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SUBJECT: PHYSICAL SCIENCES

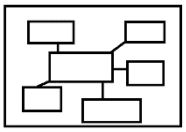
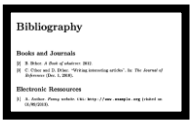
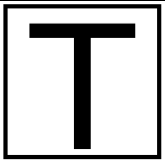
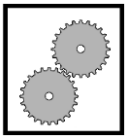
CONTENT: ELECTRICITY AND MAGNETISM

LEARNER/TEACHER CONTENT MANUAL

ELECTRODYNAMICS

CONTENTS PAGE

ICON DESCRIPTION

 MIND MAP	 EXAMINATION GUIDELINE	 CONTENTS	 ACTIVITIES
 BIBLIOGRAPHY	 TERMINOLOGY	 WORKED EXAMPLES	 STEPS

EXAMINATION GUIDELINES

Electrical machines (generators, motors):

- State the energy conversion in generators.
- Use the principle of electromagnetic induction to explain how a generator works.
- Explain the functions of the components of an AC and a DC generator.
- State examples of the uses of AC and DC generators.
- State the energy conversion in motors.
- Use the motor effect to explain how a motor works.
- Explain the functions of the components of a motor.
- State examples of the use of motors.

Alternating current

- State the advantages of alternating current over direct current.
- Sketch graphs of voltage versus time and current versus time for an AC circuit.
- Define the term rms for an alternating voltage/current. The rms potential difference is the AC potential difference which dissipates/produces the same amount of energy as an equivalent DC potential difference. The rms current is the alternating current which dissipates/produces the same amount of energy as an equivalent direct current (DC).
- Solve problems using

  $I_{rms} = \frac{I_{max}}{\sqrt{2}}$, $V_{rms} = \frac{V_{max}}{\sqrt{2}}$.

- Solve problems using

  $P_{ave} = I_{rms}V_{rms} = \frac{1}{2} I_{max}V_{max}$ (for a purely resistive circuit),

  $P_{ave} = I^2_{rms}R$ and $P_{ave} = \frac{V^2_{rms}}{R}$.

IMPORTANT TERMS AND DEFINITIONS

ELECTRICITY AND MAGNETISM: ELECTRICAL MACHINES	
Generator	A device that transfers mechanical energy into electrical energy.
Faraday's law of electromagnetic induction	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. (When a conductor is moved in magnetic field, a potential difference is induced across the conductor.)
Fleming's Right Hand Rule for generators	Hold the thumb, forefinger and second finger of the RIGHT hand at right angles to each other. If the forefinger points in the direction of the magnetic field (N to S) and the thumb points in the direction of the force (movement), then the second finger points in the direction of the induced current.
Electric motor	A device that transfers electrical energy into mechanical energy.
Fleming's Left Hand Rule for electric motors	Hold the thumb, forefinger and second finger of the LEFT hand at right angles to each other. If the forefinger points in the direction of the magnetic field (N to S) and the second finger points in the direction of the conventional current, then the thumb will point in the direction of the force (movement).
Coventional current	Flow of electric charge from positive to negative.
AC	Alternating current The direction of the current changes each half cycle.
DC	Direct current The direction of the current remains constant. (The direction of conventional current is from the positive to the negative pole of a battery. The direction of electron current is from the negative to the positive pole of the battery.)
Root-mean-square potential difference (V_{rms})	The root-mean-square potential difference is the AC potential difference that produces the same amount of electrical energy (power) as an equivalent DC potential difference.
Peak potential difference (V_{max})	The maximum potential difference value reached by the alternating current as it fluctuates i.e. the peak of the sine wave representing an AC potential difference.
Root-mean-square current (I_{rms})	Root-mean-square current is the alternating current that produces the same amount of energy (power) as and equivalent DC current.
Peak current (I_{max})	The maximum current value reached by the alternating current as it fluctuates i.e. the peak of the sine wave representing an AC current.

1. CONTENTS

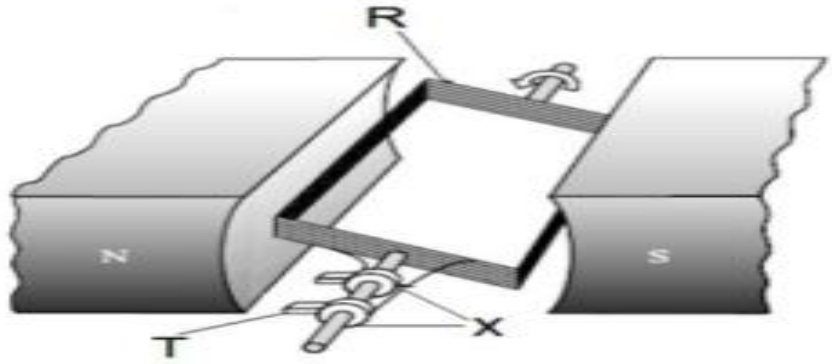
1. Key concepts

- **Basic components of electrical machines**
- **Generator and Motor**
- **AC generator and DC generator**
- **AC motor and DC motor**
- **Alternating current**
- **Basic calculations**

