			EXAMS OFFICE USE ONLY

University of the Witwatersrand, Johannesburg

Course or topic No(s)	ELEN4003 and ELEN5002A
Course or topic name(s) Paper Number & Title	HIGH VOLTAGE ENGINEERING
Examination to be held during month(s) of	JANUARY 2018 (SUPPLEMENTARY EXAM)
Year of Study (Art & Science leave blank)	FOURTH for ELEN4003
Degrees/Diplomas for which this course is prescribed (Bsc (Eng.) should indicate which branch)	BSc (Eng) (Electrical)/PGDip (Eng) (Electrical)
Faculty/ies presenting candidates	ENGINEERING & THE BUILT ENVIRONMENT
Internal examiner(s) and telephone extension number(s)	Prof. CUTHBERT NYAMUPANGEDENGU Ext. 77213
External examiner(s)	MR. THAVENESEN GOVENDER
Special materials required (graph/ music/ drawing paper/ maps/ diagrams/ tables/ computer cards, e.t.c)	Paschen's curve for air (kV vs bar.mm)

Time allowance

Course no.	ELEN4003 and ELEN5002A	**Hours**	THREE

Instructions to candidates

Answer only FIVE (5) out of a total of seven (7)
All symbols and equations as defined in the course
Show all working
Crib sheet and calculator allowed

Question 1

a) An experiment is conducted to determine the Townsend first ionisation coefficient α, of a certain dielectric gas using a parallel plate uniform electrode setup in a controlled pressure chamber. As shown in Figure 1.1, Case (A) is when the electrode gap is 1 mm and Case (B) is when the electrode gap is increased to 3 mm but maintaining the same electric field strength by adjusting the voltage accordingly.

i) Assuming negligible attachment coefficient in the gap, calculate the Townsend first ionisation coefficient, α for the gas.

(10 marks)

ii) If for the gap of 1 mm the air gap pressure is changed from 1 bar to 3 bar and the voltage increased to cause spark-over, determine the spark-over voltage in each case and explain the difference.

(4 marks)

b) In order to protect a current transformer connected to an 11 kV distribution line against conducted lightning surges, it is decided to use arcing horns (which may be considered to be a rod-rod gap) positioned across the bushing of the current transformer. Using a sketch, and assuming a probable V-t curve, show on the same axes the relative location of the V-t curves for the protective arcing horns (rod-rod gap) and the bushing. Explain your answer and how V-t curves are used in insulation coordination in general.

(6 marks)

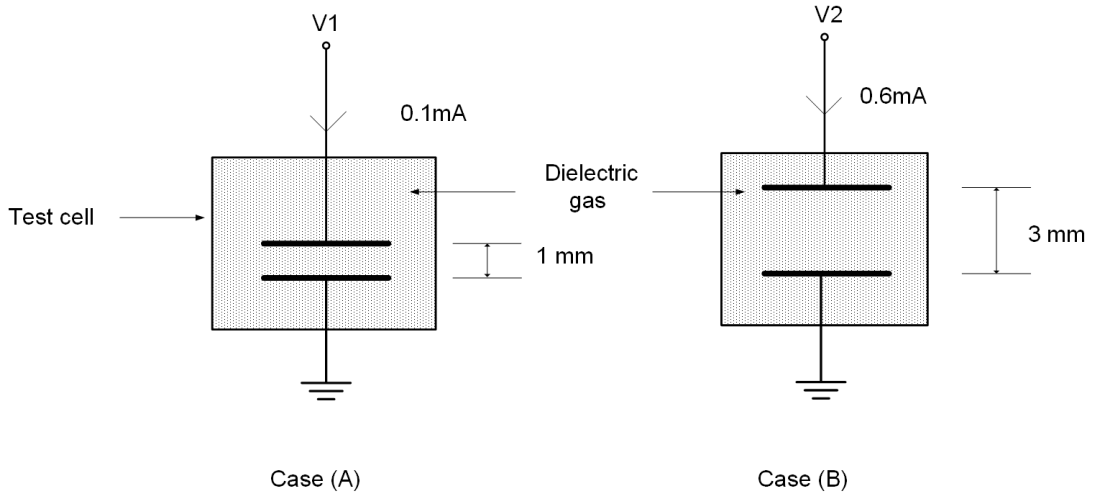

Figure 1.1: Test cell setup for determining Townsend 1st ionisation coefficient

(Total 20 marks)

