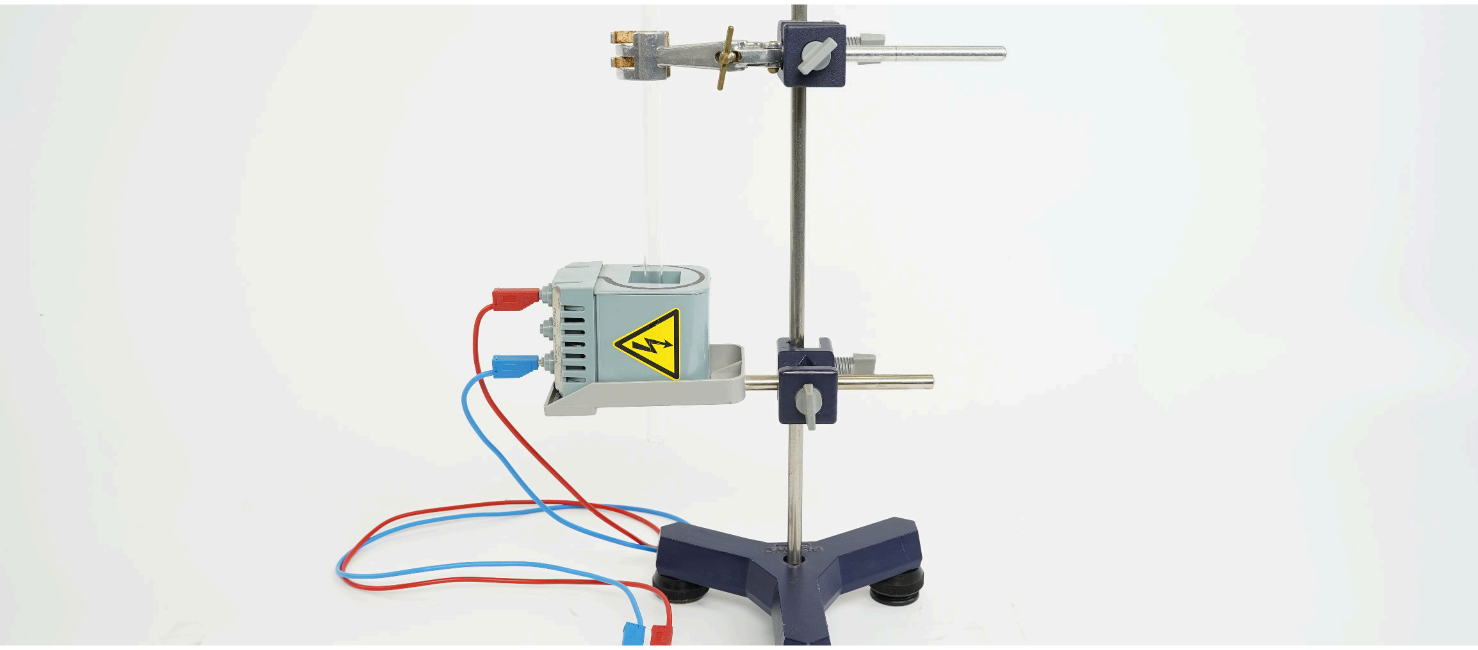
Induced voltage pulse and Faraday's law of induction with Cobra SMARTsense



Physics | Electricity & Magnetism | Electromagnetism & Induction

Difficulty level	Group size	Preparation time	Execution time
easy	-	10 minutes	10 minutes

This content can also be found online at:

http://localhost:1337/c/6492f25c5afdd5000235136e

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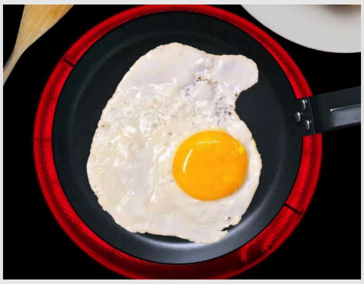
Teacher information

Application



Understanding and utilizing the principle of induction is crucial in our everyday lives, as it underpins many technologies and systems that we rely on. From the generation of electricity that powers our homes and cities, to the wireless charging of our smartphones and electric vehicles, induction is at the heart of these processes. It's also used in cooking with induction stoves, which provide rapid and precisely controlled heating. Furthermore, systems like RFID tags and metal detectors, which are used in everything from retail to security, operate based on principles of induction. Therefore, a solid understanding of induction can not only help us appreciate the technology we use daily, but also inspire innovative solutions for the future.

