The Leybold Hall Effect Apparatus

- S. Wonnell

This article reports our evaluation of the Hall effect apparatus manufactured by Leybold Didactic GmbH which was purchased and used in the Intermediate Physics Labs at Johns Hopkins University. The apparatus comprises a fairly solidly built set of equipment designed for making room-temperature measurements of the Hall effect in silver and tungsten; above room-temperature measurements in doped (n-type and p-type) germanium are also possible but we did not purchase these samples. An electromagnet fed with a high-current power supply; a constant-current power supply with ammeter for producing a large current through the sample; a microvolt-resolution voltmeter; and a Teslameter for measuring the magnetic field—DC instruments all—comprise the basic setup. The experiment consists of putting the sample specimen between the poles of the electromagnet, applying a potential difference across one length of the sample (yielding a 15-20 amp current), and measuring the resulting voltage across the other length of the sample as the magnetic field is varied.

It is cheaper and more educational to make one's own Hall effect apparatus. Compared to many real-world experiments, it is relatively easy to assemble the equipment although there are a few hurdles to overcome that are discussed below. The apparatus costs roughly $10K, so the main occasion to purchase it is for when one wants to set up an experiment quickly in a way that doesn't require much time or fuss on the part of either the student or the instructor. Assuming that this is the case, let's discuss the apparatus and evaluate the apparatus on these merits: Does it work? Does it work easily? It is safe to use? Will it stand up to abuse? Is the written documentation good?

The Apparatus

We purchased only silver and tungsten sample specimens. These turned out to be thin strips of sheet metal, 50 microns thick, measuring 2 cm by 6.4 cm in effective area, and mounted in a large supporting case. Wires clamped or soldered to the strip of metal run to this case, from which emerge banana jacks. In fact, all user-made connections are via banana connectors. A diagram of the sample is imprinted on the case so as to indicate where a given jack is attached to the sample. A support rod extends from the support case and is inserted into a hole in the bottom of the electromagnet yoke, which secures the sample in place.

A novice to Hall effect measurements may not realize that the voltage across the sample is *not* mainly due to the Hall effect, but rather to the fact that the wires measuring this voltage are attached at slightly different equipotential surfaces of the sample. This *offset* voltage, which is independent of the magnetic field strength but proportional to the current through the sample, can be so large as to mask the potential difference produced by the Hall effect. The Leybold setup minimizes this effect by attaching one wire to one side, and two to the other side of the sample in such a way that the latter two wires lie on either side of the equipotential surface to which the first is attached, exactly as in research-lab measurements. Offset adjustment electronics are enclosed in the sample case. A small knob on the sample case allows the student to minimize the offset voltage. For simplicity, only two wires emerge for measuring the potential difference across the sample.

There are two fragile parts to the Leybold apparatus, and one is the silver ribbon sample (the other is the Teslameter probe). It is only 50 microns thick, and silver is fragile. It is easy to imagine a student poking his or her finger at the sample or at the wires soldered to the sample and breaking the sample or electrical connection. I'm rather surprised that Leybold didn't use a thicker strip of silver. However, as long as students take care to handle the sample by the case, it may last a long time.

Voltage is applied to the sample with a high current power supply capable of supplying any combination of 0-20 amps and 0-24 volts up to a limit of 240 watts, with either the current or the voltage held constant. A lovely feature of this supply is that the output floats; that is, neither output jack is grounded. This is a feature the novice might not realize is necessary when building an apparatus from scratch: one has to be very careful that no more than one wire attached to the sample be grounded. Most electrical power supplies ground the "lower" voltage output, and virtually all measuring test equipment, at least of the cheaper variety, ground one of the two inputs for measuring potential difference.

The Leybold microvoltmeter (range: 100 nV to 200 V DC) measured the transverse voltage (i.e. the Hall voltage) for the silver and tungsten samples without much difficulty. Its input is ground-referenced, which puts the zero-volt equipotential surface at the center of the sample. In addition to its digital readout, it has an amplified output banana jack where the voltage reading is presented as a voltage in the 0-10V range, suitable for acquisition by a computer. This feature turns out to be quite useful because the output voltage fluctuates significantly. Although the digital readout does express a time average of the input

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signal, there appears to be no way for the user to adjust the duration of this averaging. One may certainly do this experiment without a computer, at the cost of some precision in the results. We used LabVIEW and a basic A/D converter card in a PC to speed up our data acquisition and obtain excellent precision. Figure 1 is a screen shot from our LabVIEW setup showing how the voltage (the vertical scale is in units of 10^{-5} volts) fluctuated over 10 seconds of data acquisition. Clearly, numerous data must be taken and averaged to obtain three significant figures for the value for the transverse voltage.