Question 2

A 50 kV parallel plate capacitor has a solid particle accidentally trapped in the epoxy dielectric at a position as illustrated in Figure 2.1. If the relative permittivity of the epoxy is 4 and that of the particle is 800;

a) Calculate the electric field strength in the insulation gap without the particle.
(2 marks)

b) In the presence of the imbedded particle, calculate the electric field strengths in the resultant three insulation gaps i.e. between the particle and grounded electrode, inside the particle and in the gap between the particle and the high voltage electrode.
(14 marks)

c) On the same axes, sketch well labelled electric field profiles in the insulation gap with and without the particle.
(4 marks)

The electric field (E) gradient inside a parallel plate electrode setup is given by; $E = \frac{V}{d}$

The electric field E_k in layer k of a multi-layered (n-layers) dielectric in a parallel plate electrode setup can be expressed as below:

$$\mathrm{E_k} = \frac{V}{\left\{\frac{\varepsilon_k}{\varepsilon_1} d_1 + \frac{\varepsilon_k}{\varepsilon_2} d_2 + \cdots \frac{\varepsilon_k}{\varepsilon_n} d_n\right\}}$$

All symbols have the usual meaning.

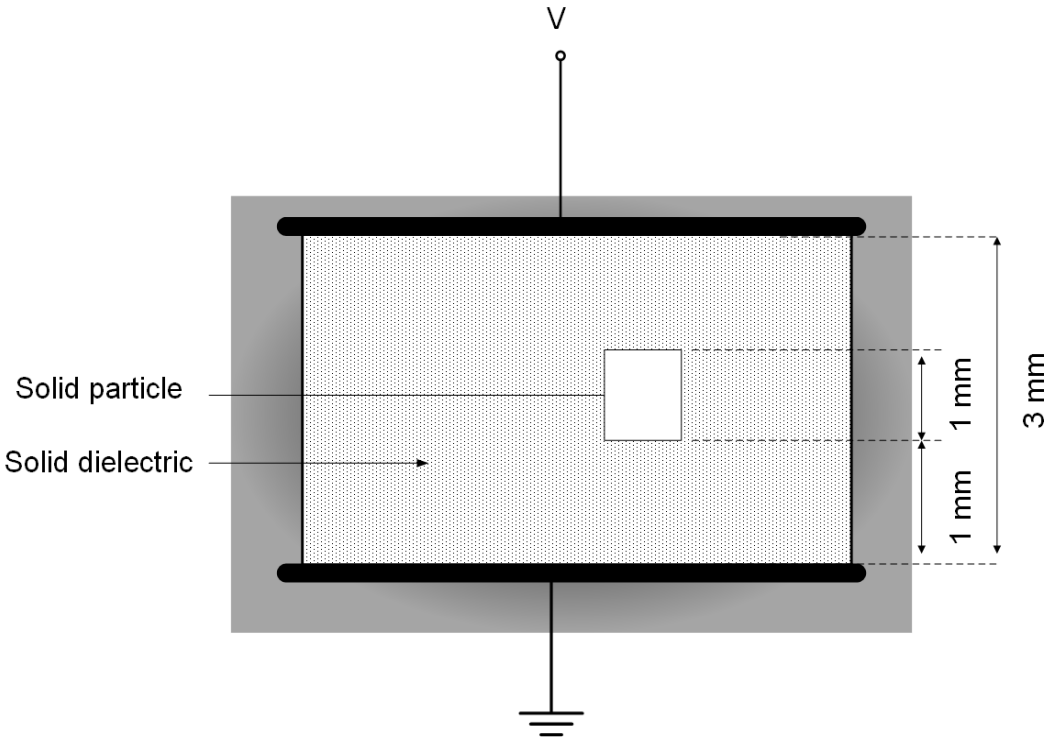

Figure 2.1: A parallel plate capacitor with a solid particle trapped in the dielectric.

(Total: 20 marks)

Question 3

(a) The breakdown voltage of an air gap under an impulse voltage is a statistical phenomenon, explain why?

