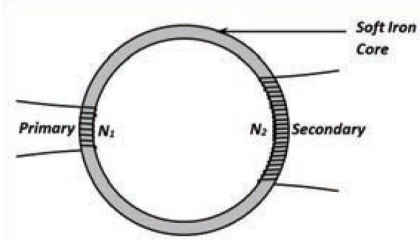

Diagram 1: Basic Transformer

As the current through the primary changes, the magnetic flux through the iron core also undergoes the similar change. Consequently, the magnetic flux linked with the secondary changes, thus inducing EMF in the secondary coil.

Let **Φ** be the magnetic flux through the soft iron core be changing at the rate $\frac{d\Phi}{dt}$.

Hence, the magnetic flux linked with the primary = $\Phi_1 = N_1\Phi$

EMF induced in the primary at any instant = $E_1 = -\frac{d\Phi_1}{dt} = -N_1\frac{d\Phi}{dt}$

Similarly, EMF induced in the secondary = $E_2 = -\frac{d\Phi_2}{dt} = -N_2\frac{d\Phi}{dt}$

Since, $\mathbf{E_1}$ is the instantaneous value of back EMF induced in the primary, the instantaneous current in the primary is due to the difference $\mathbf{(V_1 - E_1)}$ in the instantaneous values of the applied and back EMF. If $\mathbf{R_1}$ is the resistance of the primary coil, the instantaneous value of primary current $\mathbf{I_1}$ is given as

$$I_1 = \frac{(V_1 - E_1)}{R_1}$$

$$\Rightarrow V_1 - E_1 = I_1R_1 \qquad \text{.......... (6)}$$

Assuming the resistance of primary coil to be negligible, $\mathbf{I_1R_1}$ can be neglected.

Thus, $V_1 - E_1 = 0$;or $V_1 = E_1$

Therefore, induced EMF $\mathbf{E_1}$ can be taken to be equal to the applied voltage $\mathbf{V_1}$. Assuming the secondary coil to be open (or its resistance infinitely large), the potential across its two terminals can be taken to be equal to the induced EMF $\mathbf{E_2}$.

$$\therefore \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = K\text{ (say)} \qquad \text{.......... (7)}$$

i.e. $\frac{\text{Voltage induced in the secondary}}{\text{Applied Voltage in the Primary}} = \frac{\text{Number of turns in the secondary}}{\text{Number of turns in the primary}} = \frac{\text{Current flowing through the Primary}}{\text{Current flowing through the secondary}}$

The constant **K** is called transformation ratio. If $\mathbf{K > 1}$, the voltage available across secondary is more than the voltage applied at the primary. Such a transformer is called step-up transformer. It can be seen from equation (7) that in a step-up transformer, the number of turns in secondary coil is more than that of primary coil. Similarly for $\mathbf{K < 1}$, the voltage available across secondary is less than that of primary and the transformer is called step-down transformer. In this type of transformer, the number of turns of secondary coil are less than the primary coil. From equation (7), it is evident that the stepup transformer actually steps down the current and vice-versa.

Since, the working of transformer requires continuously varying voltage to be applied to primary for inducing voltage across secondary, it is basically an alternating current device.

A transformer, therefore, acts like a lever of the first order. With its help, electrical energy can be transferred from one circuit to the other

In case of step-up transformer, although, the voltage available across the secondary may be greater than the voltage applied to the primary, yet energy cannot be gained by this transformation. In fact, some energy losses occur inside a transformer, hence the power output is invariably less than the power input. Usually, a good transformer is a very efficient machine and can be designed to attain efficiency as high as 99%. The main losses in a transformer are:

1. **Magnetic Flux Leakage:** The magnetic coupling between primary and secondary is never perfect i.e., the entire flux produced by the primary is not linked to the secondary. Thus, some of the electrical energy supplied to the primary is not transferred to the secondary and goes waste. The construction of the core can be optimized to minimize this loss.

2. **Copper Losses:** The primary and secondary windings of the transformer have some resistance. The flow of electric current leads to the loss of energy due to heating of the coils ($\mathbf{I_2R}$ losses).

3. **Iron Losses or Eddy Current Losses:** Induced currents, also called eddy currents, are produced in the core of transformer that leads to heating of the core. As a result, some energy also gets wasted due to this. These losses are minimized by using core of transformer made of laminated sheets insulated from each other instead of solid core.

