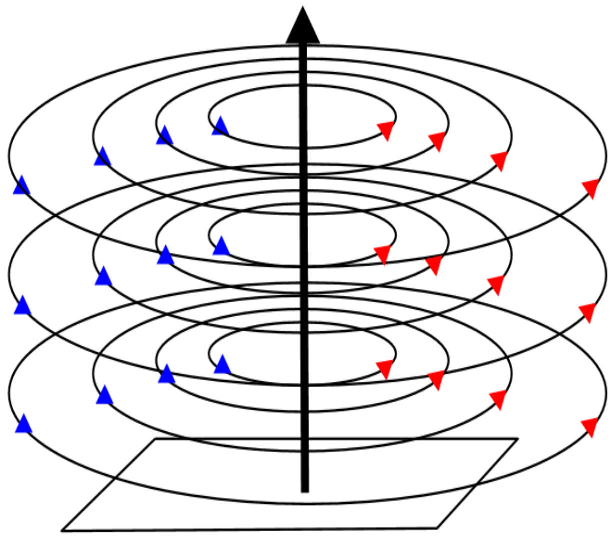
SUBJECT	Physical Sciences
GRADE	11
Term 3	Week 3
TOPIC	Electromagnetism, the Right-hand rule and Faraday's law.
AIMS	**At the end of this series of self-study lessons, you should be familiar with the following aspects pertaining to electromagnetism:** **Magnetic field associated with current-carrying conductors** • Applying the Right-hand rule to determine the magnetic field (B) associated with a: (1) Straight current-carrying conductor; (2) Current-carrying loop (single turn); and (3) Solenoid. • Drawing the magnetic field pattern around a: (1) Straight current-carrying wire; (2) Current-carrying loop (single turn); and (3) Solenoid. **Faraday's law** • Stating Faraday's law of electromagnetic induction. • Applying the Right-hand rule to determine the direction of the current induced in a solenoid when a pole of a bar magnet moves into and out of the solenoid. • Solving problems using the formula $\Phi = BA\cos\theta$. • Predicting the direction of the induced current in a coil. • Solving problems 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). *(Additional subject-related material (e.g. Mind the Gap, Science Clinic, Answer Series, etc.).* • 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://wcedeportal.co.za/;* https://wcedonline.westerncape.gov.za/elearning; *https://wcedeportal.co.za/curriculum-support;* https://wcedeportal.co.za/partners • 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=1cFl_7md76o*; *https://www.youtube.com/watch?v=Nb25_foS9Mg*
	Practical resources *(Additional / Optional)* **Materials needed for practical demonstration** (i.e. getting learners to observe the magnetic field around a current carrying wire); **or Project** (i.e. making an electromagnet): • Power supply, wire, retort stand, cardboard, several compasses. • Iron nail, thin insulated copper wire, two or more D-cell batteries, one pair of wire stripper, paper clips. **Materials needed for Faraday's law practical demonstration:** • Solenoid, bar magnet, galvanometer, connecting wires.
INTRODUCTION	Electromagnetism describes the interaction between charges, currents and the electric and magnetic fields to which they give rise. An electric current creates a magnetic field and a changing magnetic field will create a flow of charge. This relationship between electricity and magnetism has been studied extensively and resulted in the invention of many devices which are useful to humans, for example cellular telephones, microwave ovens, radios, televisions and many more. If you hold a compass near a wire through which current is flowing, the needle on the compass will be deflected. Since compasses work by pointing along magnetic field lines, this means that there must be a magnetic field near the wire through which the current is flowing. The magnetic field produced by an electric current is always oriented perpendicular to the direction of the current flow. The following sketch shows what the magnetic field around a wire looks like when the wire has a current flowing in it. We use $\vec{B}$ to denote a magnetic field and arrows on field lines to show the direction of the magnetic field.

	 The direction of the current in the conductor (wire) is shown by the central arrow. The circles are field lines and they also have a direction indicated by the arrows on the lines. Similar to the situation with electric field lines, the greater the number of lines (or the closer they are together) in an area the stronger the magnetic field. *(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).*

You are welcome to visit the following website link to watch the introductory video concerned with key concepts of Electromagnetism.