(5 marks)

(b) An up-down U_{50} test procedure was conducted on a restorative insulation gap. The data in Table 3.1 was obtained.

i) Calculate the first estimate U_{50}^{*} for the data.

(3 marks)

ii) Calculate the more accurate U_{50} for the data.

(12 marks)

Table 3.1: U_{50} up-down test data

Short number	Voltage (kV)	Withstand	Breakdown
1	145	√	
2	140		√
3	145	√	
4	150		√
5	145	√	
6	150		√
7	145		√
8	140		√
9	135	√	
10	140	√	
11	145		√
12	140	√	
13	145	√	
14	150		√
15	145	√	
16	150	√	
17	155		√
18	150		√
19	145	√	
20	150	√	

(Total: 20 marks)

Question 4

a) An air insulated co-axial duct has a core radius of 50 mm and outer conductor inner radius of 150 mm.
Assuming standard atmospheric pressure of 1 bar, use the iterative method (the equations below can be used) or any other suitable method, to determine whether or not a voltage of 225 kV will likely cause a breakdown through the streamer mechanisms.

(14 marks)

b) Discuss why SF_6 is a popular insulation medium for compact GIS and also why currently there are efforts to develop alternative insulation gases.

(6 marks)

The electric field (E) inside a coaxial electrode setup is given by,

$$E_x = \frac{V}{xln\left(\frac{R}{r}\right)}$$

The streamer criterion may be taken as:

$$\int(\alpha - \eta)dx = K = 18 \text{ or } K = \sum_{i=0}^{i=n} K_i$$

For air,

$$K_i = 1.6X[E_i - 2.2P]^2 - 0.3PX$$

All symbols in the equations have the usual meanings.

(Total: 20 marks)

Question 5

(a) In oil-insulated high voltage equipment, air bubbles are observed drifting away from the regions of enhanced electric field while water droplets behave in the opposite.
   i) Using the equation below, explain the phenomenon and how the contaminants may lead to complete insulation breakdown.
   ii) Explain why the phenomenon is independent of voltage polarity.

(8 marks)

$$F = \varepsilon_{oil} r^3 \left(\frac{\varepsilon - \varepsilon_{oil}}{\varepsilon + 2\varepsilon_{oil}}\right) E \frac{dE}{dx}$$

All symbols have the usual meaning.

(b) A 10 kA, 8/20 μs lightning current impulse terminates directly onto a phase conductor of an overhead transmission line about 200 m away from the terminal tower just outside a substation. The line is open circuited as illustrated in Figure 5.1. The line surge impedance is 100 Ω. Assuming negligible attenuation, determine the minimum clearance (d) between the phase conductor and a tree that has grown under the conductor that would ensure no flashover to the tree under the impulse overvoltage travelling wave conditions.

You may assume that the breakdown voltage of an air gap under impulse voltage is given by $V_b = 500d$ kV where the symbols have the usual meaning.

(12 marks)