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Other teacher information (1/2)

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Prior knowledge

The students should have basic knowledge in the field of electromagnetism.

Principle

A permanent magnet falls through a coil at different velocities and the respective induced voltage surge is is registered.The induction voltage is constant over the fall and thus independent of the velocity.

Other teacher information (2/2)

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Learning objective

This experiment shows the principle of generating an induction voltage.

Tasks

1. Observation of the induction voltage when the magnet falls through the coil.
2. Study of the induction voltage with different orientation of the magnet.
3. Determination of the influence of the number of turns of the coil on the induced voltage.
4. Determination of the influence of the height of fall on the induced voltage.

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Safety instructions

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The general instructions for safe experimentation in science lessons apply to this experiment.

Theory (1/2)

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The observed voltage curve can be described with the aid of Maxwell's third equation, more precisely with Faraday's induction law. This law states that a magnetic field which changes with time causes an electrical vortex field:

$$\oint_{\partial A} \vec{E} \cdot d\vec{s} + \left(\iint_A \frac{\partial \vec{B}}{\partial t} \cdot d\vec{A}\right) = 0,$$

with the electric field strength $\vec{E}$, the magnetic flux density $\vec{B}$, the area $\vec{A}$ and the line element $d\vec{s}$ tangential to its boundary curve. The electric field strength along a closed conductor loop is therefore proportional to the magnetic flux density which passes through the area enclosed by the conductor loop.

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Theory (2/2)

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When the permanent magnet enters the environment of the coil, the closed magnetic field lines running from the north to the south pole of the magnet cross the cross-sectional area of the coil. Due to the fall of the magnet, its relative position to the coil changes and consequently also the magnetic field acting there, which according to the law of induction causes an electric field along the coil. This results in an induced voltage between the two ends of the coil: $U = -N \cdot \frac{D\Phi}{dt}$,

which is proportional to the number of turns of the coil N and the time change of the magnetic flux Φ. The magnetic flux in turn describes the magnetic flux density $\vec{B}$ which penetrates the cross-sectional area $\vec{A}$. In the case, this corresponds almost to the scalar product of the two quantities:

$\Phi = -\frac{1}{N} \int U dt = \vec{B} \cdot \vec{A}.$

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Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense Voltage - Sensor for measuring electrical voltage ± 30 V (Bluetooth + USB)	12901-01	1
2	measureLAB, multi-user license	14580-61	1
3	Support rod, stainless steel, 500 mm	02032-00	1
4	Right angle clamp expert with fulcrum screw	02054-00	2
5	Tripod base PHYWE	02002-55	1
6	Universal clamp	37715-01	1
7	Glass tube,diam 10mm l 300 mm	MAU-16074510	1
8	Coil holder	06528-00	1
9	Coil, 3600 turns, tapped	06516-01	1
10	Magnet, d=8 mm, l=60 mm	06317-00	1
11	Connecting cord, 19A ,50 cm, red	07314-01	1
12	Connecting cord,19A,50cm, blue	07314-04	1

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Setup and procedure

Setup (1/2)

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The Cobra SMARTsense and the measureAPP are required to carry out the experiment. The app can be downloaded free of charge from the App Store - see below for QR codes. Check whether Bluetooth is activated on your device (tablet, smartphone).

measureAPP for Android operating systems

measureAPP for iOS operating systems

measureAPP for tablets / PCs with Windows 10

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Setup (2/2)

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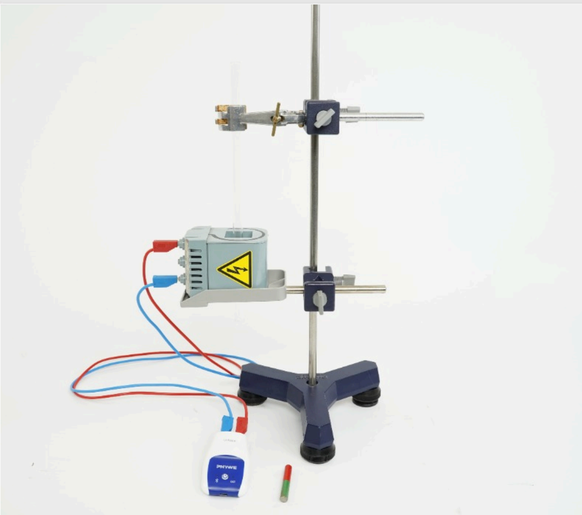

experimental setup

- Set up the experiment according to the image on the left.
- Pass the glass tube through the coil and clamp the upper end in the universal clamp so that it is perpendicular to the ground: The glass tube gives the magnet a clean guide and ensures a spin-free fall even from greater heights.
- Connect the upper and lower output to the Cobra SMARTsense voltage sensor.

