9. Magnetic Force, Electromagnetic Induction and Electric Machines

CPD 28-Mar-13

Objectives

1. To investigate the direction of a magnetic field created by a current carrying conductor and the influence of current direction.
2. To investigate the force and the direction of the force on a current carrying conductor that resides in magnetic field.
3. To investigate the polarity of the voltage induced across a conductor as the conductor moves through a magnetic field (or vice versa) and relate the observations to Faraday's Law and Lenz's Law.
4. To investigate the operation of a DC machine when converting electrical energy into mechanical energy and when converting mechanical energy into electrical energy.

Equipment

1. 5V, 12V power supply,
2. 4 multimeters,
3. Compass,
4. Galvanometer,
5. Inner and outer coil,
6. Bar magnet,
7. Two 2Ω power resistors, 25W,
8. 10Ω power resistor, 25W,
9. Coil mounted on balance,
10. 100Ω rheostat, 25W,
11. 3 lamps, 12V,
12. 2 coupled DC machines.

Preparation

The following are the fundamental physical concepts that you will apply and observe in this experiment:

- The direction of force exerted on a current carrying wire when placed in a magnetic field
- Lenz's Law and Faraday's law on induced current and voltage

You must prepare for this lab by studying these concepts before arriving in the lab. Refer to the chapters on Magnetic Fields and Electromagnetic Induction in your text and also the summative notes on the course website. To assist with your preparation, you should come prepared to resolve each of the four scenarios below.

1. In this lab you will investigate the nature of the force exerted on a current carrying when the current is constant and the magnetic field is (approximately) uniform. In particular you will experimentally establish the direction of the force on the wire in Figure 9.1 and validate using the *right hand rule*.
2. You will also investigate the nature of the force exerted by the electromagnets in Figure 9.2 when the currents are constant and then verify the direction of the force as it relates to direction of the current using the *right hand rule*.

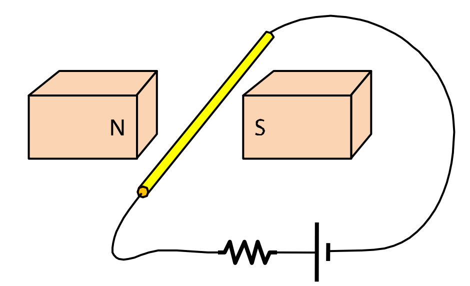

Figure 9.1. Force exerted on a conductor.

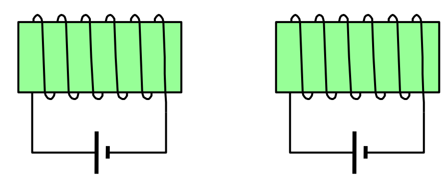

Figure 9.2. Force exerted by electromagnets.

3. The polarity of the voltage induced across a conductor will be investigated as the conductor moves with a fixed velocity through a magnetic field in a certain direction as illustrated in Figure 9.3, and the polarity of the voltage measured at *V* will be established and verified using the *right hand rule*.

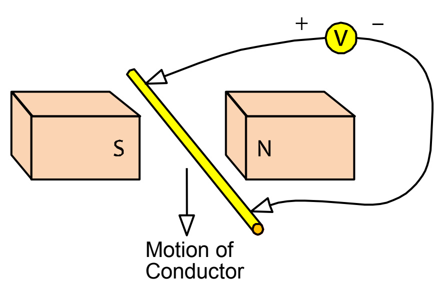

Figure 9.3. Force exerted on conductor.

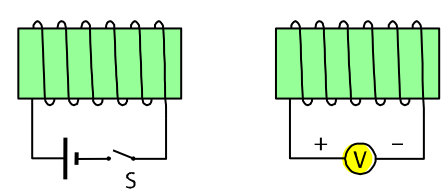

Figure 9.4. Induced voltage in coupled magnetic circuits.