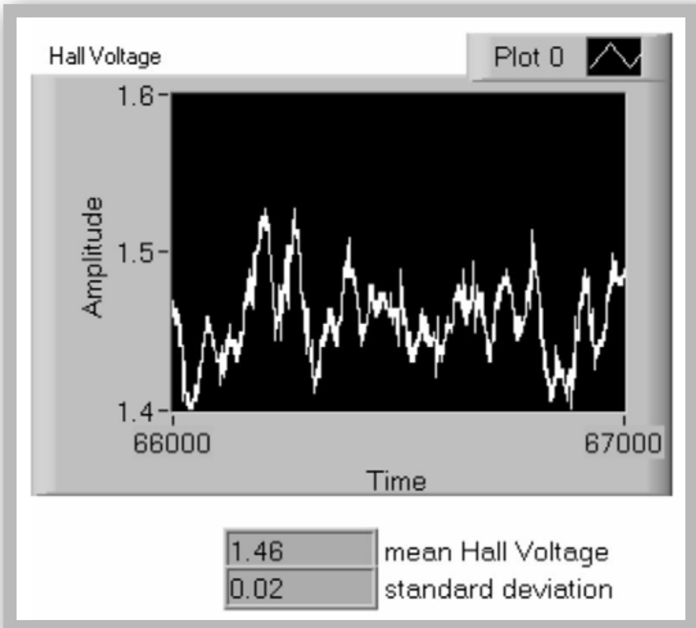

Fig. 1. Screen shot of the transverse voltage, across the Tungsten sample. Vertical scale unit is x 10^{-5} Volts, horizontal scale units is x 10^{-2} seconds.

We powered the electromagnet with their recommended supply, the "Variable Low-voltage transformer." All outputs are ungrounded, which is useful because the sample is in contact with the electromagnet. The DC output maximum is 20 V and 10A. The supply was stable; our only quibble is that there is no fine adjustment for the output voltage, so at low voltages we found that the minimum change in magnetic field was something like 25 mT.

Measuring the magnetic field using the procedure suggested by Leybold is somewhat problematic. Leybold recommends first fixing the gap to exactly the thickness required by the sample, but without the sample; using the tangential B-field probe in the gap to calibrate the coil current with the magnetic field strength; and then replacing the sample and using the calibration sheet. However, the magnet's pole pieces must be loosened and separated in order to insert the sample into the gap. Since the magnetic field is highly sensitive to the gap spacing, as shown in Figure 2, the spacing must be carefully maintained without a sample in the gap, and this is difficult to accomplish with the puny clamps that Leybold uses to hold the pole pieces in place. We preferred to make a spacer that enabled us to insert the teslameter into the gap while the sample was in place. A second problem with the Leybold procedure is the hysteresis in the magnet. Figure 3(following page) shows how the magnetic field varies as a function of the coil current when taken through a full cycle of measurements.

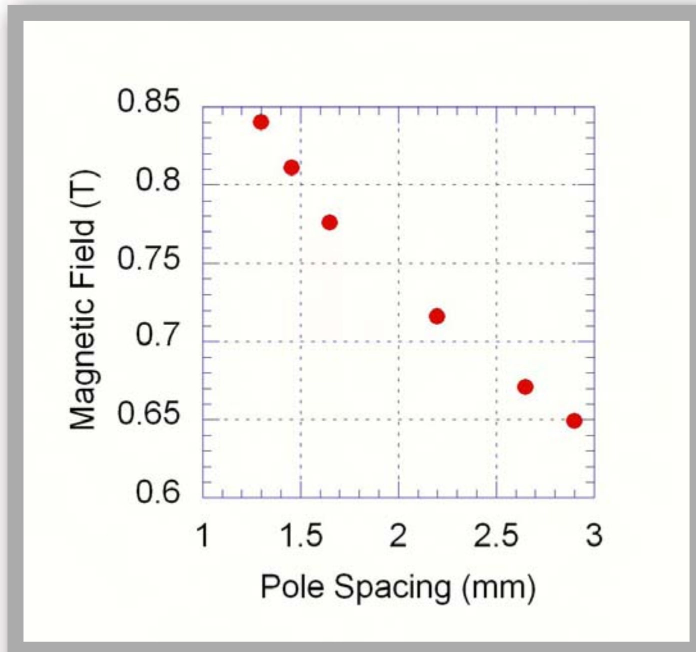

Fig. 2. Variation of the magnetic field strength with pole gap spacing. Coil current fixed at 5A; B-field probe located near center of gap.

