# OPERATING INSTRUCTIONS

## Purpose:

To generate and investigate controllable uniform magnetic fields.

## Contents:

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| One (1) | Assembled air core solenoid |

## Required Accessories:

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| One (1) | Ammeter (0 to 5 amperes) |
| One (1) | Rheostat (25 watt) |
| One (1) | Power supply (6 ampere) or Batteries |
| One (1) | Bar Magnet |

## Specifications:

The solenoid is wound on an air core in 5 layers with approximately 560 turns (570 turns #14835) of #16 Nyclad solid copper wire. The number of turns per unit length for each coil is 3720 turns/meter and results in a calculated field to current ratio of 0.00468 tesla/amp. The inside diameter of the coil is 3.2 cm (6 cm #14835). Each coil is designed to carry 5 amps continuously, and up to 10 amps for short durations.

## Discussion:

A solenoid is a long wire wound in a closely packed helix. For points very close to a single turn of the solenoid, the magnetic properties of the current carrying wire are very similar to those of a long straight wire. The magnetic field lines close to individual wires are very nearly concentric with a direction given by the right hand rule. (With the thumb of your right hand pointing in the direction of the wire's current, your fingers will wrap around the wire in the direction of the magnetic field lines.) The solenoid field is the vector sum of the fields set up by all of the turns that make up the solenoid. Therefore, between the individual turns of the coil the magnetic fields tend to cancel out, while near the center the magnetic field becomes larger and more uniform.

Figure #1 illustrates a loosely wound solenoid showing the position and direction of the magnetic field lines. As the solenoid is more and more tightly packed, the magnetic field near the center becomes more and more uniform, and the magnetic field outside the solenoid windings approaches zero. To obtain the best uniformity of the interior magnetic field, the length of the coil should be large compared to its diameter.

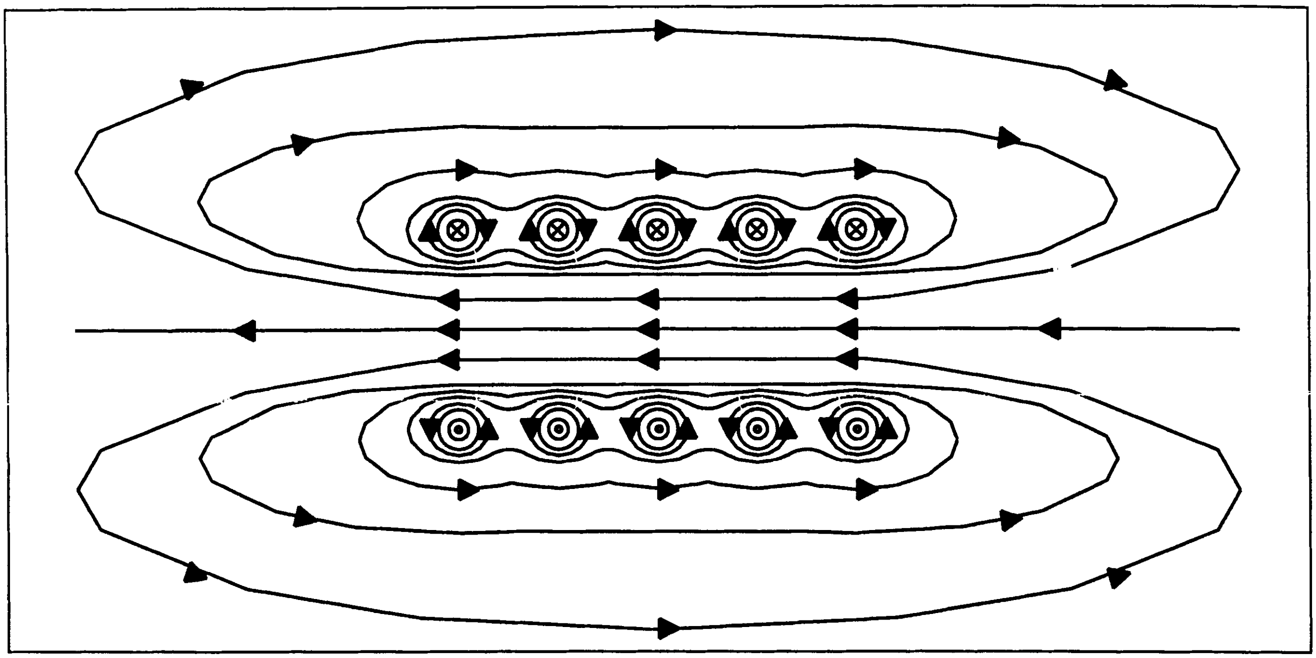

**Figure 1**

**Cross section of a loosely wound air core solenoid showing the direction of the magnetic field lines.**

By applying Ampere's law to an ideal solenoid, we can write an equation that will describe the solenoids magnetic field as a function of the current being carried by the coil and the number of turns per unit length of coil. This expression is:

$$B = \mu_0 I n$$

Where

$\mu_0 = 4 \text{ x } 10^{-7}$ H/m (permeability of free space)
I = Amp (current flowing through the solenoid)
n = 1/m (number of turns per unit length of the coil)

Although, this equation was derived for an infinitely long solenoid, it holds quite well for actual solenoids for internal points near the center of the solenoid.