4. You will also experimentally investigate the polarity of the voltage induced at *V* in the magnetically coupled circuit in Figure 7.4 when the switch, *S*, is suddenly closed and then opened – and then verify the polarity using Lenz's and Faraday's Laws, and knowledge of the direction of current flow.

Experiment

Safety Risk: The power resistors used in this experiment will become very hot if energized for extended periods. To reduce the risk of burning: i) do not touch the resistor and ii) energize the circuit for intervals of time only necessary to make observations or measurements.

For assessment, submit your answers to the attached Worksheet before leaving the lab.

1. ***Induced Voltage and Current:*** Connect the galvanometer to the terminals of the outer coil. Insert the north pole of the bar magnet into the end of the coil opposite its terminals and note the polarity of the deflection of the galvanometer as shown in Figure 9.7 (the North pole of the magnet is marked *N* or painted red). *Note*: you will have to press and hold the galvanometer "on-button" while making the measurement. Now withdraw the north pole of the magnet and observe the effect. What is the effect of changing the speed of the bar magnet? What happens if the north pole of the magnet is inserted into the other end of the coil? Now hold the bar magnet stationary and move the coil over the bar magnet and observe the effect of changing direction and speed of the coil.

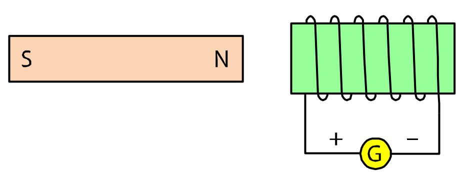

Figure 9.7. Creating an induced voltage by moving a permanent magnet within a coil.

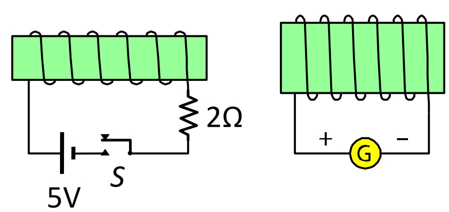

Figure 9.8. Creating an induced voltage in a magnetically coupled circuit.

2. ***Inductive Coupling of Two Coils:*** Connect the inner coil in series with the 2Ω resistor, a single pole single throw (SPST) switch and the 12V supply as shown in Figure 9.8. Carefully insert the inner coil into the outer coil. Connect a galvanometer across the terminals of the outer coil. Observe the effect of closing the switch, *S*, on the galvanometer reading. Now observe the effect of opening the switch on the galvanometer reading.

3. ***Induced Voltage across a Coil moving through a Magnetic Field:*** Connect the galvanometer to the coil mounted on the balance as shown in Figure 9.9, being careful with polarities and directions, connecting red to red, black to black – because it is the subtlety of polarities and directions that you will be investigating. Do not remove or change the orientation of the magnet blocks in the horseshoe! Note that the exposed side of the coil is free to move between the poles of the horseshoe magnet. Note the deflection of the galvanometer as the coil is moved upward through the magnetic field and then downward through the magnetic field. Verify your observations with the right hand generator rule.

4. ***Force Exerted on a Current Carrying Wire in a Magnetic Field:*** Remove the galvanometer from the coil and connect the coil in series with a 5V supply, an ammeter, a 10 Ω resister, and a rheostat as shown in Figure 9.10. Again, be careful to connect the black terminal on the coil with the ground terminal on the power supply so that the current flows in the reference direction. The rheostat may be used to adjust the current flow through the coil. Rotate the paddle so that the exposed side of the coil is directly between the poles of the magnet. Observe that a force is exerted on the coil when a current flows. What happens to the force as the current is increased and decreased? What happens if the polarity of power supply is reversed? Verify your observations with the left hand motor rule.

