PHSX 222L **Magnetic Hysteresis Curve** **Name:**______________________

Object: To plot a hysteresis curve for a steel ring, and determine the coercive force and the retentivity for the sample used.

Theory: When wire is wound around an air-core solenoid and a current i is established in the windings, a magnetic field $\boldsymbol{B}_o$ is produced inside the hollow solenoid which has magnitude

$$B_o = \mu_o n I \tag{1}$$

where n is the number of windings per unit length.

See pages 958–962 in Serway. If the wire is wound on a core of ferromagnetic material such as iron or steel, the magnetic field inside the solenoid becomes much stronger. This is due to the fact that, in addition to the magnetic field $\boldsymbol{B}_o$ produced by the current windings, there is the field $\boldsymbol{B}_M$ produced by the ferro-magnetic core material. $\boldsymbol{B}_M$ can be hundreds or thousands of times stronger than $\boldsymbol{B}_o$. The total field $\boldsymbol{B}$ within the solenoid is written as

$$\boldsymbol{B} = \boldsymbol{B}_o + \boldsymbol{B}_M \tag{2}$$

We define a new quantity, the magnetic field strength (or magnetic intensity), $\boldsymbol{H} = (\boldsymbol{B}/\mu_o) - \boldsymbol{M}$, and equation 2 can be written as

$$\boldsymbol{B} = \mu_o(\boldsymbol{H} + \boldsymbol{M}). \tag{3}$$

where $\boldsymbol{M}$ is the magnetization vector of a substance and is related by $\boldsymbol{B}_M = \mu_o \boldsymbol{M}$. The magnetic field strength $\boldsymbol{H}$ is due solely to the current in the windings and has magnitude $H = nI$. (Both $\boldsymbol{H}$ and $\boldsymbol{M}$ have units of amperes per meter.)

Once the magnetic material in the core has been fully magnetized, the current in the windings can be turned off, and there will remain a certain amount of magnetization in the material. This remaining field is called the retentivity (or remanence) of the material. In order to remove this residual magnetism, or de-magnetize the material, it is necessary to send a current through the windings in the reverse direction. The reverse magnetic field strength necessary to de-magnetize the ferro-magnetic core after having been fully magnetized is called the coercive force (or coercivity).

Set-Up: The ferro-magnetic sample will be in the form of a toroid, or Rowland ring, on which has been wrapped N_1 primary windings. A second set of windings of N_2 turns is wrapped on top of the primary windings. We will assume that the ring is large and thin enough that the magnetic field produced by the windings is given by the same formula as that for a solenoid: $B_o = \mu_o n I$.

If a current is suddenly established in the primary windings, the resulting flux change through the secondary windings will induce an emf according to Faraday's Law. A current pulse will occur around the secondary coil circuit, and this pulse can be measured by a ballistic galvanometer.

A mutual inductance can be placed in the secondary circuit to calibrate the galvanometer:

$$\Phi = kd \tag{4}$$

in which k is to be determined.

The total field change ΔB occurring within the sample is proportional to the displacement of the galvanometer. Thus, as the current in the primary windings goes through sudden changes around a cycle, the corresponding magnetization field within the sample can be plotted against B_o/μ_o, producing a hysteresis curve, from which the retentivity and the coercive force can be found.

Procedure:

1. Connect the primary winding of the Rowland ring through an ammeter to a DC power source.
2. Connect the secondary winding of the Rowland ring in series with the ballistic galvanometer and the secondary winding of a mutual inductor.
3. Calibrate the ballistic galvanometer by producing a known flux change in the mutual inductor and noting the corresponding deflection. The calibration constant is calibrated from

$$k = \frac{\text{flux change}}{\text{deflection}} = \frac{\Delta\Phi_c}{d_c} \tag{5}$$

4. Leaving the mutual inductor in the circuit, step the current in the primary winding of the Rowland ring from zero to maximum forward, then back to zero, then to maximum negative, and back to zero. Record the deflection for each step.
5. Make a plot of B versus H (called a magnetization curve).
6. From your plot of the hysteresis curve, identify the value of the retentivity and the coercive force (put the origin at the center of the hysteresis loop).

Experimental Apparatus:

Results and Data Plots:

Questions:

1. Show that the magnetic field $\boldsymbol{B}_o$ for a toroid reduces to that of a solenoid it the toroid is large and thin.

Conclusions: