

## Simple ballistic magnetometer

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# APPARATUS NOTES

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## Simple ballistic magnetometer

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Measuring magnetic fields by a search coil and undamped (ballistic) galvanometer is a well known experiment in college physics, being both simple, accurate, and instructive.

In recent years, search-coil measurements of fields have been superseded in laboratory practice by Hall-effect gaussmeters. However, ballistic principles are still being used in research on the magnetic properties of solid materials. A magnetized specimen is made to move relative

to a set of pick-up coils, and its magnetic moment is measured from the deflection of a galvanometer connected to these. The intensity of magnetization of the specimen is often plotted as a function of applied field (hysteresis loop), or as a function of temperature in a constant applied field (thermomagnetic curve).

The following very simple equipment of this kind, originally constructed for quantitative measurements of hysteresis in rock cores, can be built in any convenient size for similar work on, e.g., metals, ceramics, or minerals. It would be suitable for a laboratory exercise in electromagnetism, introductory solid state physics, or geophysics courses. An electromagnet or current coil capable of producing at least 1000 Oe is required, as well as a ballistic galvanometer with a period of 8–10 sec or more.

The author's equipment is shown in longitudinal section in Fig. 1(b). It employs a tube machined out of transparent plastic and wound with two similar coils of copper wire. Originally, 1500 turns at 30 s.w.g. wire were wound on each coil; the sensitivity of the apparatus increases with the number of turns. The coils were connected, in opposition, to a Leeds and Northrup galvanometer of Type 2239 f.

During the experiment, the tube must be held tightly in place by the magnet poles P (pole pieces being removed if necessary), or by a rigid holder. The specimen to be

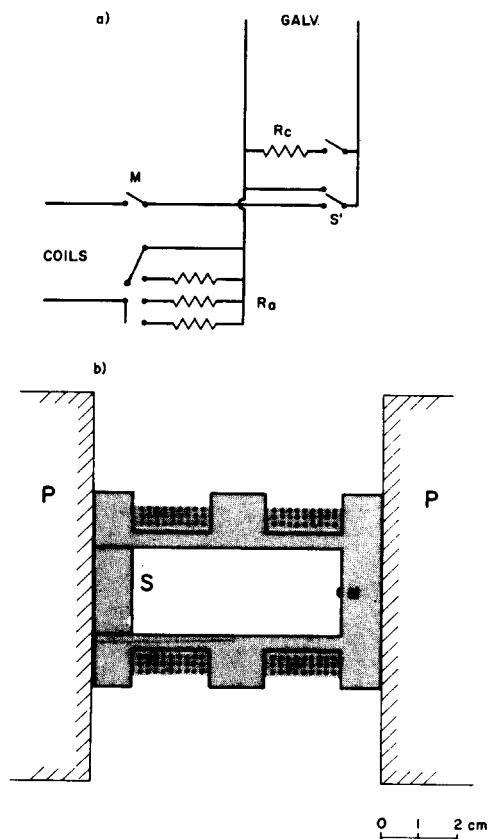


Fig. 1. (a) Wiring diagram and (b) longitudinal section of a ballistic meter where specimens move along field lines.

measured is in the form of a cylinder, of length similar to the length of one coil. It may either be a solid slug or closely packed powder in a nonmagnetic vial. The specimen or vial should just fit inside the tube and be able to slide freely along it.

Before measurement, the specimen (not shown in Fig. 1) is at the left-hand end of the tube, close to the stopper S. The experimenter then blows a short blast of air, via a few feet of flexible tubing, through a hole in the stopper. This will push the specimen, in a fraction of a second, to the right-hand end of the tube, where air is let out. The specimen will (unless strongly anisotropic) have a magnetic dipole moment along the tube. In the end positions, many more of its flux lines will be threading the near coil than the far coil, and the net change in flux resulting from its movement will hence cause a ballistic deflection ("kick") of the galvanometer. It is easily shown that the deflection is independent of the time of transit of the specimen through the tube, provided this time is much shorter than one-fourth of the galvanometer period.