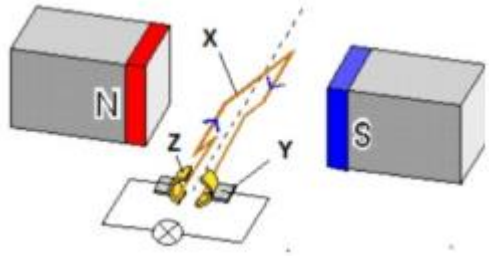
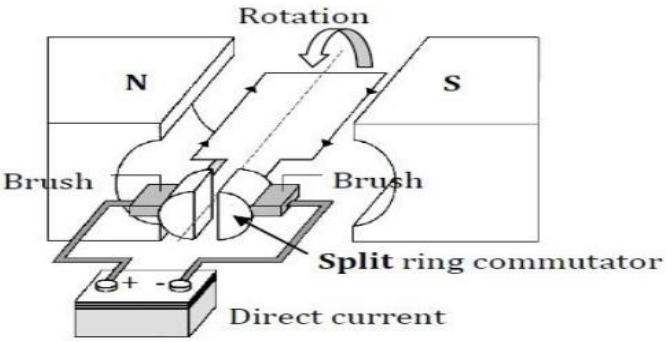
1.1. Basic components of electrical machines

Electrical generators and motors are two electrical devices that are used for generation of electricity. Basic components for two electrical devices:

- Pair of magnets (**N to S**)
- Conducting coil (R)
- Slip rings or split rings (X)
- Brushes (T)
- External circuit



1.2. Difference between Generator and Motor

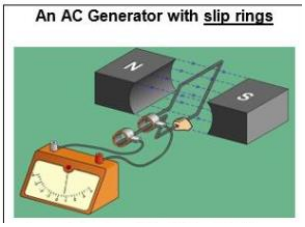
Generator	Motor
	
Energy conversion: Mechanical energy into electrical energy	Energy **conversion:** Electrical energy into mechanical energy
External circuit: load e.g. Bulb or resistor	**External circuit:** consist of power source (cell or battery)
Principle: Electromagnetic induction: states that when a conductor is rotated in a magnetic field, there is a change in the magnetic flux which induces an emf that causes an induced current to flow in the conductor.	**Principle:** Motor effect: states that when a conductor carrying current is placed in a magnetic field, the conductor experiences a force.
Rule: *Fleming's right-hand rule* Says that when the thumb, the first finger and the second finger are placed at right angles to each other, the First finger pointing in the direction of the magnetic Field (North to South), the thumb in the direction of Motion of the coil, then the second finger will point in the direction of flow of the induced current.	**Rule**: *Fleming's left-hand rule* Says that when the thumb, the first finger and the second finger are placed at right angles to each other, with the first finger pointing in the direction of the magnetic Field (North to South), the second finger in the direction of the Current, then the thumb will point in the direction of Motion of the coil.
Carbon brushes: conduct the induced current from the armature(coil) to the commutator and the external circuit.	**Carbon brushes;** conduct current from the external circuit to the commutator and the armature (coil).

1.3. Generators (AC or DC)

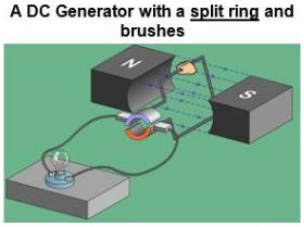
Generators

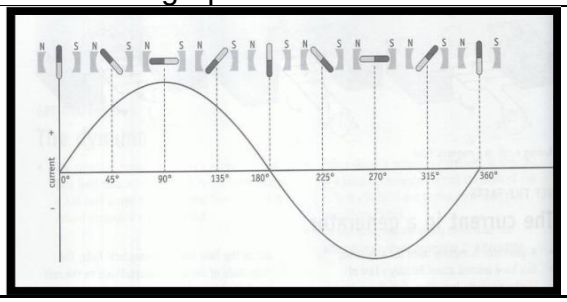
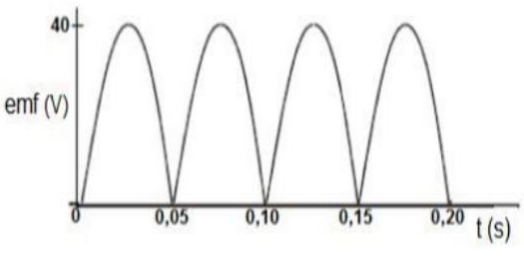
Load Resistor

AC GENERATOR
Slip rings



DC GENERATOR
Split ring



AC GENERATOR	DC GENERATOR
Structural component: **Slip rings** • Slip-rings ensures that the current that passes into the carbon brushes and the external circuit is always in the same direction	Structural component; **Split rings** • Allows induced current to flow in one direction. • The split ring commutator serves as a change switch that reverses the current after every half revolution. (ensures continuous rotation of the coil)
An AC generator produces alternating current. Our power stations produce alternating current and the current that we get from the plug points in our homes is AC.	DC generator produces direct current
The current changes direction every half revolution and is changing strength continually.	Current flows from positive to negative terminal (use conventional current
This has the advantage of changing the magnetic field in transformers on the national power grid.	The emf and current induced in a DC generator has the same polarity through the rotation of the armature. This is due to split rings
The graphs of alternating current and alternating voltage are shaped like sine and cosine graphs	
	

How AC and DC generator works?
'Electromagnetic induction'

When a conducting coil is rotated in a magnetic field an electric current is induced (created). An emf is induced across the ends of a coil by a changing magnetic flux, which in turn causes a current to flow in the coil.

