Inductive probe to measure the Earth's magnetic field: a short note

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Inductive probe to measure the Earth's magnetic field: a short note

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Abstract

This experiment provides 'hands-on' experience of Faraday's law. By flipping a coil of wire (the probe) in a horizontal or vertical plane the two components of the Earth's magnetic field are determined. The signal from the probe is recorded by a Picoscope ADC100.

Nunn [1] recently described an inductive gravimeter to measure acceleration due to gravity and used the microphone input on a PC to capture data. In this article the same principle is used but, in this case, the Earth's magnetic field is measured.

According to Faraday's law, $V = NA(\mathrm{d}B/\mathrm{d}t)$, an induced voltage is generated when a coil is moved in a magnetic field, B (or vice versa, as in [1]). The coil has N turns of mean area, A, and B is normal to the plane of the coil. If we now consider the coil to be placed on a flat surface and then flip the coil by 180°, the change in B, ΔB, can be determined as:

$$\Delta B = 1/(NA)\,.\int V.\mathrm{d}t$$

and ΔB will be twice the value of the vertical component of the Earth's magnetic field. Thus, by measuring the integrated voltage–time envelope and knowing N and A, the Earth's magnetic field can be calculated.

In the past, ballistic galvanometers were used to perform the integration, but in the 1970s low-cost operational amplifiers became available and these rapidly replaced the galvanometer [2]. Today, however, we have moved away from inductive coils as Hall probe meters are so convenient and give instant readings.

Nunn's experiment [1] did, nevertheless, spark a renewed interest in Faraday's law for me, personally, as my university experiment (of many years ago) with a ballistic galvanometer had been a failure; perhaps a second attempt would have greater success. This time the galvanometer was no longer needed as numerical integration was possible with the PC and, for the inductive coil, a bobbin of enamelled copper wire was used (figure 1).

With such a simple apparatus, a bobbin of wire connected to a Picoscope ADC100 or a sound card [1, 3] in the PC, it is felt that students can fully concentrate on the essence of Faraday's law given above.

The experimental procedure is simple—one flips the bobbin either in a horizontal or vertical plane and an induced voltage is displayed on the computer screen (figure 2).

The graph is for coil flips in the vertical plain so the measurements apply to the vertical component of the Earth's magnetic field. It is clear that a faster flip gives rise to a larger signal amplitude, but that the integrated signal depends on both the width and amplitude of the peak. A similar procedure was carried out with flips in the horizontal plane to determine the horizontal component of the Earth's field.

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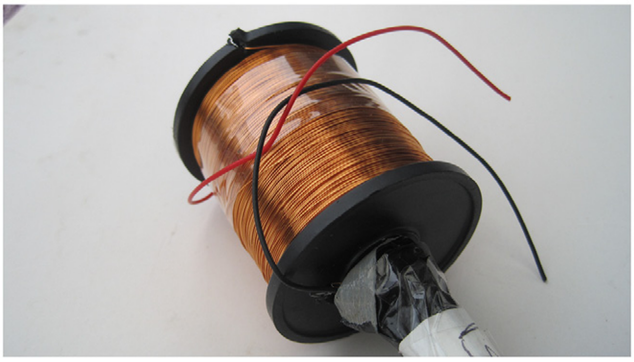


Figure 1. Bobbin of enamelled copper wire (outer diameter of wire is 0.37 mm) used as a magnetic field sensor. The handle can be made of a wood or plastic rod.