We did not have a second Teslameter against which we could test the Leybold Teslameter and Tangential B-Field probe. The scale is sensitive to 0.01 mT up to 2 T; we could easily detect the Earth's field with it as well as the stronger fields of our electromagnet. However, the zero-point adjustment, which is supposed to compensate for magnetic flux densities of up to 500 mT, did not work, and the zero point remained at about 0.5 mT. The Teslameter also expresses the magnetic field strength as a voltage at an output port, which may be used for computer acquisi-

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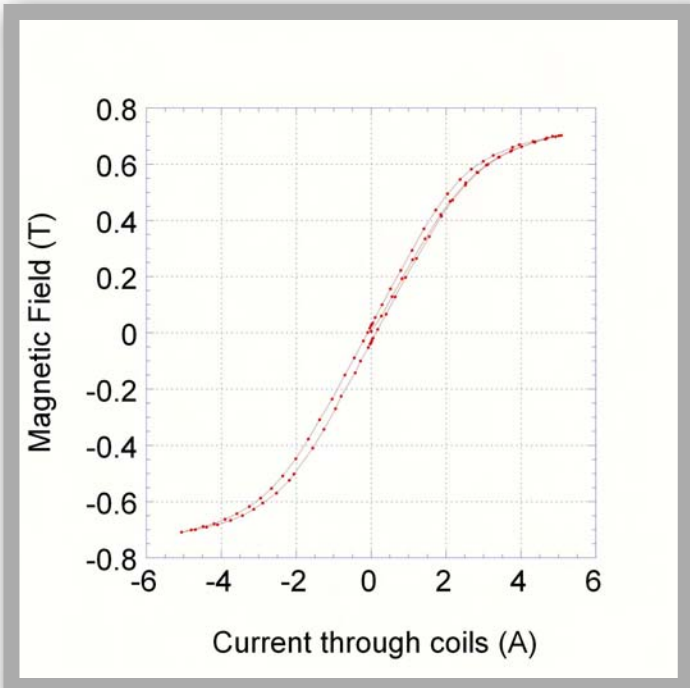

Fig. 3. Teslameter reading as a function of the current through the electromagnetic coils showing hysteresis in the magnet.

tion of the value for the strength. The digital readout of the magnetic field strength is very large and bright, suitable for use even in lecture-demonstrations.

Experimental Results

Figure 4 presents data taken after several days of experimentation; this data was acquired using LabVIEW and each data point is an average of 1000 readings. For this data, I made a U-shaped spacer, 2.2 mm thick, and closed the pole pieces of the magnet on it and the sample, clamping them into place yet leaving room for the tangential B-probe. For clarity, the data has been rescaled so that the transverse voltage is zero when B=0. Table 1 lists the Hall coefficients for these measurements.

Table 1

Sample	Hall Coefficient (V-m/T-A)
Tungsten 15A	$(8.32 \pm 0.50) \times 10^{-11}$
Tungsten 20A	$(8.15 \pm 0.50) \times 10^{-11}$
Silver 15A	$-(7.87 \pm 0.03) \times 10^{-11}$
Silver 20 A	$-(8.00 \pm 0.08) \times 10^{-11}$

The uncertainty reflects the uncertainty in the transverse voltage measurements. The current through the

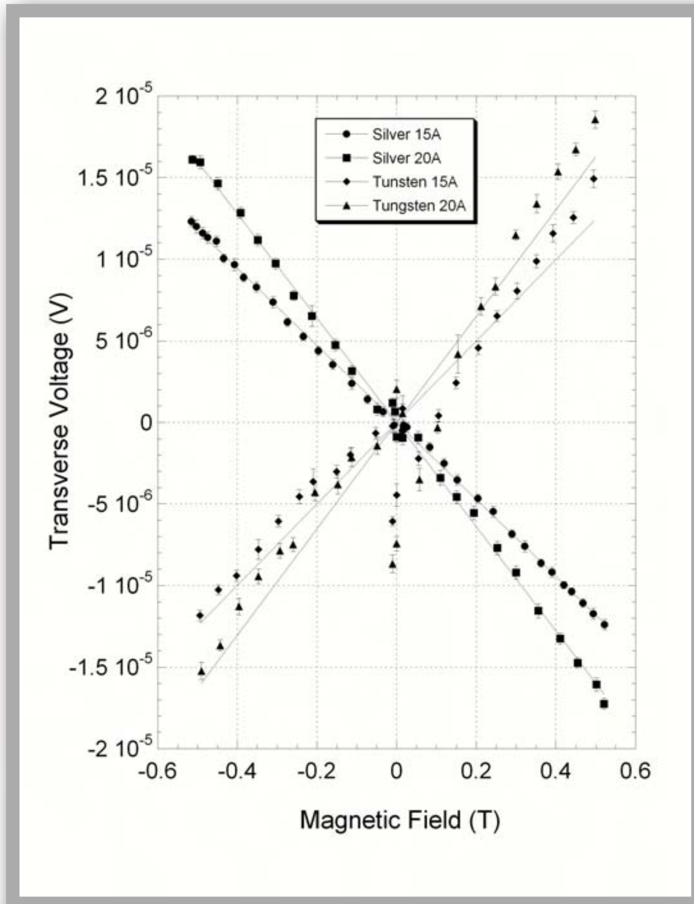

Fig. 4. Transverse voltage across the sample as a function of field strength, normalized to zero at zero Tesla.

sample and the magnetic field were each measured to better than 1%; however, for the thickness of the sample, we used the figure provided by Leybold, 50 microns, which was provided without any uncertainty. Note that the uncertainty for Tungsten is an order of magnitude larger than for silver; examination of the figure indicates that the data points for Tungsten near B=0 show some anomalies, the source of which is unknown. A repeated measurement for Tungsten, starting from B=500 mT and decreasing to B=-500 mT (so that the knob is turned one way) yields far better results, but it is unlikely that students under time pressure will be this careful.