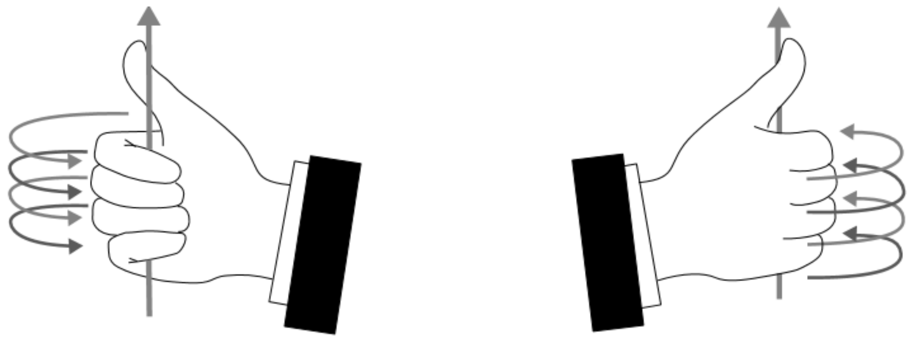
Electromagnetism

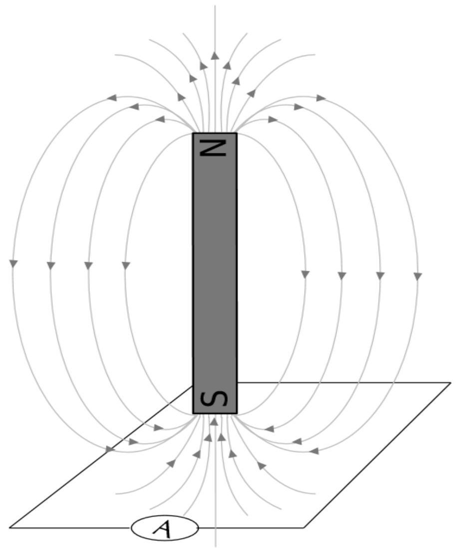
https://www.youtube.com/watch?v=1cFl_7md76o

Apart from the above-mentioned online video content, you can also access similar content regarding the topic in the Mind the Gap study guide (Book 1: pg. 118).

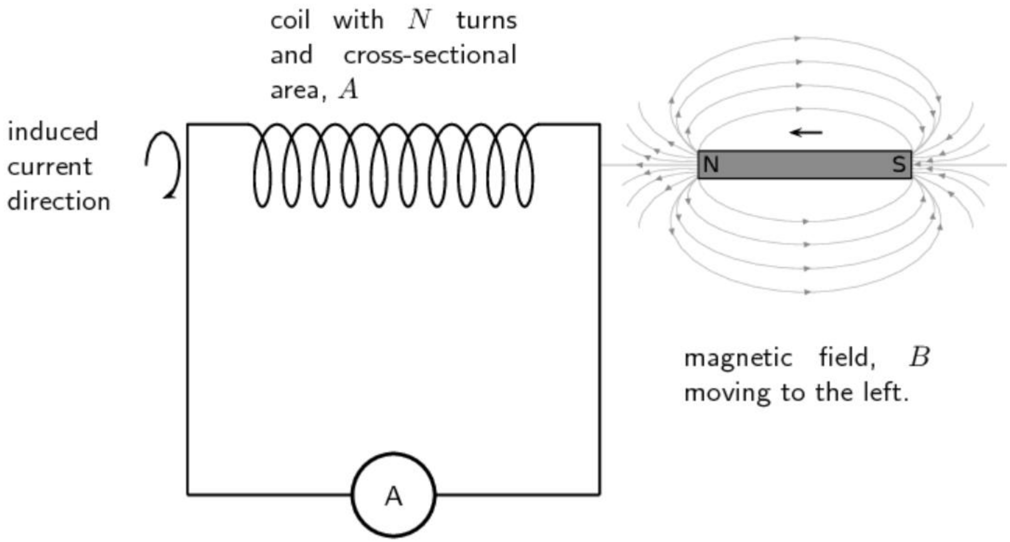
<u>Table</u>: Please ensure that you familiarise yourself with the following physical quantities, units and symbols, which will be needed for the sections of the work that will follow.

Information relating to electromagnetism		
Physical quantity	**Unit name**	**Unit symbol**
Induced emf (Ɛ)	Volt	V
Magnetic field (B)	Tesla	T
Magnetic flux (φ)	Weber	Wb
Time (t)	Seconds	S

CONCEPTS AND SKILLS	***This section must be read in conjunction with the CAPS, pg. 86 – 88.*** There is a simple method of finding the relationship between the direction of the current flowing in a conductor and the direction of the magnetic field around the same conductor. The method is called the *Right-hand rule*. Simply stated, the Right-hand rule says that the magnetic field lines produced by a current-carrying wire will be oriented in the same direction as the curled fingers of a person's right hand (in the "hitchhiking" position), with the thumb pointing in the direction of the current flow.  **Electromagnetic induction** Faraday discovered that when he moved a magnet near a wire a voltage was generated across it. If the magnet was held stationary no voltage was generated. Thus, the voltage only existed while the magnet was moving. We call this voltage the induced emf (ε).