Uses of DC and AC generators

DC Generators
- Bicycle dynamos
- Battery chargers
- Torches

AC Generators
- Battery cars
- Microphones
- Power plants

1.4. Motors (AC and DC)

Motor
Power source

DC motor
Split rings

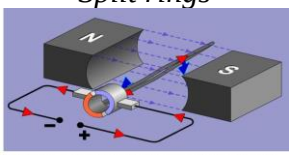
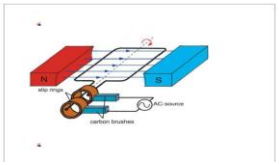
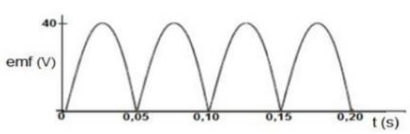
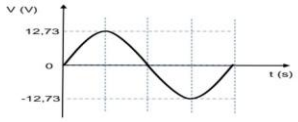


Image taken from Plato Multimedia Science School Simulations 11-16 – Physics – Electric motor

AC motor
Slip rings



DC MOTOR	AC MOTOR
Structural component: **split rings** • The split ring commutator serves as a change switch that reverses the current after every half revolution. (ensures continuous rotation of the coil)	Structural component: **slip rings** • An AC motor, with alternating current as input, works without commutators since the current of the power supply alternates after every half cycle
• The current in the coil flows through the magnetic field in the opposite direction from each arm	• The graphs of alternating current and alternating voltage are shaped like sine and cosine graphs
	

How DC and AC MOTOR works

Motor effect

A current need to be flowing in a magnetic field. The current produces a magnetic field which interacts with the magnetic field from the magnet and this combination of force fields causes movement.

The direction of the magnetic field is from North to South (N to S). The current direction is the direction of flow of the conventional current (from positive terminal to negative).

In an electric motor, an electric current pass through the coil in a magnetic field the combination of the two force fields produces a turning force which turns the motor.

Uses of motors

DC Motor
Wipers
Motor starter
Toy cars

AC Motor
washing machines
vacuum cleaner
fans
sliding gates

1.5. Alternating current

- An AC generator produces alternating current. Our power stations produce alternating current and the current that we get from the plug points in our homes is AC.
- The current changes direction every half revolution and is changing strength continually
- In South Africa, generators supply alternating current at 50 cycles per second or 50 Hz.
- The current has a constant potential difference of 220V
- The actual potential difference varies between 0V and 311V. This has the same effect as a constant value of 220V, which is known as the V_{rms} value
- Frequency is monitored to avoid damage to electrical equipment.
- One big advantage of alternating current is that the emf can be stepped up or stepped down through the use of transformers.

The potential difference produced by a DC source has the same heating effect as an AC source, it is called **root mean square voltage** :
It can be calculated using:

$$V_{rms} = \frac{V_{max}}{\sqrt{2}}$$

V_{rms} = rms potential difference (V)
V_{max} = maximum potential difference (V)

The same applies to the current strength, i.e the constant direct current that will have the same heating effect as an alternating current, it is called **root mean square:**
It can be calculated using:

$I_{rms} = \frac{I_{max}}{\sqrt{2}}$	I_{rms} = rms current (A) I_{max} = maximum current (A)

Average power

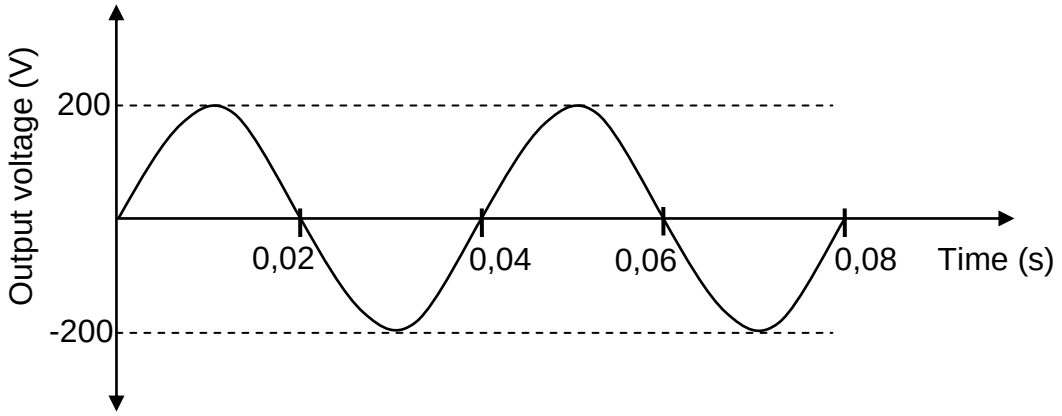
The power of an AC source fluctuates between zero and maximum for each half AC cycle. P=VI

$P_{ave} = V_{rms} I_{rms}$ $= I_{rms}^2 R$ $= \frac{V_{rms}^2}{R}$	P_{ave} = average power (W) V_{rms} = rms potential difference (V) I_{rms} =rms current (A) R = resistance (Ω)

ACTIVITY 1: MULTIPLE-CHOICE QUESTIONS

Various options are provided as possible answers to the following questions. Each question has only ONE correct answer. Choose the answer and write only the letter (A–D) next to the question numbers (1.1 to 1.5) in the ANSWER BOOK, e.g. 1.11 E.

1.1 The graph below represents the output voltage versus time for an AC generator.



The speed of rotation of the generator's coil is now DOUBLED.