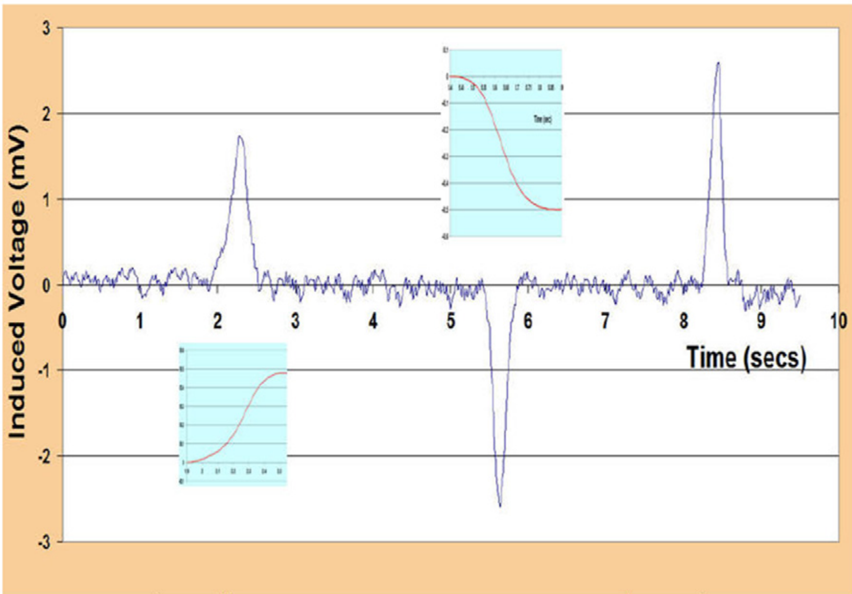


Figure 2. Induced voltage produced from a 180º flip of the bobbin in the Earth's magnetic field, integration profiles are inserted for two of the peaks (see appendix).

Experimental data:

Average integrated peak 0.48×10^{-3} Vs for vertical flip

0.11×10^{-3} Vs for horizontal flip (integration from Excel spreadsheet)

Mean area, A 0.000 86 m^2 (mean diameter is 3.3 cm)

Number of turns 5918 (coil resistance 135 ohm, wire resistance 0.22 ohm m^{-1} (length of wire 613.6 m; see appendix)

At best, the accuracy is likely to be in the range of ±10% and, in addition, one has to be aware that steel beams in buildings will alter the magnetic field significantly.

The results are as follows:

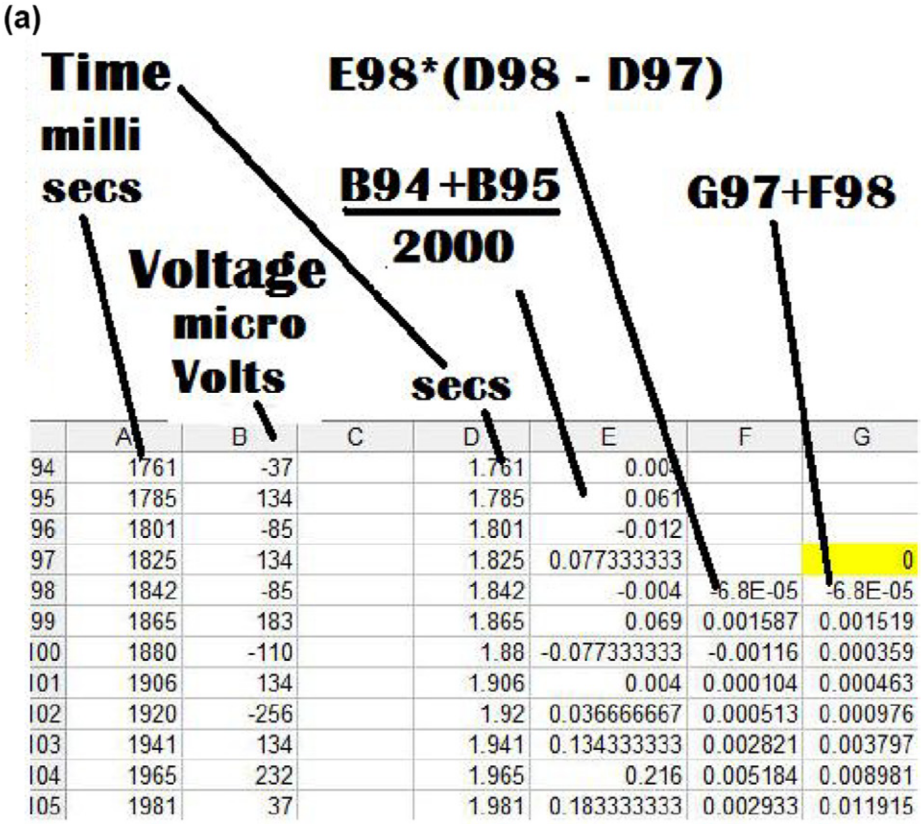
$$B_v = 47\ \mu T \text{ and } B_h = 10\ \mu T.$$

Data compiled by the National Oceanic and Atmospheric Administration (NOAA) for the location of Manchester, UK suggest

B_v = 50 μT and B_h = 12 μT, so it is felt that, within the present accuracy, there is reasonable agreement.