4. **Humming Loss:** During the cycle of AC current, the voltage varies from zero to its peak value, then to zero and to its negative peak value (reversal of direction of flow of current) and then again back to zero. Thus, during each of the voltage cycle, polarity of the magnetic flux through the core also changes accordingly. As a result, the core of lengthens and shortens with a corresponding increase and decrease in the area of cross-section with each change in polarity. This phenomenon is called magnetostriction. This results in vibration of the core and humming noise. Some part of electrical energy also gets wasted due to this humming.

5. **Hysteresis Losses:** This is due to the fact that some energy is wasted as the iron core goes through the cycle of magnetization due to the alternating current, since some electrical energy is required to magnetize the core in each cycle. This loss can be minimized by selecting the material of the core, which has a very thin hysteresis loop.

On account of the above losses, the input of energy in a transformer always exceeds the output of energy, i.e.

$$E_1R_1 > E_2R_2$$

In an ideal situation, as explained by equation (6), the induced EMF across the terminals of secondary becomes 'K' times the voltage applied to the primary, while the current induced is **1/K** times the original current. If the secondary is open, no current passes through it and there is a very small current in the primary for magnetizing the core.

On closing the secondary, the current passing in it is in a direction opposite to that of the primary current (in accordance with Lenz's law, as discussed earlier), so that it tends to demagnetize the iron core. Owing to decrease in the magnetic flux, the induced EMF in the primary $\mathbf{E_1}$ (or back EMF) decreases and the current in it increases, until the resultant flux regains its original peak value. The transformer thus works automatically with more energy being used in the primary when the load on the secondary increases.

The fall of potential in the primary coil is equal to the difference between applied potential $\mathbf{V_1}$ and induced back EMF $\mathbf{E_1}$, as shown in equation (6). Similarly, in the secondary, the induced EMF $\mathbf{E_2}$ produces a fall of potential (I2R2) in it and the available potential difference $\mathbf{V_2}$ between its ends, i.e.

$$E_2 - V_2 = I_2R_2 \quad \text{.........} (8)$$

$$\Rightarrow \quad V_2 = K(V_1 - I_1R_1) - I_2R_2 \quad \text{.........} (9)$$

$$\Rightarrow \quad V_2 = K(V_1 - I_1R_1) - I_2R_2 \quad \text{.........} (10)$$

From equation (10), it is evident that practically, voltage available across the two terminals is not equal to **K** time the voltage applied to primary, but in fact is less than that.

Transformer Kit

The kit consists of a laminated U-core, clamped to the base by the clamping screws. A laminated I-core (or armature) seals the top of the U-core while performing experiments to prevent the flux leakage.

Set of 6 coils, viz., (300 turn – 1 No, 600 turn – 2 Nos, 1200 turn – 1 No, 3600 turn – 1 No & 12000 turn –1 No) are included for different experiments. The coils are provided with 4mm socket terminals for electrical connections. The hollow cross-section of the coil bobbins fit accurately on the arms of U-core, with almost negligible flux leakage due to air-gap.

Also included are a pair of quadrant shaped plate (one plane and other slotted for eddy current experiments and an aluminum disc to demonstrate the working of shaded pole motor.

Experiment 1:

To Study the induction of AC and its dependence on the core of the transformer, and to show the relationship between input voltage and output voltage (Principle of Step-Up and Step-Down Transformer).

Materials Required:

1. U-Core mounted on stand
2. I-core
3. Power supply
4. Set of coils
5. Connecting leads
6. Multimeter

Procedure:

1. Take any coils (say 300 turn and 600 turn coils) and position them side by side on a table. In this case, air acts as a core material.

2. Connect the low voltage AC supply across the terminals of 300 turn coil.

3. Switch on the power supply and gradually increase the voltage applied to 300 turn coil.

4. Using voltmeter, note the voltage applied to the 300 turn coil and the corresponding voltage induced in the 600 turn coil.
5. Repeat step 4 for different voltages applied to the 300 turn coil.

6. Position both the coils in the arms of U-core so that both are facing the same side. Cover the top of the U-core with the I-core and clamp the I-core firmly to minimize flux leakage.