Which ONE of the combinations below shows the CORRECT new peak output voltage and the time for ONE rotation?

	PEAK OUTPUT VOLTAGE (V)	TIME FOR ONE ROTATION (S)
A	400	0,02
B	200	0,02
C	200	0,04
D	100	0,04

(2)

1.2 Consider the statements below regarding AC power and DC power:

I AC voltage can be changed during AC power transmission.

II DC power transmission requires transformers.

III AC power transmission is more energy efficient.

Which of the above statement(s) is/are CORRECT?

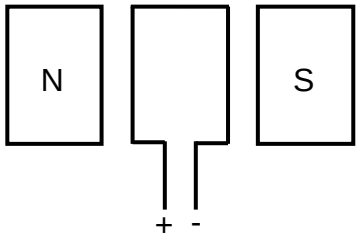
A I only

B II only

C I and III only

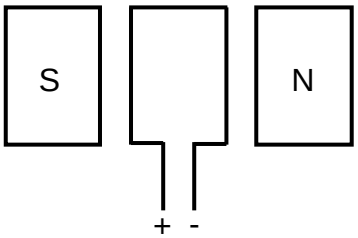
D II and III only (2)

1.3 The simplified diagram below represents a DC motor.

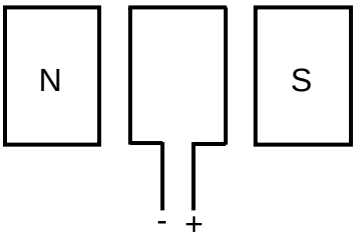


The diagrams below indicate some changes made to the above motor.

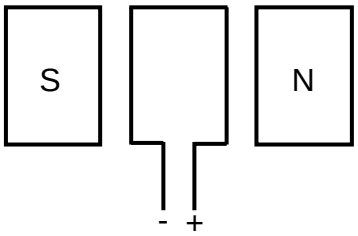
(i)



(ii)



(iii)



Which of the changes to the motor above will change the original direction of rotation of the coil?

A (i) and (ii) only

B (i) and (iii) only

C (ii) and (iii) only

D (iii) only (2)

1.4 In which ONE of the following electrical machines is electrical energy converted to mechanical energy?

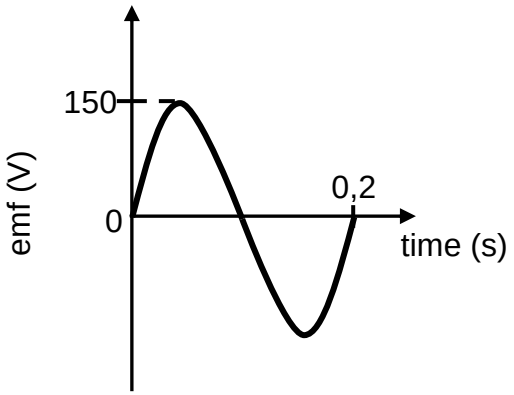
A AC generator

B DC generator

C AC dynamo

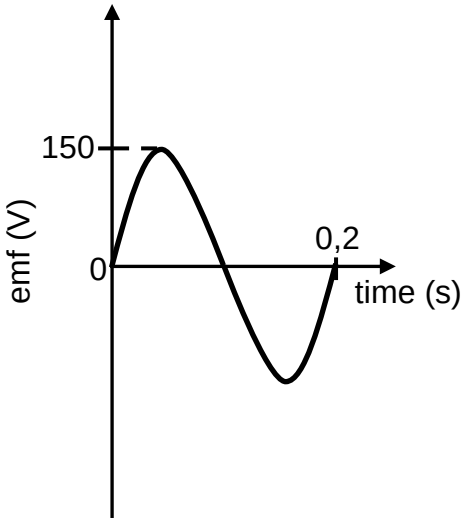
D DC motor (2)

1.5 An AC generator consists of a coil which is rotated in a magnetic field. The emf time graph for one complete rotation of the coil is shown below.

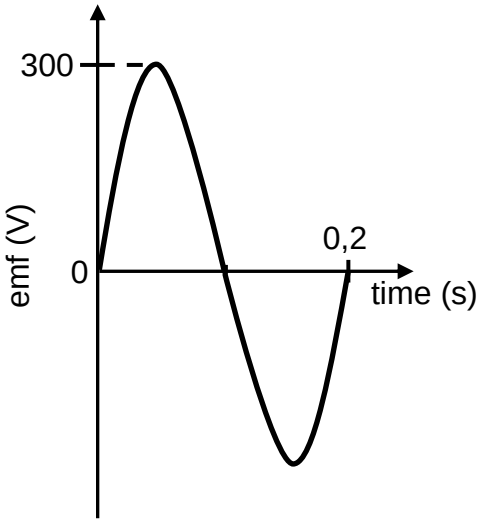


If the speed of rotation of the coil is now DOUBLED, which ONE of the following graphs is CORRECT for one complete rotation of the coil?