Procedure (1/4)

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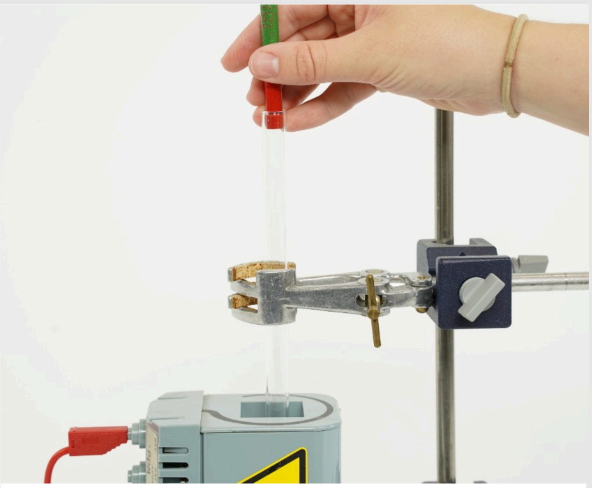

1st measurement

- Turn on the Cobra SMARTsense voltage sensor and connect it to the measureAPP.

1st measurement:

- Start the measurement in the measureApp.
- In order to ensure a constant drop height, grasp the magnet in the middle and - with the red side (north pole) first - insert it halfway into the glass tube from above.
- Now drop the magnet and catch it below the coil.

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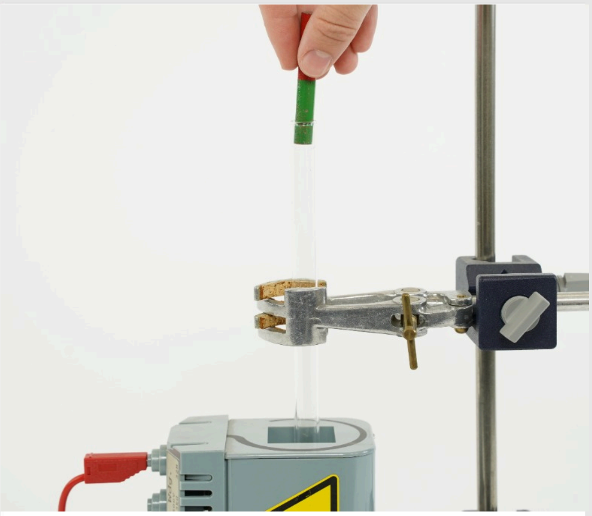
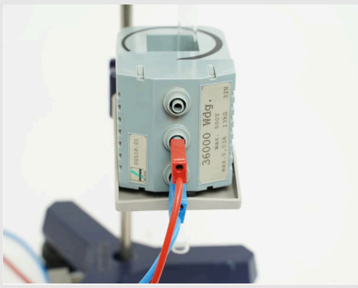
Procedure (2/4)

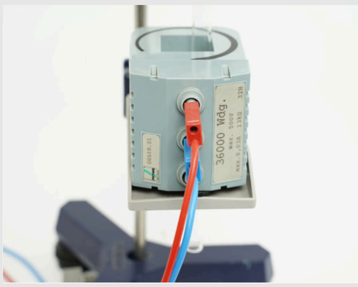

2nd measurement

2nd measurement:

- In the second measurement, the effect of the orientation of the magnet is considered.
- To do this, press the start button again and drop the magnet through the glass tube as before, but with the green side (south pole) first.

Procedure (3/4)





3rd/4th measurement:

- Now consider the effect on voltage when the number of turns of the coil is halved.
- For the 3rd measurement the center tap and the lower sockets of the coil are connected to the Cobra SMARTsense voltage sensor, for the 4th measurement the center tap and the upper socket are connected to the Cobra SMARTsense voltage sensor.

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Procedure (4/4)

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5. measurement

5. measurement:

- In the last part of the experiment, the influence of the drop height is investigated.
- To do this, push the glass tube further up in the universal clamp until the lower end is approximately level with the upper edge of the coil.
- Activate the measurement by pressing the start button and drop the magnet (any side first) through the glass tube.