7. Repeat steps 2 to 5 for similar voltages applied to the 300 turn coil as in the previous case with soft iron core through the coils. It will be observed that with the use of cores, the voltage induced in the 600 turns coil (secondary coil) is considerably more than that in the previous case. This is due to the effect of the core on the magnetic coupling between the two coils.

8. From the observations obtained in the second part of the experiment, the relationship (called transformation ratio) between input voltage in primary and induced output voltage in the secondary can be studied. For better results, repeat the procedure using different sets of coils for getting different transformation ratios. The results obtained will indicate that within the limits of experimental error, the voltage induced in secondary is slightly less than 'K' times the voltage applied to the primary (K being the transformation ratio).

Observations and Calculations:

1. Table of Observations (With air as the core in the two coils)

S. No.	Voltage Applied to the 300 turn coil (V_1)	Voltage induced in the 600 turn coil (V_2)	$\frac{V_2}{V_1}$
1			
2			
3			
4			
5			

2. Table of Observations (With laminated iron U and I cores in the two coils)

S. No.	Voltage Applied to the 300 turn coil (V_1)	Voltage induced in the 600 turn coil (V_2)	$\frac{V_2}{V_1}$
1			
2			
3			
4			
5			

It can be seen from the above tables that the value of $\frac{V_2}{V_1}$ in the second case is much more than that in first case. This is due to the better magnetic coupling provided by the laminated iron cores than the air. Using different sets of coils with the U and I cores to obtain different transformation ratio (**K**), tabulate the observations after repeating the experiment as in the table given below and study the relationship between **K** and . $\frac{V_2}{V_1}$

3. Table of Observations for studying relationship with **K**.

S. No.	Number of Turns in Primary Coil (N_1)	Number of Turns in Secondary Coil (N_2)	$K = \frac{N_2}{N_1}$	Voltage Applied to the Primary (V_1)	Voltage Induced in the Secondary (V_2)	$K' = \frac{V_2}{V_1}$	$\frac{K'}{K}$
1							
2							
3							
4							

The ratio $\frac{K'}{K}$ indicates the degree of magnetic coupling between the two coils or the transformation efficiency.

From the above results it is evident that using various combinations of coils as primary and secondary, the kit can be used as a step-up and step-down transformer.

For exploring the phenomena of electromagnetic induction in details, use a suitable oscilloscope to observe the relationship between waveforms of applied voltage (in the primary) and induced voltage (in the secondary).

Experiment 2:

Experiments Using Motor Accesory Set

Materials Required:

1. Motor Accessory Set
2. Connecting Leads
3. Variable DC Power Supply
4. Continuously Variable AC Power Supply
5. Two 600 turns Coil
6. 300 turns Coil
7. Multimeter

Motor Accesory Set:

1. Vertical Support Rod
2. Quadrant Shaped Metal plate, plain
3. Quadrant Shaped Metal plate, slotted
4. Circular aluminum Disc

Motor accessory set is useful for the demonstration of some of the phenomena related to electromagnetic induction, such as eddy current braking, principle of shaded-pole motor etc.

A. Eddy Current Braking: Whenever the number of magnetic lines of force (magnetic flux) linked with a conductor changes, EMF is induced inside the volume of the conductor irrespective of its shape. This induced EMF produces currents, which flow in many closed paths throughout the body of the conductor, in the same way as in a closed circuit placed in varying magnetic field. The direction of flow of these currents is in accordance with Lenz's law. Such currents are known as eddy currents since they are like eddies or whirlpools. These currents were first discovered by Focault, hence are also called Focault's currents. The magnitude of induced EMF in such cases may be small, but owing to the negligible resistance of the conductor, the induced currents will be strong giving rise to strong magnetic fields. As such, when a conductor moves across a magnetic field, the magnetic flux across the conductor changes producing eddy currents. According to Lenz's law, the direction of these currents will be so as to oppose the motion of the conductor (producing the change in magnetic flux) due to which these currents are setup. When the conductor enters the magnetic field, the induction of eddy currents causes repulsion of the conductor away from the magnet. Similarly, when the conductor leaves the magnetic field, the eddy currents are set-up in the opposite direction so as to oppose the movement of conductor out of the region of magnetic field. This results in damping in the motion of conductor, also called eddy current braking.

