



SUBJECT and GRADE	Physical Sciences Gr 11
TERM 3	Week 4
TOPIC	Electromagnetism: Faraday's law (Consolidation lesson)
AIM OF LESSON	Consolidation of Faraday's law, which include the following: • Stating <u>Faraday's law of electromagnetic induction</u>. • Applying the <u>Right-hand rule</u> to determine the <u>direction of the current induced</u> in a solenoid when a pole of a bar magnet moves into and out of the solenoid. • <u>Solving problems</u> using the formula $\Phi = BA\cos\theta$. • Predicting the <u>direction of the induced current</u> in a coil. • <u>Solving problems</u> using the formula $\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$.
RESOURCES	Paper-based / physical resources • Prescribed CAPS Physical Sciences textbook, as well as Siyavula Grade 11 Physical Sciences resource (learner book, pg. 350 - 373); Physical Sciences CAPS document (pg. 86 - 88); and Grade 11 Physical Sciences Examination Guideline (pg.12). (<i>Additional subject-related material (e.g. Mind the Gap, Science Clinic, Answer Series, etc.).</i>) • Scientific calculator • Ruler, black or blue pen and pencil. Digital resources • Technological devices such as a cell phone, tablet, laptop, etc. and sufficient data would be very useful. • WCED ePortal – Website links to access recommended platforms: http://wcedportal.co.za/; https://wcedonline.westerncape.gov.za/elearning; https://wcedportal.co.za/curriculum-support; https://wcedportal.co.za/partners1

	• Mind the Gap: https://www.education.gov.za/Curriculum/LearningandTeachingSupportMaterials(LTSM)/MindtheGapStudyGuides.aspx • Siyavula links (electrostatics/Coulomb's law): https://www.siyavula.com/read/science/grade-11/electrostatics/09-electrostatics-01 • Youtube videos: https://www.youtube.com/watch?v=zRmfNvTzlhk Practical resources (Additional / Optional) Materials needed for Faraday's law practical demonstration: • Solenoid • Bar magnet • Galvanometer • Connecting wires
INTRODUCTION	Crash-course video link: Practical demonstration of Faraday's law.  https://www.youtube.com/watch?v=zRmfNvTzlhk
CONCEPTS AND SKILLS	<i>This section must be read in conjunction with the CAPS, pg. 86 – 88.</i> Magnetic flux The magnetic flux (Φ) is expressed as $\Phi = BA\cos\theta$, where: θ = the <u>angle between</u> the <u>magnetic field</u>, B, and the <u>normal</u> to the loop of area; A = the <u>area of the loop</u>; and B = the <u>magnetic field</u>.

Faraday's Law of electromagnetic induction

The emf, ϵ , produced around a loop of conductor is proportional to the rate of change of the magnetic flux, Φ , through the area, A , of the loop.

Faraday's law can be expressed mathematically by the formula $\epsilon = -N \frac{\Delta\Phi}{\Delta t}$, where $\Phi = B \cdot A$ and B is the strength of the magnetic field. N is the number of circuit loops. A magnetic field is measured in units of teslas (T).

Table: Ensure that you familiarise yourself with the following physical quantities, units and symbols, which will be needed to answer the questions that follow.

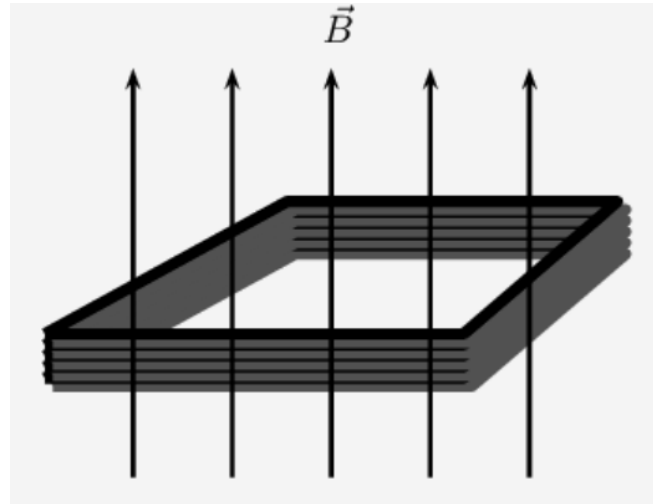
Information relating to electromagnetism		
Physical quantity	Unit name	Unit symbol
Induced emf (ϵ)	Volt	V
Magnetic field (B)	Tesla	T
Magnetic flux (Φ)	Weber	Wb
Time (t)	Seconds	s