## Induction:

A current can be induced in a wire by either moving a loop of wire in a constant magnetic field or by exposing the loop of wire to a changing magnetic field. An important law that describes the generation of an emf is Faraday's Law which states that the induced emf in the circuit is numerically equal to the rate of change of the magnetic flux through it. For a coil of many turns, Faraday's Law becomes:

$$E=N(d\Phi/dt)$$

Where N is the number of turns in the coil of wire. This equation says that the emf is the time rate of change of the magnetic flux through the coil. The magnetic flux through a coil of wire is the strength of the magnetic field perpendicular to the open surface of the coil times the area of the coil.

$$\Phi=B*A$$

Substituting this expression for the magnetic flux into the equation for induced emf yields:

$$E=N(d(B*A)/dt)$$

or upon expansion:

$$E=N((A*dB/dt)+(B*dA/dt))$$

The first term says that we will generate an emf if our coil of constant area is exposed to a changing magnetic field. The second term says that we will generate an emf if the area of our coil changes while being held in a constant magnetic field. And the total emf is the sum of both parts. Remember that the area of the coil is merely the area perpendicular to the magnetic field lines. With this in mind, the area can be changed by either physically distorting the shape of the coil or by tipping it with respect to the magnetic field lines.

There is just one more piece to add to the equation for induced emf; this is Lenz's Law. This law simply states that the direction of the induced current is such that this current opposes its cause (this is very similar to inertia). This law shows up as a minus sign in the equation for Faraday's Law.

$$E= -N((A*(dB/dt)+(B*dA/dt))$$

## Applications:

Your solenoid can be used to demonstrate the principles of induction. For this experiment you will need a sensitive volt meter or an oscilloscope (the oscilloscope will provide a much more graphic image of the changing voltages than will the voltmeter). Connect the two leads of the coil directly to the leads of the meter. While watching the meter, bring the north pole of a magnet close to the open end of the coil. What happened to the voltage that you were monitoring? Pull the magnet away. What happened to the voltage this time? Make a note about the polarity of the voltage as the magnet is brought up to the coil and then when the magnet is withdrawn. Compare these observations with a second trial using the south pole of the bar magnet. How did the trial using the north pole differ from the trial using the south pole? What you have been observing is evidence of Lenz's Law which says that the direction of the emf is such that it will oppose its cause (in other words, the small magnetic field produced by the emf in the coil will oppose the change in magnetic flux that generated the emf in the first place!).

What happens to the emf when the bar magnet is brought up to the coil very quickly? Try this while watching the volt meter. This is evidence of the first part of Faraday's Law: the area of the coil is constant and we are changing the magnetic flux through the coil. This emf is also dependent upon the speed with which this flux changes; the shorter the length of time required to change the flux, the larger the emf.

Try holding the bar magnet stationary a small distance in front of the coil and then (without changing the distance between the coil and the magnet) turn the coil away from the pole of the magnet. What happens to the emf? This is evidence of the second part of Faraday's law where the area of the coil (remember, it's the area that is perpendicular to the magnetic lines of force) changes. We could also demonstrate this by changing the physical shape of the coil by pushing the sides of the coil together. You may wish to make a small coil from spare wire and try this yourself. Do not try to change the shape of your solenoid because this would damage your apparatus.

With this you have just demonstrated the different components of Faraday's Law and Lenz's Law. This principle of inductance is used in many types of scientific and industrial devices. Instruments as sensitive as seismographs use this very method to detect and record earth quakes. Radio speakers, record player needles (the cartridge), and tape recording heads all make use of inductance.

**Additional applications:**

The Science Source Product #14850 ( or #14855) are internal printed circuit board current balances which are to be used with Product #14825 (or #14835) air core solenoids to measure the magnitude of the uniform magnetic field in the respective solenoid. Either air core solenoid can be used with The Science Source Product #14880 to determine the Mass of the Electron.

**Time Allocation:**

To prepare this product for an experimental trial should take less than ten minutes to set up the required accessories. Actual experiments will vary with needs of students and the method of instruction, but are easily concluded within one class period.

**Feedback:**

If you have a question, a comment, or a suggestion that would improve this product, you may call our toll free number **1-800-299-5469**, or e-mail us: **info@thesciencesource.com**. Our FAX number is: **1-207-832-7281**.