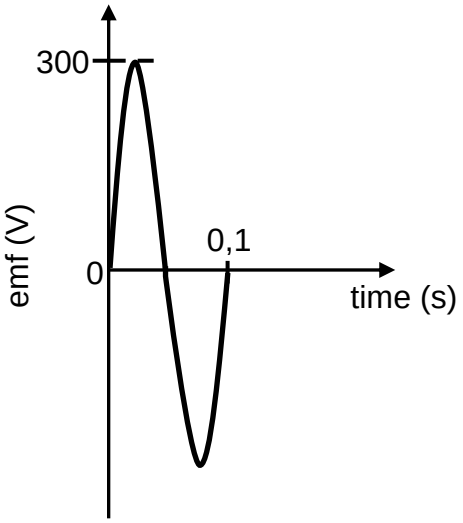
A



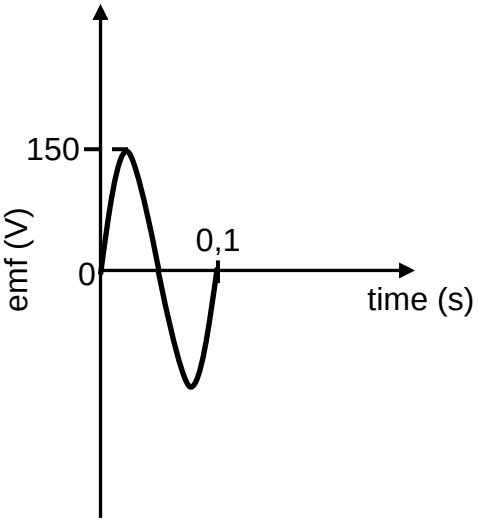
B



C



D

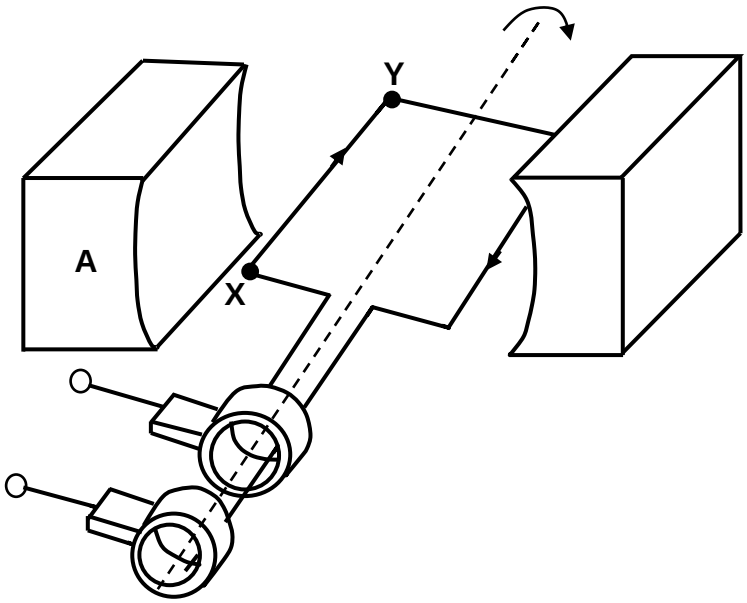


(2)

[10]

ACTIVITY 2

2.1 The simplified sketch below represents an AC generator with the coil initially horizontal between the poles of a magnet. **X** and **Y** are two points on the coil, while **A** is one of the poles of the magnet.



When the coil of the generator rotates clockwise between the two poles of the magnet, the direction of the induced current is from **X** to **Y**, as shown above.

2.1.1 Is **A** the NORTH POLE or the SOUTH POLE of the magnet? (1)

2.1.2 The coil is now rotated through 180°.

Will the direction of the current be from **X** to **Y** or from **Y** to **X**? (1)

2.1.3 Sketch an emf-time graph for TWO complete rotations of the coil, starting from the position of the coil as shown in the diagram above. (3)

2.2 An electrical device is connected to an AC generator. The rms potential difference across the device is 200 V and the maximum current passing through the device is 6 A.

Calculate the:

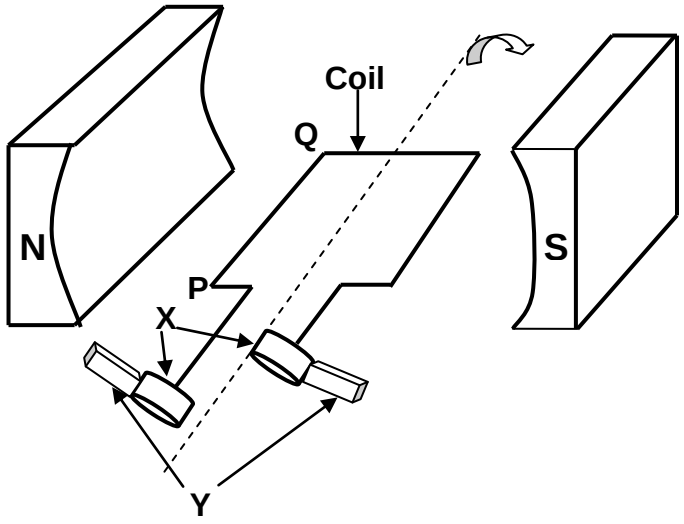
2.2.1 Resistance of the device (4)

2.2.2 Energy consumed by the device in two hours (4)

[13]

ACTIVITY 3

The diagram below is a simplified representation of an AC generator. The coil is rotated in a clockwise direction in the magnetic field.



