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# Magnetic Induction Kit

Investigating Faraday's laws of electromagnetic induction

**Appendix – Derivation of the free-fall formula**

The easiest way to derive the free-fall formula is to use the law of conservation of energy.

Let  $m$  be the mass of the magnet. The other variables are as defined in the text. Then:

Kinetic energy of magnet at initial speed  $u$ :

$$E_{K1} = \frac{1}{2}mu^2$$

Gravitational potential energy of magnet at top of tube, relative to bottom of tube:

$$E_{G1} = mas$$

Kinetic energy of magnet at final speed  $v$ :

$$E_{K2} = \frac{1}{2}mv^2$$

Gravitational potential energy of magnet at bottom of tube, which is our reference level and is therefore, by definition:

$$E_{G2} = 0$$

Using the law of conservation of energy, the kinetic energy gained by the magnet is equal to the gravitational potential energy it loses:

$$E_{K2} - E_{K1} = E_{G2} - E_{G1}$$

Substituting:

$$\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = mas - 0$$

Cancelling the  $m$ :

$$\frac{1}{2}v^2 - \frac{1}{2}u^2 = as$$

Multiplying both sides by 2 and rearranging:

$$v^2 = u^2 + 2as$$

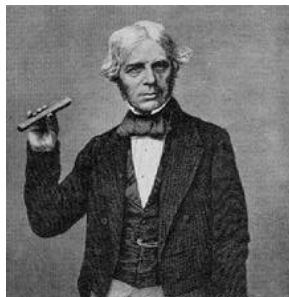
(Q.E.D.)

## DO094 Revision History

- 1) 2003 Original.
- 2) 23.7.07 Corrected EMF definition. Reformatted.
- 3) 6.11.08 New address.

## 4 Michael Faraday

English scientist Michael Faraday's scientific work laid the foundations of all subsequent electrical technology. From his experiments came devices that led directly to the modern electric motor, generator and transformer. Faraday was also the greatest scientific lecturer of his day, and did much to publicise the great advances of nineteenth-century science and technology through his articles, correspondence and the Friday evening discourses which he established at the Royal Institution. The Royal Institution Christmas lectures for children, begun by Faraday, continue to this day.



Michael Faraday holding a glass bar, c. 1857

On 29th August 1831, using his "induction ring", Faraday made one of his greatest discoveries, electromagnetic induction: the "induction" or generation of electricity in a wire by means of the electromagnetic effect of a current in another wire. The induction ring was the first electric transformer. In a second series of experiments in September he discovered magnetoelectric induction: the production of a steady electric current. To do this, Faraday attached two wires through a sliding contact to a copper disc. By rotating the disc between the poles of a horseshoe magnet he obtained a continuous direct current. This was the first generator.

Faraday's three laws of electromagnetic induction state:

- A changing magnetic field induces an electromotive force in a conductor
- The electromotive force is proportional to the rate of change of the field
- The direction of the induced electromotive force depends on the orientation of the field.

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## 1 Introduction



The Pico Magnetic Induction Kit provides a simple and effective method for students to investigate the concept of Faraday's laws of electromagnetic induction. A small bar magnet is dropped down the tube and, as it passes through the coil, an electromotive force (EMF) is induced. The voltage pulse is monitored on an oscilloscope and its characteristics can be investigated as the rate of cutting of field lines is varied.

## 2 Applications

The system can be used to demonstrate electromagnetic induction, the direction of induced currents and variation of the size of induced EMF with speed. It can also be used as a student-based investigation, either with full instructions or as an open investigation where the students research the concepts.

## 3 Operation

Use a laboratory stand to clamp the main tube near its top so that it is in a convenient position for the magnet to be dropped down the tube and caught at the bottom. Slide the coil assembly on to the tube from below.

The output from the coil can be viewed using a Pico PC oscilloscope, a DrDAQ data logger or on most other digital storage oscilloscopes. The instructions vary slightly depending on the oscilloscope used:



### 3.1 Pico dual channel PC oscilloscopes / other digital oscilloscopes

Connect the output sockets to channel A on the oscilloscope. Set channel A to 500mV/div and the timebase to 5ms/div. Set the trigger to 'Repeat' so that the pulse is displayed each time the magnet is dropped down the tube. Set the trigger level to +50mV (rising) and the trigger delay to -50% (pre-trigger).