(Extracted and summarized from: Siyavula Grade 11 Physical Sciences resource (learner book, pg. 350 - 373); Physical Sciences CAPS document (pg. 86 - 88); and Grade 11 Physical Sciences Examination Guideline (pg.12)).

ACTIVITIES / ASSESSMENT

EXAMPLE: FARADAY'S LAW

Consider a flat square coil with 5 turns. The coil is 0,50 m on each side and has a magnetic field of 0,5 T passing through it. The plane of the coil is perpendicular to the magnetic field: the field points out of the page. Use Faraday's Law to calculate the induced emf, if the magnetic field is increases uniformly from 0,5 T to 1 T in 10 s. Determine the direction of the induced current.



SOLUTION

STEP 1: Identify what is required

We are required to use Faraday's Law to calculate the induced emf, which is concerned with the following equation:

$$\mathcal{E} = -N \frac{\Delta\Phi}{\Delta t}$$

STEP 2: Write Faraday's Law

We know that the magnetic field is at right angles to the surface and so aligned with the normal. This means we do not need to worry about the angle that the field makes with the normal and $\Phi = BA$. The starting or initial magnetic field, B_i , is given as is the final field magnitude, B_f . We want to determine the magnitude of the emf so we can ignore the minus sign.

The area, A , is the area of square coil.

STEP 3: Solve Problem

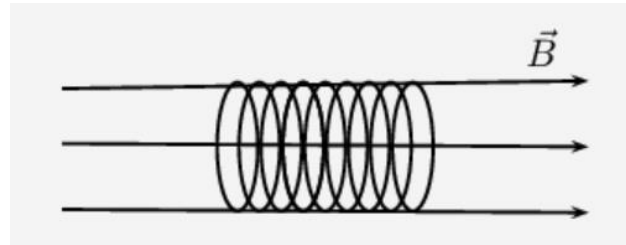
$$\begin{aligned}\mathcal{E} &= N \frac{\Delta\phi}{\Delta t} \\ &= N \frac{\phi_f - \phi_i}{\Delta t} \\ &= N \frac{B_f A - B_i A}{\Delta t} \\ &= N \frac{A(B_f - B_i)}{\Delta t} \\ &= (5) \frac{(0,50)^2(1 - 0,50)}{10} \\ &= (5) \frac{(0,50)^2(1 - 0,50)}{10} \\ &= 0,0625 \text{ V}\end{aligned}$$

CONSOLIDATION EXERCISES

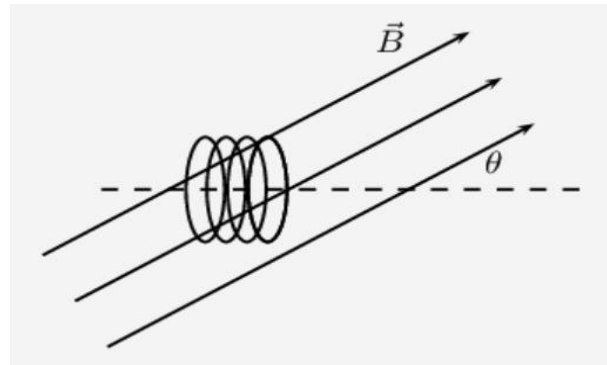
Please use ample time to complete the following activities (questions 1 - 3), which will aid in preparing you for the final examination.