3.1 Write down the name of component **X**. (1)

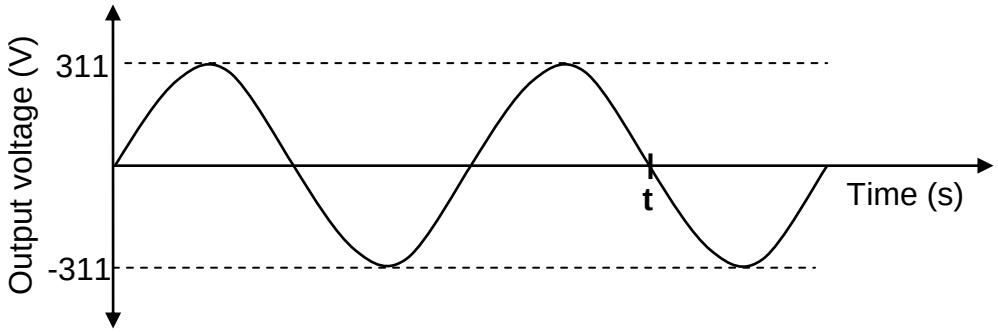
3.2 Write down the function of component **Y**. (1)

3.3 Use the relevant principle to explain why an emf is induced in the coil when the coil is rotated in the magnetic field. (2)

3.4 The coil rotates CLOCKWISE from the position shown in the diagram. In which direction will current be induced in segment **PQ** of the coil?

Choose from '**P to Q**' or '**Q to P**'. (2)

The output voltage versus time graph below was obtained for the above generator.



The output voltage is generated at a frequency of 50 Hz.

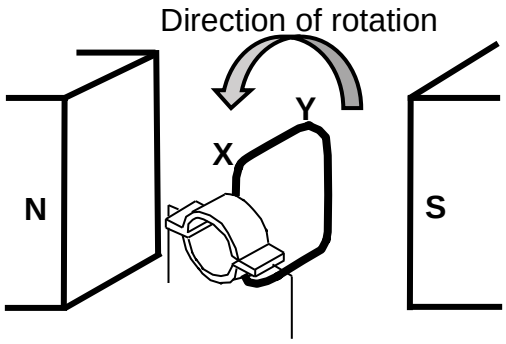
3.5 Calculate the time **t** indicated in the above graph. (3)

3.6 The generator is now connected to an appliance with a resistance of 100 Ω. Calculate the energy dissipated when the appliance is in operation for ONE minute. (5)

[14]

ACTIVITY 4

4.1 The diagram below shows the initial position of the coil in a simple DC generator. The coil is rotated in an anticlockwise direction, as shown.



4.1.1 Name the component in this generator that ensures that the induced current in the external circuit is in one direction only. (1)

4.1.2 Is the direction of the induced current from **X to Y** or from **Y to X**? (1)

A maximum voltage of 90 V is generated when the coil is rotating at a frequency of 20 Hz.

4.1.3 Write down the time taken for the coil to complete ONE rotation. (1)

4.1.4 The coil starts rotating from the initial position, as shown in the diagram above.

Sketch a graph of output voltage versus time for one complete rotation of the coil. Indicate the maximum voltage and the relevant time values on the graph. (4)

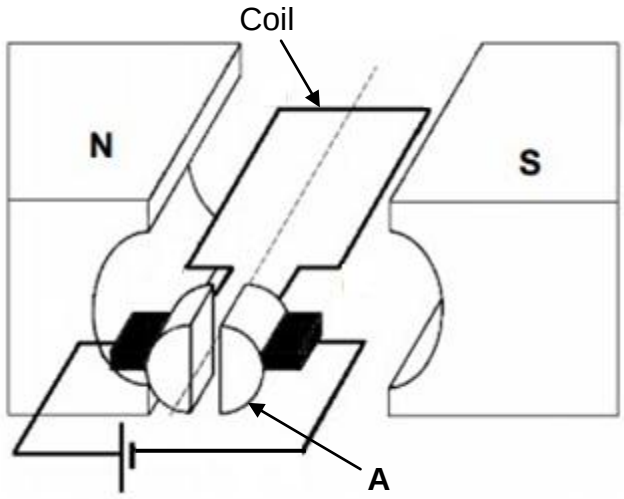
4.2 Wall sockets supply rms voltage and current.

A 220 V AC voltage is supplied from a wall socket to an electric kettle having a resistance of 32 Ω.

Calculate the average energy dissipated by the kettle in TWO minutes. (4)
[11]

ACTIVITY 5

5.1 A simplified diagram of an electrical machine is shown below.



5.1.1 Is this machine a DC motor or a DC generator? (1)

5.1.2 Write down the energy conversion that takes place while this machine is in operation. (2)

5.1.3 Write down the name of component **A** in the diagram. (1)

5.1.4 In which direction will the coil, shown in the diagram above, rotate? Choose from CLOCKWISE or ANTICLOCKWISE. (2)

5.2 An electrical device is marked 200 W ; 220 V.

5.2.1 Define the term *rms voltage*. (2)

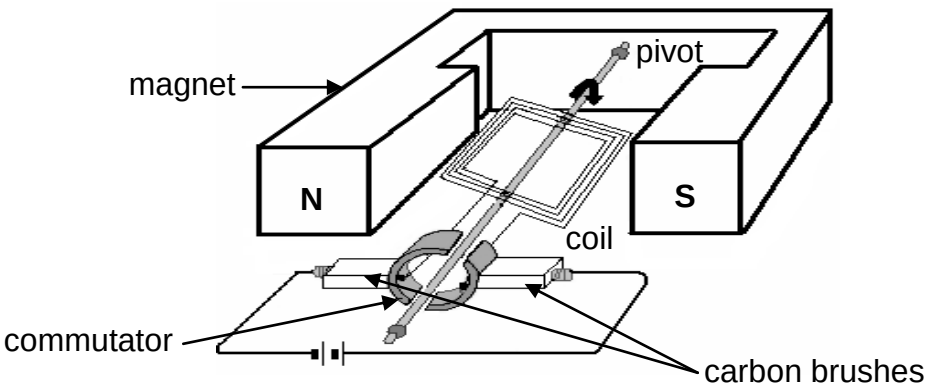
5.2.2 Calculate the resistance of the device. (3)

This device is now connected to a 150 V AC source.