In case the total resistance of the circuit is of the same order as, or less than, the critical damping resistance of the galvanometer, it is necessary that the specimen be made to break the circuit just as it has traversed the tube. This may be arranged by means of an ordinary spring-loaded microswitch M built into the end wall of the tube (Fig. 1). Fig. 1(a) shows this circuit, including three different attenuation resistors  $R_a$ , a shorting switch  $S'$ , and a critical damping resistor  $R_c$  for rapid zeroing of the galvanometer between measurements. The equipment is reset by sucking the specimen back to the left-hand position while  $S'$  is kept closed.

Suitable calibration materials include several paramagnetic salts and some pure magnetite mixed with any inert nonmagnetic substance; their magnetization parameters may be found in handbooks. Skilled experimenters may construct special calibration coils. In either instance, it should be possible to find the magnetization of an unknown by direct proportions, without detailed knowledge of the properties of the pick-up coils or the galvanometer. All specimens should be of the same size, to avoid the need for geometrical correction factors.

In the original equipment, the repeatability of individual measurements was good to about 1% of full-scale deflection. The repeatability of an average from six measurements over a period of weeks was also found to be of order of 1%.

A variation on the magnetometer tube is shown in Fig. 2. This tube is to be mounted transversely in the pole gap of a magnet, to attain closer pole spacing and hence higher field strengths. The pick-up coils form two oppositely wired pairs; this type is more difficult to construct than the first one. A specimen vial, the tube stopper, and part of the blow tubing are also seen.

The basic design of Fig. 1(b) was devised by J. P. H. during Ph.D. studies at the University of Toronto. The microswitch and the variation of Fig. 2 were designed by L. K. at Memorial University and the University of Iceland.

## Centripetal force apparatus

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A commercial centripetal force apparatus which is notable for its simplicity, economy, and elegance of design is the hand-powered model, Cat. No. 9030, supplied by the Sargent-Welch Scientific Company. We wished to incorporate an experiment using this apparatus in our elementary laboratory sequence. The standard experiment with the apparatus as supplied investigates the relation describing the centripetal force:

$$F = mR\omega^2. \quad (1)$$

For a given mass,  $m$ , the angular velocity,  $\omega$ , necessary to maintain the mass in orbit at radius,  $R$ , against the tension of a stretched spring is first determined and the centripetal force,  $F$ , calculated using Eq. (1). Then the value of the centripetal force is measured independently by stretching the spring an equal amount using appropriate weights. Finally, the measured and the calculated

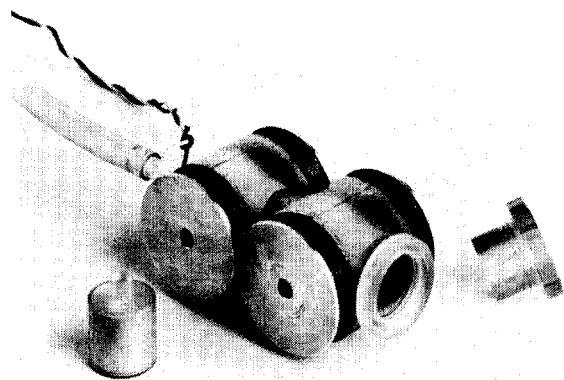


Fig. 2. Ballistic meter where specimens move across field lines.

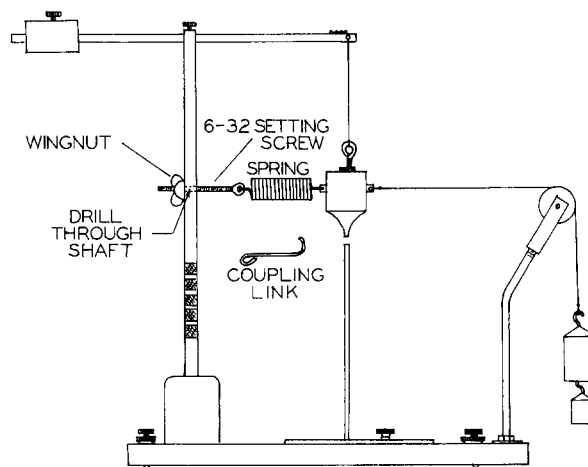


Fig. 3. Schematic of centripetal force apparatus as modified.