QUESTION 1

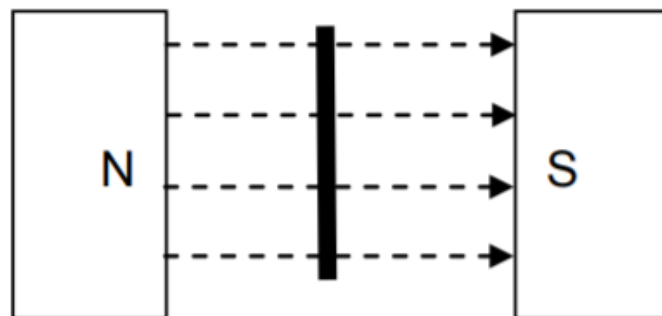
Consider a solenoid of 9 turns with unknown radius, r . The solenoid is subjected to a magnetic field of 0,12 T. The axis of the solenoid is parallel to the magnetic field. When the field is uniformly switched to 12 T over a period of 2 minutes an emf with a magnitude of $-0,3$ V is induced. Determine the radius of the solenoid.

**QUESTION 2**

Consider a circular coil of 4 turns with radius 3×10^{-2} m. The solenoid is subjected to a varying magnetic field that changes uniformly from 0,4 T to 3,4 T in an interval of 27 s. The axis of the solenoid makes an angle of 35° to the magnetic field. Find the induced emf.

**QUESTION 3 (Exam-related question)**

A SQUARE induction coil with a side length 3 cm and 400 windings, is placed perpendicularly in a uniform magnetic field and then rotated through an angle of 45° in 0,08 s.



An emf of 7 V is induced in the coil.

3.1 State Faraday's law of electromagnetic induction in words.

(2)

3.2 Calculate the change in the magnetic flux.

(3)

3.3 Calculate the magnitude of the magnetic field.

(4)

The coil is now rotated through an angle of 45° in 0,05 s.

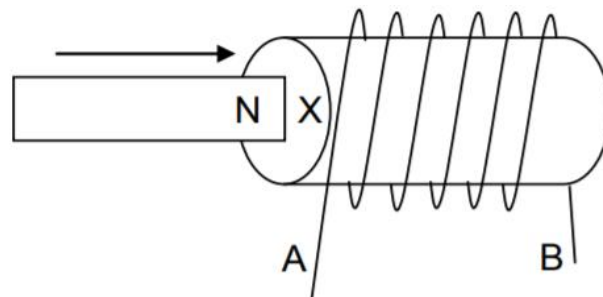
3.4 How will the induced emf be affected? Write only **INCREASE**, **DECREASE** or **STAY THE SAME**.

(1)

3.5 Explain the answer to QUESTION 3.4.

(1)

The north pole of a bar magnet is pushed into a solenoid, as shown in the sketch below.



3.6 Which pole will be induced at point X? Write only **NORTH** or **SOUTH**.

3.7 In which direction will the induced current flow? Write only **FROM A TO B** or **FROM B TO A**.

(1)

[13]

GUIDELINES TO ANSWER PREVIOUS QUESTIONS

QUESTION 1

Explanation

Identifying what is required: We are required to determine the radius of the solenoid. We know that the relationship between the induced emf and the field is governed by Faraday's law which includes the geometry of the solenoid. We can use this relationship to find the radius, which is concerned with the formula $\mathcal{E} = -N \frac{\Delta\phi}{\Delta t}$.

Applying Faraday's law: We know that the magnetic field is at right angles to the surface and so aligned with the normal. This means we do not need to worry about the angle the field makes with the normal and $\phi = BA$. The starting or initial magnetic field, B_i , is given as is the final field magnitude, B_f . We can exclude the minus sign because we are working with the magnitude of the emf only.

The area, A , is the surface area of the solenoid which is πr^2 .

