Application Note: Physics Teaching Labs

A strong and controllable magnetic field can be valuable for undergraduate physics teaching labs, allowing hands-on experimentation around a range of magnetic phenomena, enabling the students to gain a deeper understanding of fundamental principles. We recently developed *FLUXvario*, a device which uses a configuration of permanent magnets to generate a tunable magnetic field with strength up to 280mT, and at far lower cost than electromagnets with comparable field strengths. Here we briefly outline some potential uses of *FLUXvario* in advanced undergraduate teaching labs.

Hall Effect

A transverse potential is generated when a current flows perpendicular to an applied magnetic field. A teaching lab which demonstrates the Hall effect requires thin conductive samples to be mounted on an insulating substrate (Fig. 1). This could be produced either by attaching a thin foil or by depositing a thin metal film on the substrate, and then attaching electrical leads and mounting to fit to the *FLUXvario.* Students would measure the electric potential induced as current passes through the conductor at a range of orthogonal magnetic fields. In addition to the thin samples, the lab requires a sensitive voltage probe and high current supply.

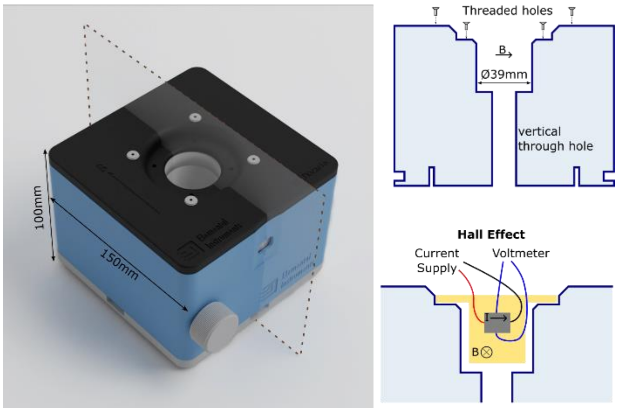

Fig. 1: Layout of a FLUXvario device. The B arrow labels the region where the magnetic field is optimized. Lower: An example schematic of a Hall effect experiment.

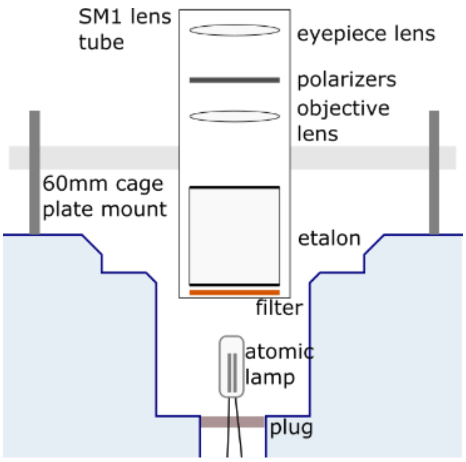

Fig. 2: Schematic of a Zeeman effect experiment.

Zeeman effect

Atomic energy levels are shifted and split by a magnetic field, which shifts the frequency of fluorescent emitted light. Such shifts can be visualized by viewing mercury or neon discharge lamps through an etalon, which generates a series of circular interference fringes at angles that depend on the wavelength. Students can observe the fringes shifting due to the Zeeman effect as the magnetic field changes. Careful quantification of the frequency shift at different magnetic fields can allow calculation of atomic energy levels and the Landé *g* factor. The etalon and optics can be easily mounted on *FLUXvario* as it is compatible with 60mm cage mounts.

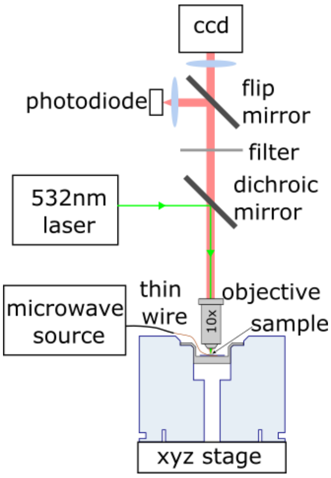

Fig. 3: Quantum microscope with NV centers in diamond.