	A circuit loop connected to a sensitive ammeter will register a current if it is set up as shown in the following figure which indicates the upward- and downward movement of the magnet:  **Magnetic flux** Before we move onto the definition of Faraday's law of electromagnetic induction and examples, we first need to spend some time looking at the magnetic flux. For a loop of area A in the presence of a uniform magnetic field, $\vec{B}$, the magnetic flux (Φ) is expressed as: $\Phi = BA\cos\theta$, where: θ = the angle between the magnetic field, B, and the normal to the loop of area; A = the area of the loop; and B = the magnetic field. The S.I. unit of magnetic flux is the weber (Wb).

	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. This can be stated mathematically as: $$\varepsilon = -N\frac{\Delta\phi}{\Delta t},$$ where φ = B·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). The minus sign indicates direction and that the induced emf tends to oppose the change in the magnetic flux. We know now that Faraday's Law relates induced emf to the rate of change of flux, which is the product of the magnetic field and the cross-sectional area the field lines pass through. When the north pole of a magnet is pushed into a solenoid the flux in the solenoid increases so the induced current will have an associated magnetic field pointing out of the solenoid (opposite to the magnet's field). When the north pole is pulled out, the flux decreases, so the induced current will have an associated magnetic field pointing into the solenoid (same direction as the magnet's field) to try to oppose the change. The directions of currents and associated magnetic fields can all be found using only the Right-hand rule. When the fingers of the right hand are pointed in the direction of the current, the thumb points in the direction of the magnetic field. When the thumb is pointed in the direction of the magnetic field, the fingers point in the direction of the current.



ACTIVITIES / ASSESSMENT

EXERCISE

QUESTION 1 (Multiple-choice questions)

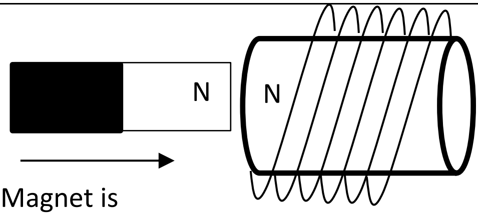
Please take some time to answer the following multiple-choice questions, before attempting to answer the exam-related questions which will follow.

1.1 A circular coil is placed inside a magnetic field and rotated clockwise to induce an emf. Which ONE of the following changes will increase the induced emf?

A Rotating the coil slower
B Decreasing the number of turns/windings of the coil
C Increasing the speed of rotation of the coil
D Changing the polarity of the magnets (2)

1.2 In which ONE of the sketches below is the induced polarity of the coil CORRECTLY indicated?

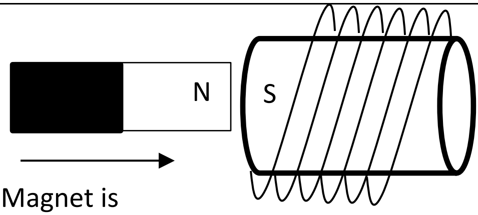
A



Magnet is

pushed into the

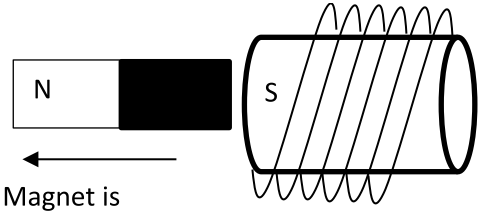
B



Magnet is

pushed into the

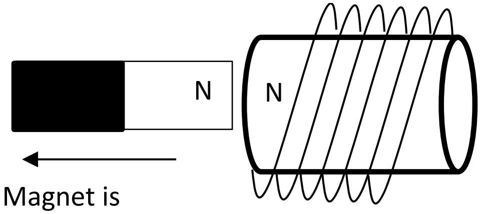
C



Magnet is

pulled out of

D



Magnet is

pulled out of

(2)

1.3 In the diagram below, the north pole of a bar magnet approaches end **A** of a solenoid.

Which ONE of the following statements about the polarity of **A** and the direction of the magnetic field INSIDE the solenoid is CORRECT as the NORTH POLE approaches **A**?