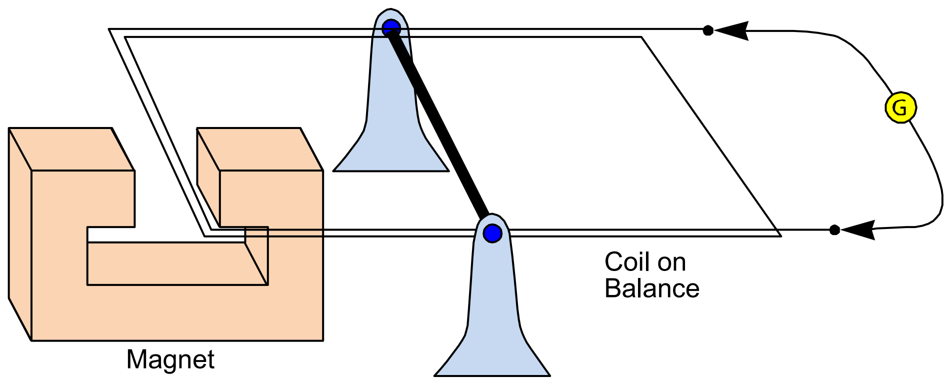

Figure 9.9. Coil on balance with galvanometer.

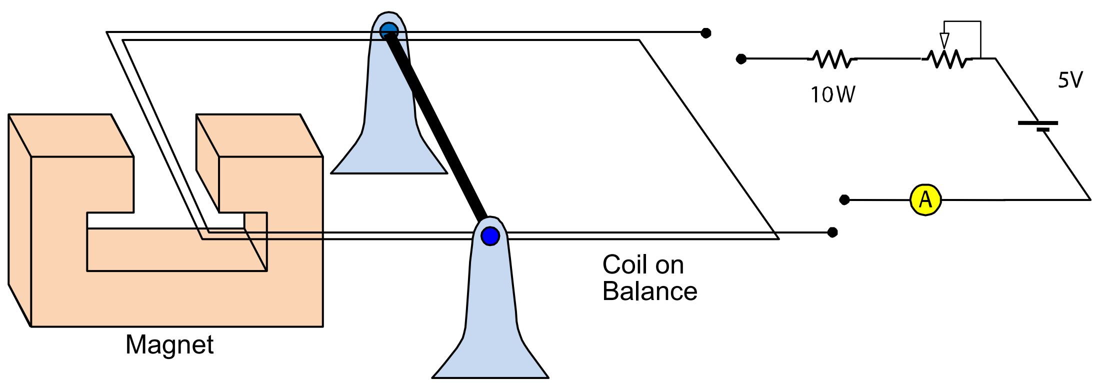

Figure 9.10. Coil on balance with external power supply.

7. ***A DC Machine as a Generator:*** Connect the hand crank to the shaft of the two coupled DC machines and connect a voltmeter across the terminals of the machine. Manually crank the shaft at various speeds and observe the effect on the voltmeter reading. Now connect three of the incandescent lamps in parallel across the terminals of one of the machines and repeat. You should notice a difference in the required cranking force when compared to the case of no load. Connect an ammeter to measure the total current supplied by the machine. Crank the shaft such that you maintain a voltage of approximately 12V across the lamps.

Record the current. What is the power supplied by the generator? For the two DC generators it is possible to double the generated voltage by connecting the generators in series. You might investigate this.

8. ***A DC Machine as a Motor:*** Now remove the crank from the shaft and connect 12 VDC across one of the machines so it acts as a motor as shown in Figure 9.11. Record the motor and generator voltages and currents, I_M, V_M , I_M and V_G . Now connect three incandescent lamps across terminals of the generator and record I_M, V_M , I_M and V_G . Compute the efficiency.

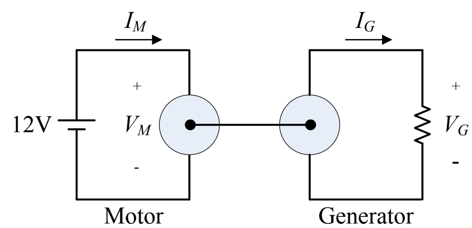

Figure 9.11. Motor – Generator.