In summary, it is seen that the present measurements have yielded the horizontal and vertical components of the Earth's magnetic field to an accuracy of ±10%. The readings can be made in a very short period of time and the data analysis will give students experience of integration on a spreadsheet. The choice of coil (bobbin) was largely decided by availability, but a bobbin with thinner wire (increased number of turns) would be an advantage, as it would result in an increased induced voltage. As stated, Hall probe meters are the preferred method of magnetic field measurement, but students should appreciate that these instruments do have to be calibrated whereas field measurements with the present probe depends only on the geometry of the coil. As a final thought, the demise of ballistic galvanometers has not proved detrimental to experimental physics.

Appendix A



	A	B	C	D	E	F	G
94	1761	-37		1.761	0.00		
95	1785	134		1.785	0.061		
96	1801	-85		1.801	-0.012		
97	1825	134		1.825	0.077333333		0
98	1842	-85		1.842	-0.004	-6.8E-05	-6.8E-05
99	1865	183		1.865	0.069	0.001587	0.001519
100	1880	-110		1.88	-0.077333333	-0.00116	0.000359
101	1906	134		1.906	0.004	0.000104	0.000463
102	1920	-256		1.92	0.036666667	0.000513	0.000976
103	1941	134		1.941	0.134333333	0.002821	0.003797
104	1965	232		1.965	0.216	0.005184	0.008981
105	1981	37		1.981	0.183333333	0.002933	0.011915

Figure A.1. Data manipulation—note, a zero (highlighted yellow) is placed in cell G97 to ensure that the summation starts with zero. Modest smoothing is applied to column E as data is converted from micro-volts to milli-volts. Column F contains elemental areas, Vdt, calculated with a simple rectangular approximation rather than the more accurate trapezoidal formulation.

(b)

Part Number Table

Description	Diameter (mm)	Tolerance (mm) On Conductor	Enamel Coat (mm)		Resistance Ω/m @ 20°C			Part Number
			Min. Increase in Dia.	Max. O.D.	Min.	Nom.	Max.	
Wire, Copper Enamelled, 35SWG	0.2	± 0.003	0.027	0.0239	0.5237	0.5441	0.5657	ECW0.2
Wire, Copper Enamelled, 34SWG	0.224		0.029	0.0266	0.4188	0.4338	0.4495	ECW0.224
Wire, Copper Enamelled, 33SWG	0.25	± 0.004	0.032	0.0297	0.3345	0.3482	0.3628	ECW0.25
Wire, Copper Enamelled, 30SWG	0.315		0.035	0.367	0.2121	0.2193	0.227	ECW0.315
Wire, Copper Enamelled, 27SWG	0.4	± 0.005	0.04	0.459	0.1316	0.136	0.1407	ECW0.4
Wire, Copper Enamelled, 25SWG	0.5		0.045	0.566	0.08462	0.08706	0.08959	ECW0.5
Wire, Copper Enamelled, 24SWG	0.56	± 0.006	0.047	0.63	0.06736	0.0694	0.07153	ECW0.56
Wire, Copper Enamelled, 22SWG	0.71	± 0.007	0.053	0.789	0.04198	0.04318	0.04442	ECW0.71
Wire, Copper Enamelled, 21SWG	0.8	± 0.008	0.056	0.884	0.03305	0.03401	0.035	ECW0.80
Wire, Copper Enamelled, 19SWG	1		0.063	1.094	0.02116	0.02176	0.0224	ECW1.0
Wire, Copper Enamelled, 18SWG	1.25	± 0.013	0.067	1.349	0.01353	0.01393	0.01435	ECW1.25
Wire, Copper Enamelled, 16SWG	1.5	± 0.015	0.071	1.606	0.0094	0.00967	0.00995	ECW1.5

Figure A.2. Wire sizes and resistance.

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[3] Hunt M B and Dingley K 2002 *Phys. Educ.* **37** 251–3

Frank Thompson joined the Physics School at Manchester Polytechnic, UK after spending some years working in oil prospecting in Libya. In the late 1990s he took early retirement, and he has done consultancy work since then. At present, he is working at the MACE Centre, Manchester University.