	POLARITY OF A	DIRECTION OF FIELD IN SOLENOID
A	South pole	A to B
B	North pole	B to A
C	North pole	A to B
D	South pole	B to A

(2)

ANSWERS TO MULTIPLE-CHOICE EXERCISE

1.1 C ✓✓ (2)

1.2 A ✓✓ (2)

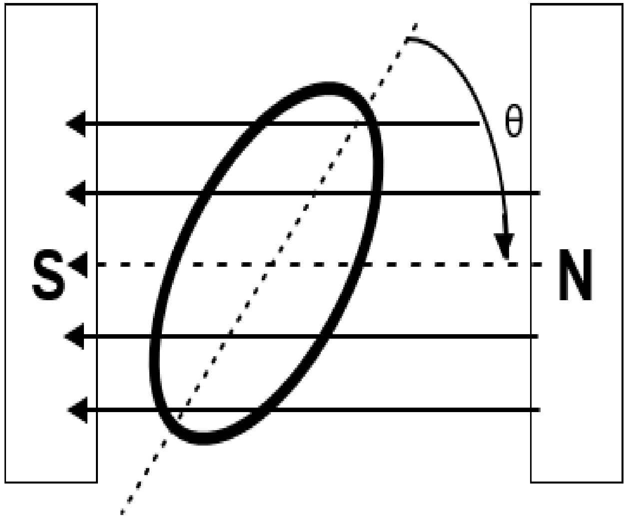
1.3 B ✓✓ (2)

EXAM-RELATED QUESTIONS

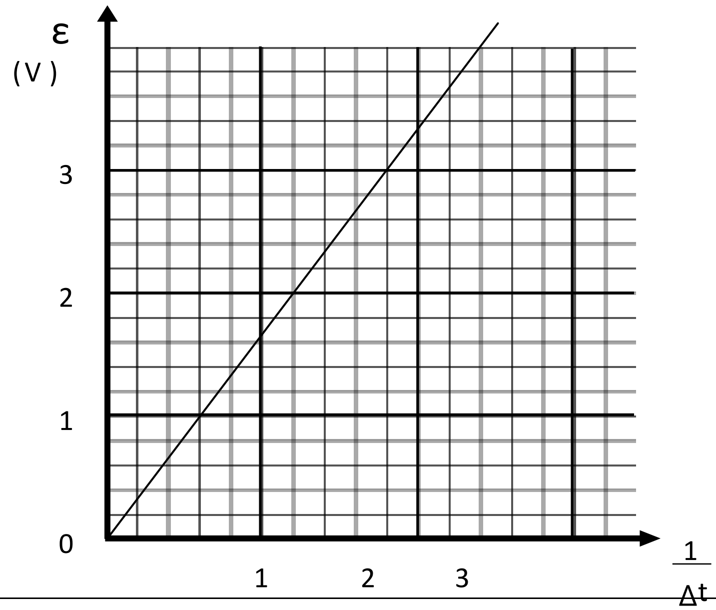
Please use ample time to complete the following activities (2 - 4), which will aid in preparing you for the final examination.

QUESTION 2

An induction coil of area 48,6 cm^2 and 200 windings is rotated clockwise in a constant magnetic field of magnitude 2,4T. Refer to the diagram below.



The graph below shows how the induced emf varies with the inverse of time.



2.1 State *Faraday's law* in words. (2)

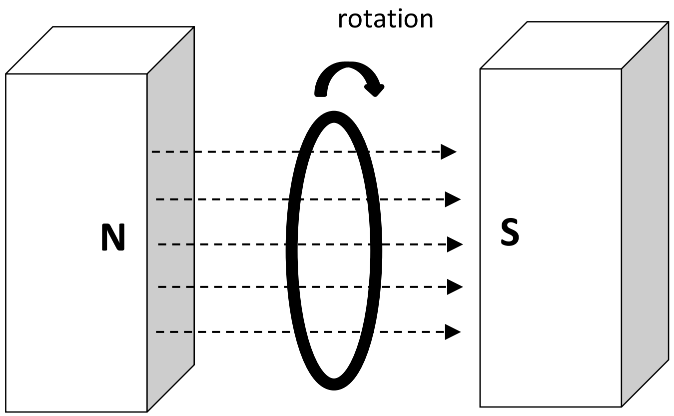
2.2 Use the information in the graph to calculate the change in magnetic flux. (5)

2.3 The coil rotates through an angle θ to a position where the magnetic flux becomes zero. Calculate angle θ. (4)

[11]

QUESTION 3

A circular coil with 250 windings (turns) and a radius of 0,04 m, is rotated clockwise inside a magnetic field with a field strength of 3,2 T.