WORKSHEET

1. What is the difference in effect on the galvanometer needle between moving inward towards the coil or outwards away from the coil?

   What is the effect of changing the speed of the bar magnet on the galvanometer needle?

   What is the effect of inserting the north pole of the bar magnet into the opposite end of the coil?

   What is the effect when the coil moves relative to the stationary magnet? Why?

2. Describe the voltage measured with the galvanometer when the switch is pressed.

   Describe the voltage measured when the switch is released.

   Explain the reason for the needle movements.

3. From Part 5 of the Experiment, carefully label the following diagram showing magnet polarity, direction of conductor motion, galvanometer deflection and direction of current flow.

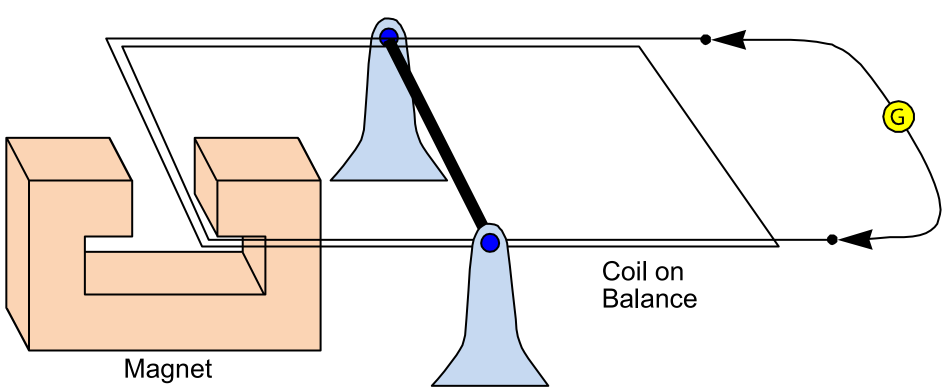

Figure 9.12. Coil on Balance with Galvanometer

4. From Part 6 of the Experiment, carefully label the following diagram with magnet polarity, direction of current flow and the direction of the force exerted on the conductor.

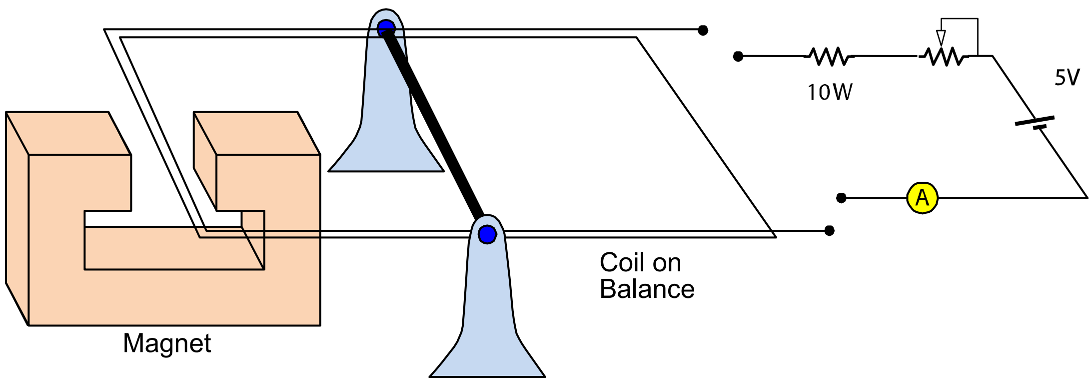

Figure 9.13. Coil on Balance with External Power Supply

7. How do you account for the difference in the torque required to turn the motor shaft when the generator is unloaded and loaded.

8. Compute the efficiency of the motor generator pair			
Number of Lamps		0	3
Generator	V_G		
	I_G		
Motor	V_M		
	I_M		
Generator Power		0	
Motor Power			
Efficiency			