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Evaluation

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Observation

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1. The fall of the magnet causes a voltage in the coil, which is noticeable in both positive and negative direction
2. The second deflection is always greater than the first.
3. If the magnet falls with the other side first, the signs of the caused voltage are reversed.
4. If the number of turns of the coil is halved, the induced voltage decreases.
5. If the voltage is measured across the lower coil half, the deflections occur later, the distance peak-to-peak is greater than with a measurement in the upper coil half.
6. A greater drop height also results in an increase in the maximum voltage.

Evaluation (1/4)

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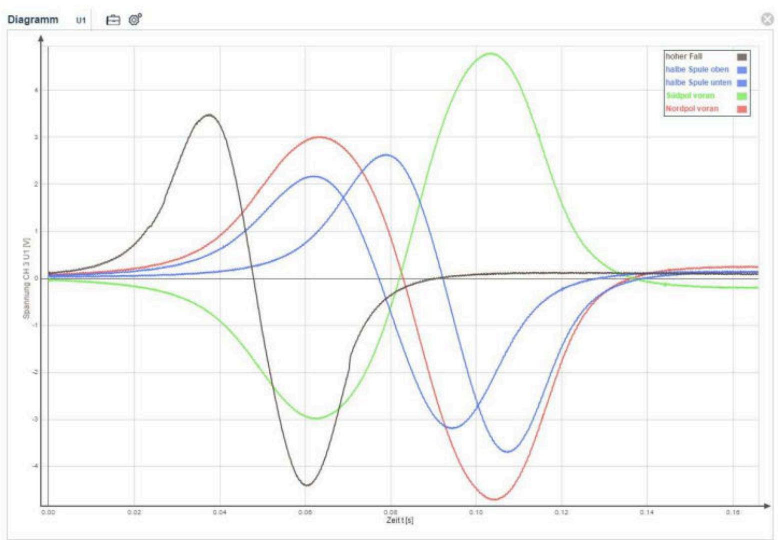
The figure shows the different measurement examples:

- Red : North Pole ahead
- Green : South pole ahead
- Blue : half coil
- Black: higher free fall



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Evaluation (2/4)

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1. Behavior when passing through the coil

If we look at the first measurement (red measuremnt), we first see an increase of the induction voltage. As the magnet approaches, more and more field lines intersect the cross-sectional area of the coil, the magnetic flux thus increases and also causes an increasing induction voltage. As soon as the magnet is completely inside the coil, all field lines leaving the north pole or entering the south pole intersect the cross-sectional area of the coil. The magnetic flux thus reaches a maximum and remains constant until the magnet leaves the coil again. The temporal changes of the magnetic flux and thus the of the induced voltage are zero. When the magnet leaves the coil, the magnetic flux in the coil drops again, the change in time causes again an induced voltage with opposite sign. Furthermore, it is noticeable that the magnitudes of the voltage maxima differ when the magnet enters and exits. It must be considered that the magnet is continuously accelerated by the gravitational field of the earth when passing through the coil.
Due to the higher exit velocity, the temporal change of the magnetic flux is larger and consequently also the induced voltage. At the same time, this change takes place in a shorter time, which means that the area is identical under both parts of the curve according to the law of induction.

Evaluation (3/4)

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2. Reversed falling direction of the magnet

If the magnet falls from the same height with the south pole instead of the north pole in front, the qualitative course of the induction impulse is the same, but the voltage shows an opposite sign throughout (green curve in the measurement example). Since the field lines always run from north to south pole they now intersect the cross-sectional area $\vec{A}$ of the coil in the opposite direction. This results in a reversed magnetic flux Φ and therefore also in a opposite induced voltage.

3. Reduction of the number of turns

The two blue curves of the measurement example were recorded with the number of turns halved. Since the induced voltage U is proportional to the number of turns N, the area under these curves is also half the area under the curves at full number of turns. The offset and the different voltage maxima of the two curves can also be explained by the increase in the speed of the magnet. While the lower half of the coil is reached later and is passed through in a shorter time, the maximum voltage increases.

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Evaluation (4/4)

4. Larger drop height

The black trace was recorded with a significantly greater drop height at half the number of turns of the coil (compare witht the blue curves). Here it is again clear that with higher velocity the maximum induction voltage increases noticeably.

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