3.1 Calculate the magnetic flux through the coil at the position indicated on the diagram, where the coil is perpendicular to the field. (3)

3.2 If the coil rotates clockwise through 25°, and the potential difference induced is 2,8 V, calculate the time in which this rotation took place. (4)

3.3 Which law can be used to explain the phenomenon described in QUESTION 3.2? State this law. (2)

3.4.1 If the circular coil is replaced with a square coil with a side length of 0,04 m, and the same movement is performed in the same amount of time, will the induced emf be the same as, larger than or smaller than the circular coil?

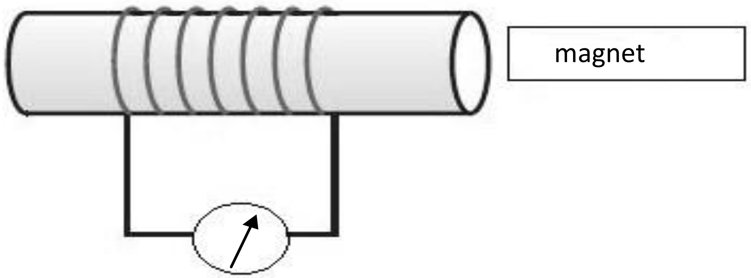
Write down only THE SAME AS, LARGER THAN or SMALLER THAN. (1)

3.4.2 Explain the answer to QUESTION 3.4.1. (2)

[12]

QUESTION 4

4.1 The arrangement of apparatus to demonstrate Faraday's law of electromagnetic induction is shown below.



4.1.1 State Faraday's law of electromagnetic induction in words. (2)

4.1.2 State TWO ways in which the deflection on the galvanometer can be increased. (2)

4.2 A coil with area 0,6 m^2 is held with its axis coinciding with the direction of a magnetic field of strength 0,4 T.

4.2.1 Calculate the magnetic flux linkage. (3)

In order to produce an emf of 9 V, the area of the coil, with its axis coinciding with the direction of a magnetic field, is halved from 0,6 m^2 to 0,3 m^2 in 2 minutes.

4.2.2 Calculate the number of turns in the coil. (4)

[11]

MEMO to questions 1 to 4 is available on:	https://wcedeportal.co.za/eresource/130026
CONSOLIDATION	**Summary of activities which you should be able to do:** • Providing reasons for the existence of a magnetic field (B) near a current carrying wire. • Use the Right-hand rule to determine the magnetic field (B) associated with: (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid. • Draw the magnetic field lines around (i) a straight current carrying wire, (ii) a current carrying loop (single) of wire and (iii) a solenoid. • State Faraday's Law. • Use words and pictures to describe what happens when a bar magnet is pushed into or pulled out of a solenoid connected to a galvanometer. • Use the Right-hand rule to determine the direction of the induced current in a solenoid when the north or south pole of a magnet is inserted or pulled out. • Know that for a loop of area A in the presence of a uniform magnetic field B, the magnetic flux (Φ) passing through the loop is expressed as: $\Phi = BA\cos\theta$, where θ is the angle between the magnetic field B and the normal to the loop of area A. • Know that the induced current flows in a direction so as to set up a magnetic field to oppose the change in magnetic flux. • Calculate the induced emf and induced current for situations involving a changing magnetic field 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	An electromagnet is a piece of wire intended to generate a magnetic field with the passage of electric current through it. Though all current-carrying conductors produce magnetic fields, an electromagnet is usually constructed in such a way as to maximise the strength of the magnetic field it produces for a special purpose. Electromagnets are commonly used in research, industry, medical, and consumer products. An example of a commonly used electromagnet is in security doors, e.g. on shop doors which open automatically. As an electrically-controllable magnet, electromagnets form part of a wide variety of “electromechanical” devices: machines that produce a mechanical force or motion through electrical power. Perhaps the most obvious example of such a machine is the electric motor which will be described in detail in Grade 12. *(Refer to Mind the Gap study guide, Part 1: pg.116 – 133).* Other examples of the use of electromagnets are electric bells, loudspeakers and scrapyard cranes. **Applications of electromagnetism** https://www.youtube.com/watch?v=Nb25_foS9Mg