To demonstrate the effect of eddy current braking, insert two 600 turns' coils on each arm of the U-core. Connect the lower terminals of both the coils to each other using connecting leads and the upper terminal of the coils to a continuously variable DC power supply through an ammeter. In this way, both the coils are connected in series. Mount the vertical support rod on top of one of the pole pieces and suspend the plain metal quadrant from the upper hole of the vertical support rod in such a way that the quadrant is positioned between the flat ends of the two U Core. Make suitable adjustments to the vertical support rod and horizontal shaft as required and ascertain the free unobstructed motion of the quadrant. Switch on the power supply. Flow of direct current through the coils connected in series will produce a strong electromagnet with each pole piece representing one of the magnetic polarities. Adjust the current flowing through the coil to around 1.5-2A. Move the quadrant to one side up to horizontal position and release it. Its motion will be observed to damp significantly as it crosses the U Core. On repeating the same procedure after switching off the power supply, no retardation to the motion of quadrant plate will be observed when it crosses the pole pieces.

On repeating the same experiment with the slotted quadrant plate, the damping effect will be observed to be greatly reduced even when the current is flowing through the coils.

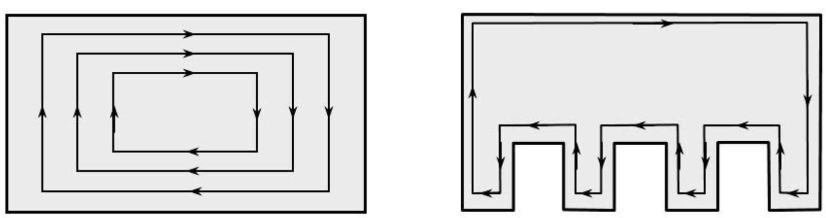

Diagram 2: Eddy Currents (as shown by arrow); (a) in a plain metal plate (b) in a slotted metal plate

This is because the eddy currents have a much longer path in the slotted quadrant plate than in the plain quadrant plate as shown in diagram 2 (a) & (b). Longer path of flow of electric current implies greater resistance to the flow of current resulting in smaller magnitude of current flowing through the slotted quadrant plate. Reduction in the magnitude of eddy currents reduces the damping produced, as observed with the slotted quadrant. This provides a method of reducing eddy currents where desired. This is also the reason for using laminated cores in transformers.

B. Demonstration of Principle of Shaded Pole Induction Motor: A shaded pole motor basically consists of insulated copper wire wound on iron, in which varying magnetic flux is obtained by a different method than discussed previously. In this case, a pole-shading part is used to partially cover pole piece. As the gap flux is changing in response to the alternating coil current, transformer action causes currents to be induced in the pole shading part, always so directed as to oppose the changing magnetic flux. The net effect of this action is that for one portion of AC cycle, the currents in the pole shading piece cause the magnetic flux to concentrate in the uncovered part of the pole piece. During the subsequent portion of the AC cycle, the current in the pole shading piece acts to crowd the gap flux through the part of the pole piece covered by the pole shading piece. In this manner, the air-gap flux undergoes a sweeping motion across the pole face. It appears to be moving from the unshaded to the shaded portion of the pole piece. The sweeping action of the magnetic flux occurs periodically (as per frequency of AC supply), thereby producing starting as well as running torque. Such motors normally have starting torque of 50 percent of the rated value and also have a very low breakdown torque. These motors find extensive application in case of requirements up to 1/20 hp or less. The construction of these motors is extremely rugged and little can go wrong with them apart from overheating.

To demonstrate the working of shaded pole induction motor, position one 300 turn coil in one arm of the U-core and connect it to the variable AC power supply. Mount the vertical support rod on top of the U Core and suspend the metal disc from the lower hole of the vertical rod using the horizontal shaft in such a way that the disc passes midway between the gap across the flat ends of the U core. Make suitable adjustments to the vertical support rod and horizontal shaft as required and ascertain the free unobstructed motion of the disc. Cover half of the top inner vertical portion of one arm of the U core (that is facing the of the aluminium disc) with a non-magnetic substance Switch on the power supply and gradually increase the voltage applied to the coil. When the voltage is sufficiently high, the disc will start rotating slowly with the speed of rotation increasing progressively with the increase in voltage applied.