

Introduction

These are instructions for six basic experiments in electricity and magnetism that students assemble from kits, either in a lab, a dorm room or at home. There are also brief theoretical explanations. The level is suitable for use in an introductory course with calculus. The experiments are similar to ones developed at MIT beginning in 1988 and later at Caltech, and used there and elsewhere since.

The E&M course with take-home kits in the initial MIT version has been described in *ZAP!*¹. The Caltech version, also called *ZAP!* is a published book². Also, the MIT instruction sheets for some 30 experiments in both E & M and mechanics have been collected and bound, *Physics 8.01X (Fall) & 8.02X (Spring) Experiment Instructions*³. The remainder of this introduction is adapted from the foreword to that collection.

It was once common for people, especially in their youth, to build model planes and boats and radios and audio amplifiers, etc., from kits, getting the pleasure of making something work from scratch. Not only did they get a strong practical sense of how things worked, but they also got much incidental knowledge about materials, fasteners, joining methods (glue and solder), miscellaneous articles of commerce (mostly from hardware and electronic parts stores), etc. This informal education enabled people to recognize items and methods when they saw them in the world and was valuable background for future experimenters and designers. This background was also valuable for the non-technical person who would not then, later in life, find the many surrounding technological devices entirely mysterious.

Nowadays, people who have grown up with computers generally have had little contact with hardware, as was once commonplace. They have acquired a background of other valuable knowledge and skills. But both kinds of background are needed, not only fingers typing and the screen displaying, but also connecting components, so that current flows and things happen.

Introductory physics as generally taught in high school and college, whether with classic set-piece labs, simulations, or MBL (or no lab) does little to develop the sort of manual and mental skills generated by doing hundreds of individually trivial actions and operations—for example: stripping vinyl insulated number 22 tinned solid copper wire, bending it, and soldering it with a well tinned iron to another wire or a device terminal; or: breaking off a short piece of 0.040 inch tungsten rod and pressing into the slot of a 4-40, 1/2 inch round-head brass screw, as for experiment EB.

Providing kits, tools and instruments to do physics experiments at home or in the dormitory as part of the course, on an equal footing with problem solving, is one way to compensate for the lack of earlier experience of this kind. The experiments, about six or seven per semester, are designed to be assembled in one to two hours from 10 to 30 parts; running, getting data, analysis and presentation take another hour or two. They all yield quantitative results, and usually require graphing and sometimes error analysis. Generally the results are within $\pm 10\%$ of expected values (or better, for some experiments and some experimenters)—good, considering the simple, low-cost materials and student inexperience (the latter often masked by well-engineered commercial apparatus in the standard teaching laboratory). For many of the experiments, everyone's results can be compiled, and a histogram of the values of,

for instance, ϵ_0 , displayed in lecture. Mostly students work in pairs in construction and data taking, but keep individual notebooks and prepare separate short reports. Ideally the notebooks should be reviewed and commented on weekly, but this is hard to do with large groups. The partnership scheme has obvious advantages and troubles but generally works well enough.

Whereas in the mechanics course time and temperature are read out with digital multimeters (they being no more mysterious than a stop watch or an A to D converter), in the E&M course analog multimeters are used. Besides enforcing the reading of a scale they can be gradually understood in every detail—the d'Arsonval movement, the range switch, shunts, multipliers, diodes—in contrast to digital meters with chips and displays whose workings are hidden and harder to explain. Furthermore, low-cost digital meters, rated for 400V dc, can easily be destroyed by the over 1kV generated by the high voltage power supply. And, paradoxically, the limited selection of ranges of the low-cost analog meters is an advantage; it requires the use of external shunts and multipliers, so that knowledge of these useful topics, mostly gone from modern texts, is acquired in a natural way.

The reader or student should be aware that many of the acronyms used here are not standard usage. Experiments are not numbered but are labeled with letters; power supplies are LVPS and HVPS; the analog multimeter, depending as it does on the torque on a coil in a magnetic field, is called MMM, magnetic multimeter (DMM for digital multimeter is standard).

Contact with the real stuff that working with these kits provides is likely to be increasingly valuable as more and more complex equipment becomes available everywhere. It's not that 50 to 100 hours of this works will make anyone expert, but it's a beginning and one should be aware that "a little knowledge... [though] a dangerous thing" is vastly better than none. Students who have worked with the kits say: "they liked the chance to fool with stuff", "it was gratifying to recognize components on computer circuit boards" and in two cases, that they could, some years later, use the LVPS (10 of them in one case) in their research.

1. Philip & Phylis Morrison & John King, *ZAP!: A Hands-On Introduction to Electricity and Magnetism* (1991) [Available, as are kits, from KT Associates, 454 Hockomock Road, Woolwich, ME 04579].
2. Jerry Pine, John King, Philip Morrison, Phylis Morrison, *ZAP!: Experiments in Electrical Currents and Fields* [Jones and Bartlett, Boston, 1996].
3. J.G.King & A.P.French, *Physics 8.01X (Fall) & 8.02X (Spring) Experiment Instructions* (1998) [Available, as are kits, from KT Associates, 454 Hockomock Road, Woolwich, ME 04579].