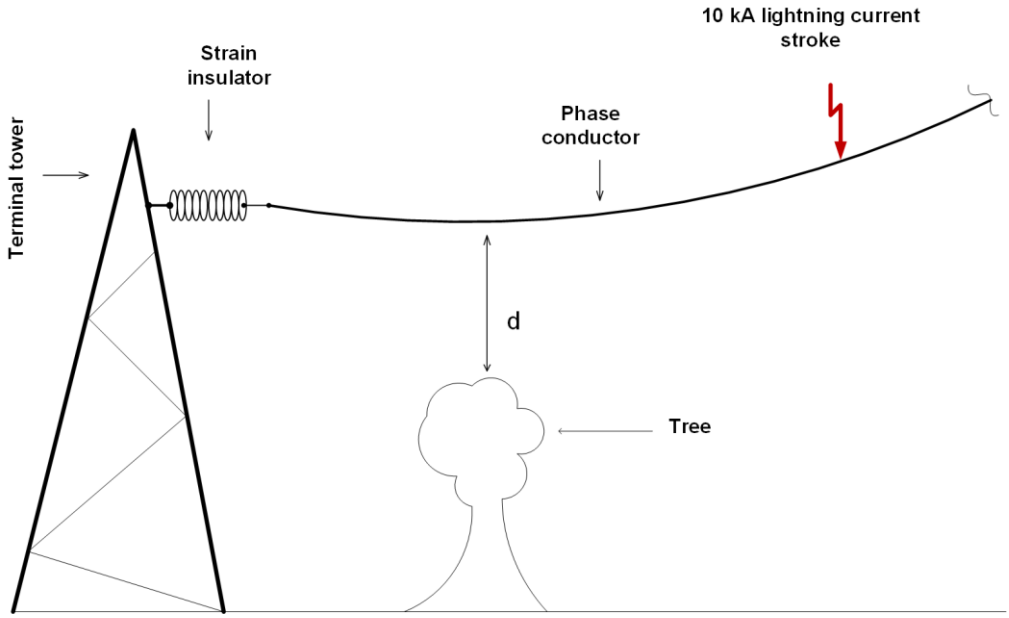

Figure 5.1: Lightning voltage surge on a transmission line

(Total: 20 marks)

Question 6

a) The equivalent circuit of a series resonant test system connected to a power cable under test is as shown in Figure 6.1.

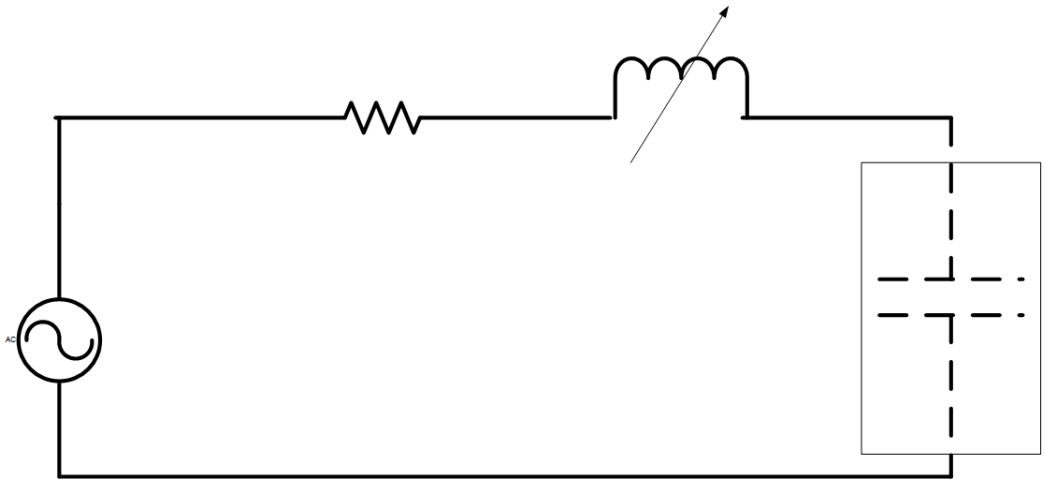

Figure 6.1: Equivalent circuit of a series resonant test system

i) Label and explain the role of each component in the test circuit.

(8 marks)

ii) What are the advantages of the series resonant test system over alternative HV test methods for power cables?

(4 marks)

b) Explain the meaning and importance of each of the following partial discharge (PD) parameters in the interpretation of PD signals;
- PD apparent charge magnitude
- PD inception voltage (PDIV)
- PD pulse repetition rate
- PD phase-resolved-pattern (PDPRP)

(8 marks)

(Total: 20 marks)

Question 7

Consider a two stage Cockroft-Walton generator with each capacitor being 0.10 μF. If this multiplier supplies a mean current of 50 mA to a test object and the RMS value of the input voltage is 100 kV at 50 Hz,

(a) Discuss with the aid of an equivalent circuit how voltage escalation is achieved in the two stage voltage generator.

(6 marks)

(b) Determine the generator output voltage with and without the test object connected.

(6 marks)

(c) Calculate the percent ripple and discuss how to reduce the value to below the 3% as required by standards.

(8 marks)

Voltage drop and ripple voltage are expressed as follows:

$$\Delta V = \frac{I}{fC}\left[\frac{2n^3}{3} - \frac{n}{6}\right]$$

$$\partial V = \frac{I}{2fC}\left[\frac{n(n+1)}{2}\right]$$

All symbols have the usual definition.

(Total: 20 marks)

Paschen's curve for air (kV vs bar.mm)