### 3.2 Pico ADC-40 or ADC-42

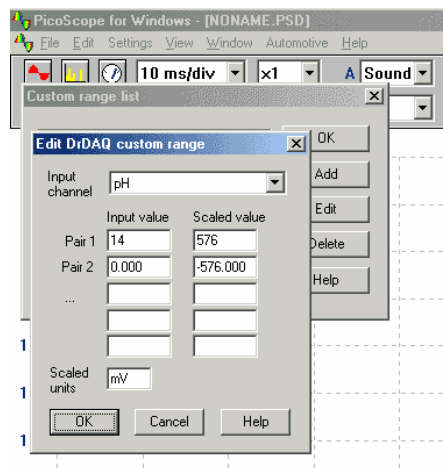
The ADC-40 and ADC-42 have a fixed 5V input range, so initially the waveform on the screen will appear very small. In PicoScope set the Y multiplier to x10 to zoom in on the signal.

### 3.3 DrDAQ data logger

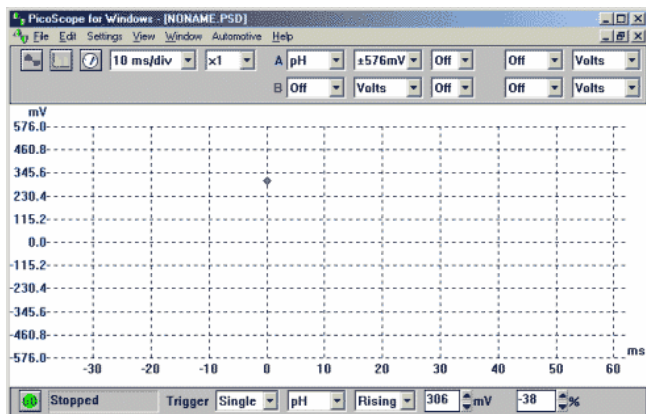
To use the magnetic induction kit with DrDAQ, connect to the BNC input. Normally this is calibrated to measure pH, but by adding a custom range it can be made to read in mV.

Follow this procedure to configure the pH input for use with the Magnetic Induction Kit:

1. Select **File | Settings | Custom ranges**
2. Select **Add** in the Custom range list
3. Enter the settings as shown in the image on the right
4. Use the drop-down menus for channel A to select pH and the range "576mV"



The DrDAQ screen should now look like the image below:



**Note 1.** The DrDAQ BNC input is filtered to reduce noise pickup when measuring pH. This filtering may reduce the amplitude of the measured signal. For this reason, whilst we recommend using DrDAQ for quick demonstrations, it is better to use one of the oscilloscope products for more detailed investigations.

**Note 2.** Due to the variations in coil and magnet strength, it may be necessary to adjust the settings of the oscilloscope you are using.

The speed of the magnet is calculated using the formula:

$$v^2 = u^2 + 2as$$

where  $v$  is the velocity as it passes through the coil,  $u$  is the initial velocity (assumed to be zero),  $a$  is the acceleration due to gravity ( $g$ , or about  $9.81 \text{ m/s}^2$ ) and  $s$  is the distance from the release point to the coil. (See Appendix for derivation.)

There are many points to note in the procedure and these can be explained to students or used in assessing their practical skills. The main points are:

- The pulse maximum occurs when the bottom end of the magnet passes through the middle of the coil. If the magnet is released with its centre level with the top of the tube, the distance fallen can be taken as the distance from the top of the tube to the top of the coil.
- If a graph of results is drawn (pulse amplitude against velocity), the intercept on the velocity axis (velocity when amplitude is zero) can be used to determine at which point in the coil the pulse maximum occurs.
- Multiple drops of the magnet for any given distance should be used to get the best estimate for the pulse amplitude.
- The pulse shape is asymmetric. The first maximum occurs as the lower pole enters the coil and the second peak occurs as the upper pole leaves the coil. The speed of travel changes during this process so that the second maximum is larger than the first. The effect is most obvious at small values of distance fallen since the percentage change is larger. When the coil is at the bottom of the tube the pulse is almost symmetrical. A very large distance between the release point and the coil is required for a truly symmetrical pulse. An imaginative student could explore this idea.