Hall Effect Measurements as a Set of Serial Experiments in the Undergraduate Physics Laboratory

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Among the shortcomings frequently encountered in the elementary physics laboratory program are: (1) a lack of intrinsic appeal or interest on the part of the experiment to be performed; (2) a lack of continuity from experiment to experiment, contrasting with the smoothly developing chain of thought normally present in the theory presentation; and (3) the inability, because of time limitations, to pursue an experimental problem in depth. With sufficient thought and imagination these shortcomings can be overcome in several different ways. We have had some success in adding interest to the laboratory as well as in providing depth and continuity to the program by the use of serial experiments.

The procedure is to select a rather lengthy experimental problem and to reduce it to a set of observational tasks each of which can be performed in a laboratory period. For maximum effect the separate observations must each stand alone as a complete experiment and yet the successful completion of each should depend directly upon the preceeding exercises. In addition it is important that the entire sequence of experiments be understood before starting the first so that the student will see the series as a single integrated investigation. An example may serve to illustrate the procedure.

When a current-carrying conductor is immersed in a magnetic induction, B, directed at right angles to the direction of current flow, a force is exerted on the charge carriers and they are crowded toward one side of the conductor. As a result a transverse electric field, E_H, is produced. The ratio of this transverse field to the product of current density and the original longitudinal field is defined as the Hall coefficient for the material; thus,

$$R = E_H/jE.$$

The student is to measure the Hall coefficient for a sample of bismuth in the form of a flat ribbon. In addition the sign of the charge carrier and the density and mobility of the carriers are to be determined. The experiment is performed over a period of three weeks. With the exception of the bismuth sample, sample holder and magnet, all the equipment required is normally available in any undergraduate laboratory. The bismuth is commercially available (Fitzpatrick Electric Supply Co., 444 Irwin Avenue, Muskegon, Wis.) and is held in a plexiglass sample holder by clips of spring brass which also form the current and potentiometer contacts. We use a war-surplus magnetron magnet (Edmund Scientific Co., Barrington, N. J.) with shims introduced to reduce the width of the air gap.

Calibration of the Ballistic Galvanometer for Magnetic Flux Measurements

The first laboratory period, after a brief development of the overall problem, is devoted to the calibration of a ballistic galvanometer for magnetic flux measurements. A long solenoid (see Fig. 1) has a small sec-

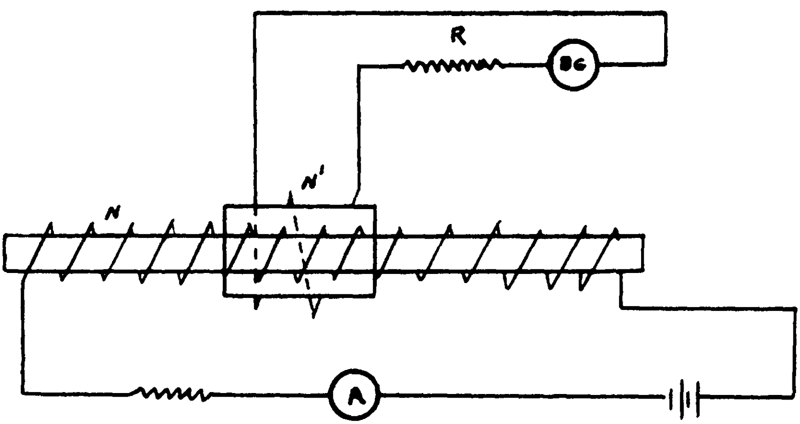

Fig. 1. Galvanometer calibration.

ondary wound about the central portion. The primary is connected to a DC power supply through a tap switch and the secondary to the galvanometer through a small variable series resistance. When the tap switch is opened or closed an induced Emf is produced in the secondary and a momentary current flow deflects the galvanometer. The effective flux F through the secondary is given by the solenoid equation

$$F = \mu NN'AI$$

where I is the primary current, N and N' are the primary and secondary turns, and A is the cross sectional area of the solenoid proper. Galvanometer deflections are plotted against total magnetic flux to provide an instrument calibration curve. A quick investigation shows that the deflection is also a function of the secondary resistance and therefore the student must measure the resistance of the search coil circuit to be used in the following week's experiment before producing the calibration curve.

This first period gives the student some contact with induced Emf, resistance measurement, magnetic field of a solenoid, and instrument calibration.

Measurement of Magnetic Flux Density

During the second laboratory period the student uses a search coil technique with the ballistic galvanometer to measure the magnetic induction of the magnetron magnet. The student is expected to investigate the homogeneity of the field as well as to determine the magnetic induction at the center of the pole piece. The search coil is intentionally wound with an appreciable wall thickness so that it is necessary carefully to consider such questions as the meaning of "coil area". The action of the relatively large coil as an averaging or integrating device is considered and the effect of removal time on galvanometer deflection is investigated. The experiment is completed when the student has determined the average magnetic induction in the area to be occupied by the bismuth sample in the following week's work.

Determination of the Hall Constant

The final week of the series is devoted to measurement of the Hall constant. The bismuth ribbon is placed in the magnetic field (see Fig. 2), a direct current is established in the sample and the transverse Hall

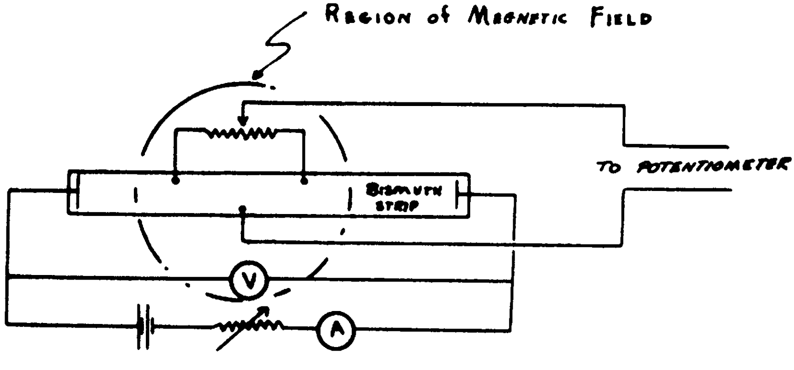

Fig. 2. Hall voltage circuit.

voltage is measured with a potentiometer. The current through the sample and the corresponding potential difference also are recorded. A simple voltage-divided shunt is used to establish lines of equipotential for the potentiometer contacts in the absence of the magnetic field. The student then calculates the Hall Coefficient, *R*, the density, *n*, and the carrier mobility, *m*, from the relationships:

$$R = E_H/jE, \quad m = E_H/BE, \quad \bar{v} = mE, \quad \text{and} \quad n = I/qA\bar{v}$$

where *q* is the carrier charge and $\bar{v}$ is the mean carrier drift velocity. The constancy of the Hall Coefficient under variations in current flow is investigated and magneto-resistance effects are observed. This phase of the experiment requires use of the potentiometer, measuring miscroscope, and other instruments all in a natural experimental setting. Results have proven to be quite consistent and comparable to published values.

I have found that this type of serial experiment has been relatively effective in stimulating student interest, and in providing a more realistic setting for the use of many experimental instruments.