Solving the problem:

$$\begin{aligned}\mathcal{E} &= N \frac{\Delta\phi}{\Delta t} \\ &= N \frac{\phi_f - \phi_i}{\Delta t} \\ &= N \frac{B_f A - B_i A}{\Delta t} \\ &= N \frac{A(B_f - B_i)}{\Delta t} \\ (0,30) &= (9) \frac{(\pi r^2)(12 - 0,12)}{120} \\ r^2 &= \frac{(0,30)(120)}{(9)\pi(12 - 0,12)} \\ r^2 &= 0,107175 \\ r &= 0,32 \text{ m}\end{aligned}$$

The solenoid has a radius of 0,32 m.

QUESTION 2

Explanation

Identifying what is required: We are required to use Faraday's Law to calculate the induced emf, which is concerned with the formula $\mathcal{E} = -N \frac{\Delta\phi}{\Delta t}$.

Applying Faraday's law: We know that the magnetic field is at an angle to the surface normal. This means we must account for the angle that the field makes with the normal and $\phi = BA\cos(\theta)$. The starting or initial magnetic field, B_i , is given as is the final field magnitude, B_f . We want to determine the magnitude of the emf so the minus sign can be ignored.

The area, A , will be πr^2 .

Solving the problem:

$$\begin{aligned}\mathcal{E} &= N \frac{\Delta\phi}{\Delta t} \\ &= N \frac{\phi_f - \phi_i}{\Delta t} \\ &= N \frac{B_f A \cos(\theta) - B_i A \cos(\theta)}{\Delta t} \\ &= N \frac{A \cos(\theta) (B_f - B_i)}{\Delta t} \\ &= (4) \frac{(\pi(0,03)^2 \cos(35))(3,4 - 0,4)}{27} \\ &= 1,03 \times 10^{-3} \text{ V}\end{aligned}$$

The induced current is anti-clockwise as viewed from the direction of the increasing magnetic field.

QUESTION 3 (Exam-related question)

3.1 The magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor. ✓✓ (2)

3.2 $\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$ ✓

$$7 = -400 \frac{\Delta\Phi}{0.08} \checkmark$$

$$\Delta\Phi = -1,4 \times 10^{-3} \text{ Wb} \checkmark$$

(3)

3.3 $\Delta\Phi = AB(\cos \theta_f - \cos \theta_i)$ ✓

$$-0,0014 \checkmark = (0,03)^2 B (\cos 45^\circ - \cos 0^\circ) \checkmark$$

$$B = 5,31 \text{ T} \checkmark$$

(4)

3.4 Increase ✓

(1)

3.5 $\varepsilon \propto \frac{1}{\Delta t}$ ✓

OR: Emf is inversely proportional to time. If the time decreases, the emf will increase. ✓

(1)

3.6 North ✓

(1)

3.7 From A to B ✓

(1) **[13]**

CONSOLIDATION	Summary of activities which you should be able to do: • State <u>Faraday's Law</u>. • Use words and pictures to describe what happens when a <u>bar magnet is pushed into or pulled out of a solenoid</u> connected to a galvanometer. • Use the <u>Right-hand rule</u> to determine the <u>direction of the induced current</u> in a solenoid when the <u>north or south pole of a magnet is inserted or pulled out</u>. • Know that for a <u>loop of area A</u> in the presence of a <u>uniform magnetic field B</u>, the <u>magnetic flux</u> (Φ) passing through the loop is expressed as: $\Phi = BA\cos\theta$, where θ is the <u>angle</u> between the <u>magnetic field B</u> and the <u>normal</u> to the loop of <u>area A</u>. • Know that the <u>induced current</u> flows in a direction so as to set up a <u>magnetic field to oppose the change in magnetic flux</u>. • <u>Calculate</u> the <u>induced emf</u> and <u>induced current</u> for situations involving a <u>changing magnetic field</u> using the equation for Faraday's Law: $\varepsilon = -N \frac{\Delta\Phi}{\Delta t}$, where $\Phi = BA\cos\theta$ is the magnetic flux.
VALUES / APPLICATIONS IN PRACTICE	Real-life applications of Faraday's Law If you find the topic of Electromagnetism interesting, then you are welcome to do further research on the application of Faraday's law in the following devices: • Induction stoves • Tape players • Metal detectors • Transformers