

## Measuring the axial magnetic field of a thin coil

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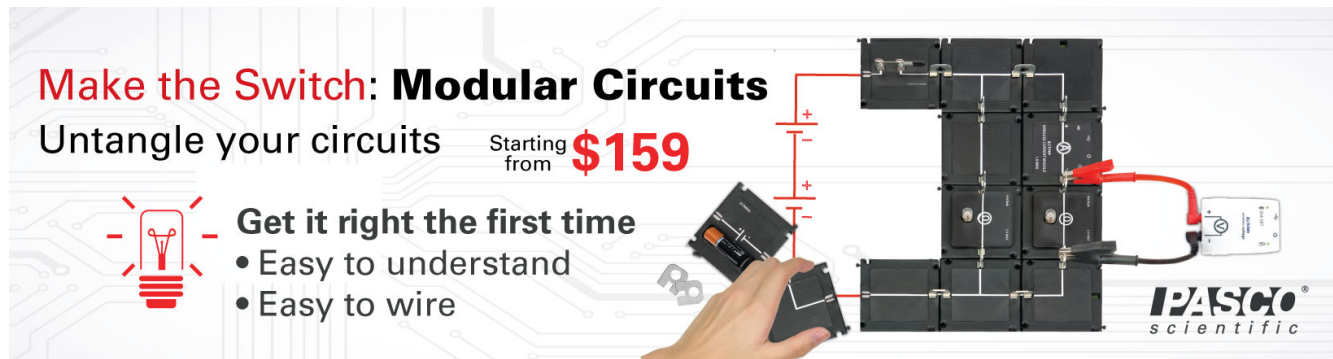
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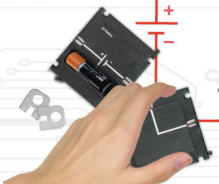



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# Measuring the axial magnetic field of a thin coil

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A remarkably precise laboratory verification of the functional behavior of the magnetic field along the axis of a thin coil can be made with the apparatus described here and shown in Fig. 1.

The coil consists of 30 turns of #22 enameled copper wire, wound on a Lucite form 40 cm in diameter. The dimensions or number of turns are not critical; any thin coil of approximately these specifications would be suitable, for example, one of the coils typically used in the Helmholtz pair of an E&M experiment.

The coil is driven with a 10-V rms sine-wave generator, at a frequency  $f \approx 5$  kHz, generating an ac magnetic field  $B(t)$  at its center given as a function of time  $t$  by

$$B(t) = B_0 \sin(2\pi ft), \quad (1)$$

$$\text{where } B_0 = (\mu_0 IN)/(2R), \quad (2)$$

with  $R$  being the coil radius,  $I$  the coil current,  $N$  the number of turns, and  $\mu_0 = 4\pi \times 10^{-7}$  hy/m the permeability of free space.

A meter stick is attached with one end just below the center of the coil, as shown in Fig. 1. A probe containing a small 32-turn field-sensing coil of about 1.2-cm diameter is mounted on the meter stick, and is capable of sliding along its entire length. An ac voltage  $V(t)$  is induced in the small coil by the time-varying magnetic field at the location of the probe coil. The amplitude of  $V(t)$  is proportional to the amplitude of  $B(t)$ .

At this point, the probe coil could be directly connected to the vertical input of an oscilloscope, but it was found that a better signal-noise ratio could be obtained by first pre-amplifying the probe signal with a simple battery-powered 741 operational amplifier with a gain of about 100.<sup>1</sup> The gain of the amplifier was adjusted so that its output was about 0.5-V rms when the probe coil was at the center of the large coil.

The output of the pre-amp was now fed to an oscilloscope, and simultaneously to an ac digital voltmeter. (It is not necessary to use both instruments; the DVM was used in this study for greater precision than could be obtained with the oscilloscope alone.)

When the probe coil is moved a distance  $x$  away from the center of the large coil along the meter stick, the amplitude of the magnetic field drops from  $B_0$  to a new value  $B(x)$ , given by

$$B(x) = (\mu_0 INR^2)/2(R^2 + x^2)^{3/2} \quad (3)$$

$$\text{or } B_0/B(x) = V_0/V(x) = (1 + x^2/R^2)^{3/2}, \quad (4)$$

where  $V_0/V(x)$  is the ratio of the oscilloscope (and DVM) voltage amplitude reading at the center of the large coil to the reading at position  $x$ .

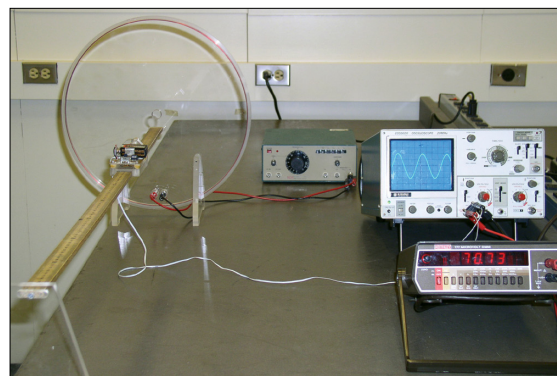


Fig. 1. Overall view of apparatus. See text for description.

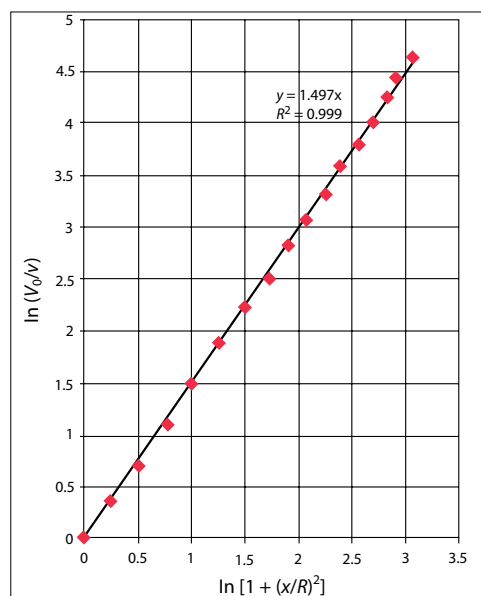


Fig. 2. Plot of the log of the sensing coil voltage ratio,  $\ln [V_0/V(x)]$  as a function of  $\ln [(1 + x^2/R^2)]$ , where  $x$  is the axial distance from the center of the large coil and  $R$  is the large coil radius. The uncertainty in the slope is a fraction of a percent.

A plot of  $\ln [V_0/V(x)]$  versus  $\ln [(1 + x^2/R^2)]$  is shown in Fig. 2. If Eq. (4) is correct, the slope of this plot should be 3/2, and indeed the experimental data verify this to within a fraction of a percent. If only oscilloscope data are used, verification to within a few percent is possible with careful work.

## Conclusion

The apparatus described here has been used for some years in a lab for an elementary course in electricity and magnetism. It provides students with an impressively accurate verification of a non-trivial application of the law of Biot and Savart.

## Reference

1. Contact the author for a schematic of the op-amp circuit.