5.2.3 Calculate the energy dissipated by the device in 10 minutes. (5)
[16]

ACTIVITY 6

6.1 The simplified sketch of an electric motor is shown below.

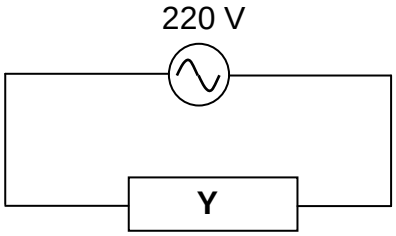


6.1.1 Write down the energy conversion that takes place in this motor. (1)

6.1.2 Is the motor above an AC motor or a DC motor? (1)

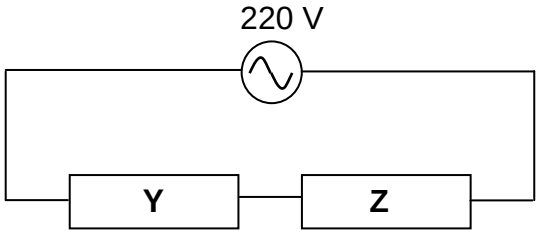
6.1.3 What is the function of the commutator in this motor? (1)

6.2 A resistor **Y** is rated 220 V, 100 W and is connected to a 220 V AC source, as shown in the circuit below.



6.2.1 Calculate the resistance of resistor **Y**. (3)

Another resistor **Z** with a rating 220 V, *X* W, is now connected in series to resistor **Y** and to the same AC source. See the diagram below.



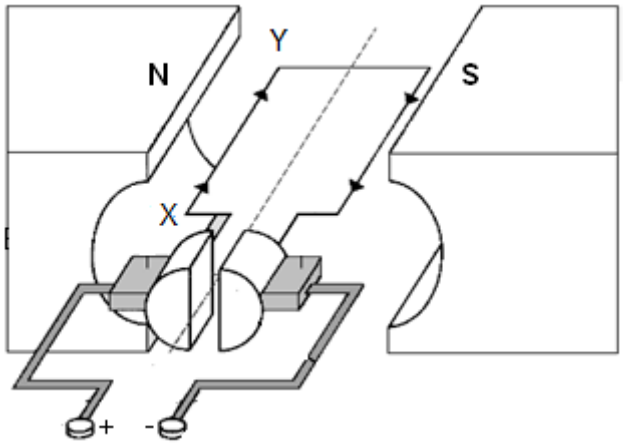
The power dissipated by resistor **Y** changes to 80 W, while its resistance remains constant.

6.2.2 Calculate the power rating *X* of resistor **Z**, assuming that resistor **Z** has constant resistance. (6)

[12]

ACTIVITY 7

7.1 The diagram below is a simplified representation of a DC motor. The current in the coil is in the direction XY.



7.1.1 Name the component that ensures that the coil rotates continuously in ONE DIRECTION. (1)

7.1.2 In which direction will the coil rotate? Write down only CLOCKWISE or ANTICLOCKWISE. (2)

7.1.3 Write down the energy conversion which takes place while the motor is working. (2)

7.2 An AC generator, producing a maximum voltage of 320 V, is connected to a heater of resistance 35 Ω.

7.2.1 Write down the structural difference between an AC generator and a DC generator. (1)

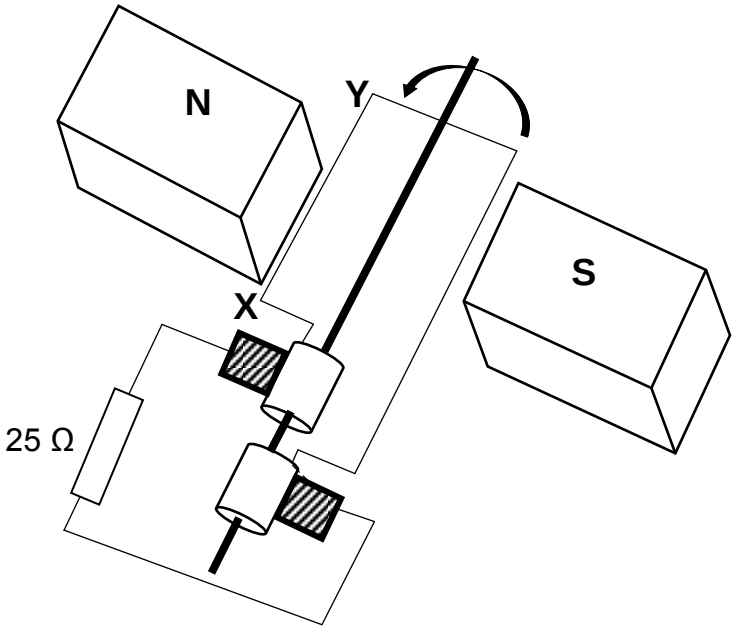
Calculate the:

7.2.2 Root mean square (rms) value of the voltage (3)

7.2.3 Root mean square (rms) value of the current in the heater (4)
[13]

ACTIVITY 8

A simplified diagram of an AC generator connected to a 25 Ω resistor is shown below. The coil rotates anticlockwise.