Photoluminescent Point Defects

The nitrogen-vacancy center in diamond is a photoluminescent defect, providing a 2-level quantum system in which energy levels can be probed and manipulated relatively easily using light and microwaves. The design and construction of a simple and low-cost NV nanodiamond imaging setup for teaching labs is detailed in Ref.[1]. We extend that approach with addition of a controllable bias field, which allows use with an NV implanted diamond chip for quantum imaging[2]. Students can observe the Zeeman splitting, and also observe how the high field decouples the spin states from many environmental effects which greatly increases sensitivity to magnetization of samples[3]. It would be a valuable experience for advanced students to assemble this system and image magnetic fields from a sample of magnetic nanoparticles.

Spintronics

The spin valve is an essential component in the field of spintronics with a wide range of applications in information technology. Electrical resistance changes as ferromagnetic layers have magnetic domains either aligned or anti-aligned. A simple spin valve can be constructed from thin film stacks, with a nonmagnetic layer sandwiched between ferromagnetic layers of different magnetic coercivity[4]. The free layer can be magnetized at low magnetic field, while the fixed layer is magnetized at high field, which allows any configuration of magnetization to be prepared by tuning the field.

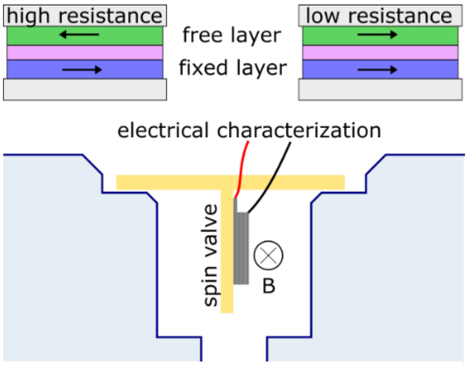

Fig. 4: Spin valve concept and simplified experimental schematic.

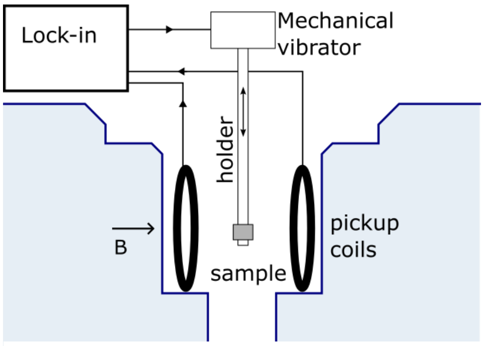

Fig. 5: Vibrating-sample Magnetometer. The FLUXvario magnetizes the sample so that its movement induces a current in the pickup coils. A lock-in amplifier is the only costly piece of electronics required.

Vibrating-sample Magnetometer (VSM)

VSM characterizes the magnetic properties of materials by magnetizing a sample material in an applied magnetic field, and vibrating it between wire coils so that the magnetic field generated by the sample incudes a measurable current. A large variable magnetic field is required to characterize the magnetic susceptibility, saturation, and hysteresis. A simple and economical VSM has already been developed for teaching courses utilizing an air-cooled electromagnet to supply the magnetic field[5]. That design can be followed closely using the lower-cost *FLUXvario*, which delivers the same magnetic field range as the electromagnet used there and with comparable space to fit the coils and sample holder.

In conclusion, *FLUXvario* is a affordable, powerful, and tunable magnetic field source that can enable undergraduate physics teaching labs to cover a range of advanced topics. It is sturdy and robust, easy to use, and totally unpowered. Providing students with a chance to explore fundamental magnetic principles can greatly aid understanding, foster critical thinking, and prepare them for a broad range of future scientific endeavors. This is a worthwhile investment for educational institutions committed to providing a comprehensive and engaging physics education.

References

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