On the whole, this is a very well thought out albeit expensive apparatus that works well and which is capable of taking superb data.

Acknowledgments - Thanks to Chirag Patel for helping to set up the LabVIEW acquisition system.

Product Information - Listed by product name, followed by the Leybold catalog number and 1999 cost.

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Hall effect apparatus, silver, 58681, $651; Hall effect apparatus, tungsten, 58684, $687; Microvoltmeter, 53213, $2070; Teslameter, 51662, $1566; Tangential B-probe, 51660, $333; multi-core cable 50116, $28; High current power supply 52155, $1748; Variable extra low voltage transformer 52139, $1010; U-core with yoke, 56211, 246; Pair of bored pole pieces, 56031, $582; two coils with 250 turns, 56213, $155 ea.. Additional cables, a support rod, and DVM were also used in the experiment.

Leybold-Didactic GmbH
Leyboldstrasse 1
50354 Huerth Germany
sold in the U.S. by Klinger Educational, phone 718-461-1822

PIRA Elections

This year we have two officer positions under contention. As usual, the vice President's spot is being contended for by David Sturm of University of Maine and Keith Warren of NCSU. It is an agonizing choice but I am sure we will be well served by either of these fine gentlemen. We also have a special election for Secretary. Jerry Hester, Tom Senior and Dave Kardelis are vying for this slot. The elections will take place at the PIRA business meeting in Syracuse on Tuesday, July 25 at 6:30. If you will not be attending the meeting, I encourage you to vote online by going to the PIRA web site and following the links.

Vice President

David E G Sturm, University of Maine, Orono.

- Instructional Laboratory Coordinator/Lecture-Demonstration Specialist, UMaine.
- Active in outreach via the Mainely Physics Road Show.
- Since '99, Instructor, Beal College, math/comp sci.
- Asst to lab mgr at Auburn '91-'94. Lab mgr at Wake Forest '94-'97. Since '97,
- AAS, bus mgmt/comp sci, Southern Union. BS, physics, Auburn.
- PIRA Member since 2002.

Statement: In PIRA since '94 (after discovering the joy of tap-l) I see our association as the one resource improving our own knowledge base, access to ideas, and bringing support from peers who uniquely understand the tremendous job demands we face daily in our own environment. I've gained insight from being in positions that include both laboratories and lecture-demonstration, but also through outreach in traveling and onsite shows, and teaching; that is helpful in interacting with our diverse membership where we all have a variety of daily tasks. I'm strongly driven by my own experiences for our continuing need to address together professional concerns of instructional resource physicists.

In the VP year, I would concentrate on the duty organizing the Resource Room for the Greensboro Summer Meeting, involving as many as possible (have a useful resource or quality item you'd like to bring and donate for a silent auction?); and add ideas that will be revenue-positive, seeking additional vendor backing. In the president-elect year, I would focus on meeting sessions and talks, and additionally, a crackerbarrel on professional certification: through existing programs and to determine if PIRA could develop a peer-certification (to pick up on a topic from the Utah meeting).

In the presidential year, I would see to representing PIRA throughout AAPT, but also the APS community. I'd wish to see PIRA-led demo workshop and show at the March APS meeting, and a really tight, focused Summer PIRA meeting.

In the past-presidential year, I would want to enable colleagues following in the presidential cycle; seek out more members, more involvement, and continue to grow PIRA. As part of the exec committee, I wish to: expand membership rolls; create value for members by seeking backing from vendors (after all, we're some of their best customers!); investigate with AAPT to have PIRA members afforded breaks similarly given to grad students (since a majority of us according to the salary survey are paid like graduate students!); support TAP-L, the Web, DCS, LCS and other projects for the benefits of the members, and encourage all of us to attend APS/AAPT Section Meetings and share with each other whenever we get the opportunity.

Keith Warren, North Carolina State University, The Science House

- Operations Manager, The Science House, NCSU (2005-Present)
- Hardware Engineering Manager, G2 Test & Measurement (2001-2005)
- Director of Demonstrations, North Carolina State University (1992-2001)
- B.S Physics, Appalachian State University (1990), M.S.

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