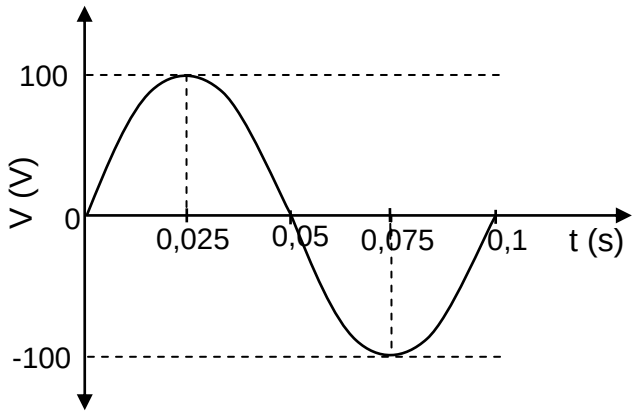


8.1 Name the component that distinguishes this generator from a DC generator. (1)

8.2 In which direction will the induced current flow in section **XY** of the coil?

Choose from **X to Y** OR **Y to X**. (2)

The graph below shows the output voltage of the generator for one cycle of rotation of the coil.



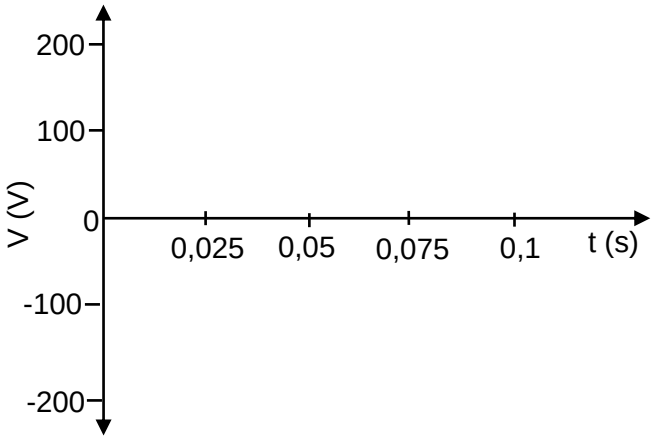
8.3 Define the term *rms potential difference*. (2)

8.4 Calculate the rms current in the circuit. (4)

8.5 Calculate the average power dissipated in the 25 Ω resistor. (3)

The speed of rotation of the coil in the generator is now DOUBLED.

8.6 Copy the set of axes below in your ANSWER BOOK and sketch the graph of output voltage versus time for 0,1 s.



(3)
[15]

DATA FOR PHYSICAL SCIENCES GRADE 12
PAPER 1 (PHYSICS)

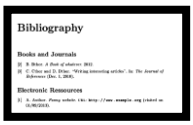
GEGEWENS VIR FISIESE WETENSKAPPE GRAAD 12
VRAESTEL 1 (FISIKA)

TABLE 1: PHYSICAL CONSTANTS/*TABEL 1: FISIESE KONSTANTES*

NAME/*NAAM*	SYMBOL/*SIMBOOL*	VALUE/*WAARDE*
Acceleration due to gravity *Swaartekragversnelling*	g	$9{,}8\ m{\cdot}s^{-2}$
Universal gravitational constant *Universele gravitasiekonstant*	G	$6{,}67 \times 10^{-11}\ N{\cdot}m^2{\cdot}kg^{-2}$
Speed of light in a vacuum *Spoed van lig in 'n vakuum*	c	$3{,}0 \times 10^{8}\ m{\cdot}s^{-1}$
Planck's constant *Planck se konstante*	h	$6{,}63 \times 10^{-34}\ J{\cdot}s$
Coulomb's constant *Coulomb se konstante*	k	$9{,}0 \times 10^{9}\ N{\cdot}m^2{\cdot}C^{-2}$
Charge on electron *Lading op elektron*	e^-	$-1{,}6 \times 10^{-19}\ C$
Electron mass *Elektronmassa*	m_e	$9{,}11 \times 10^{-31}\ kg$
Mass of Earth *Massa van Aarde*	M	$5{,}98 \times 10^{24}\ kg$
Radius of Earth *Straal van Aarde*	R_E	$6{,}38 \times 10^{3}\ km$

ALTERNATING CURRENT/*WISSELSTROOM*

$I_{rms} = \frac{I_{max}}{\sqrt{2}}$ / $I_{wgk} = \frac{I_{maks}}{\sqrt{2}}$	$P_{average} = V_{rms} I_{rms}$ / $P_{gemiddeld} = V_{wgk} I_{wgk}$
$V_{rms} = \frac{V_{max}}{\sqrt{2}}$ / $V_{wgk} = \frac{V_{maks}}{\sqrt{2}}$	$P_{average} = I_{rms}^2 R$ / $P_{gemiddeld} = I_{wgk}^2 R$
	$P_{average} = \frac{V_{rms}^2}{R}$ / $P_{gemiddeld} = \frac{V_{wgk}^2}{R}$



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