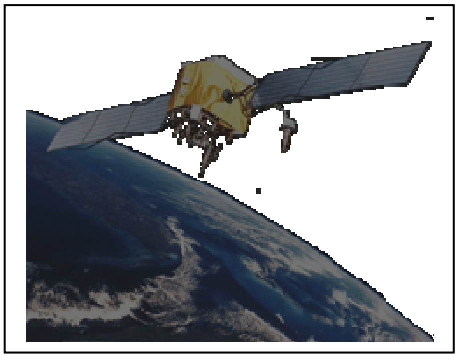
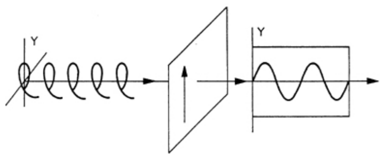
King Fahd University of Petroleum and Minerals
ELECTRICAL ENGINEERING DEPARTMENT

EE-340

ELECTROMAGNETICS

LABORATORY MANUAL





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Introduction to EE 340 Laboratory

Laboratory Procedures and Report Writing

Laboratory Procedures

- Smoking, food, beverages and mobile phones are not allowed.
- Because of the limitations on experimental set-ups, no make-ups will be allowed.
- All equipment should be switched off upon completion of the experimental work. The workbench should be left as neat as possible, and all connection wires returned to their proper place.
- Experiments will be carried out is groups of four students (maximum). Groups are expected to remain the same throughout the semester. Each individual in a group is expected to participate in performing the experimental procedures. Most experiments have several parts, so, students should alternate in doing these parts.

Experimental Results

- Each group should present their results to the lab instructor before moving to a new part of the experiment.
- For each part of the experiment, the group should present the result in the form of a sketch. This way, a validation of the data taken is made if the sketch shows the expected characteristics.
- All experimental data taken and all sketches made should be produced using the blank page included in each experiment handout.

Performance in Lab

- Both group performance and individual performance will be evaluated.
- Group performance is based on (1) ability of the group to produce correct and accurate results and (2) ability of the group to independently carry out troubleshooting while conducting the experimental procedures.
- Individual performance is based on (1) attendance on time (2) participation in carrying out the experiment and (3) answer to questions given by lab instructor upon inspection of the results.

Report Writing

- Each student is expected to produce his own report. Groups share experimental results only. Any copying of reports will be considered an act of cheating.
- In writing the report a student is supposed to follow the formal report writing studied in ENGL214. A guideline for formal report writing is given in Appendix A.
- Evaluation of the reports is based on the quality of the following (1) correct format (2) Error analysis (3) Presentation of results and (4) Discussion and answer to questions.
- Use of computers in preparing report is highly encouraged.

Final Exam

- A combination of experimental and written exams will be given in the last week of classes.
- Both exams will test the experimental knowledge acquired by the student throughout the semester regarding (1) equipment (2) measurement methods and procedures and (3) basic concepts.

King Fahd University of Petroleum and Minerals
Electrical Engineering Department

Software Lab # 1
VECTOR REPRESENTATION AND COORDINATE SYSTEMS USING SOFTWARE PACKAGE: 'CAEME'

Objective:
To become familiar with basic coordinate systems, vector and scalar quantities using the software "CAEME".

Equipment Required:
'CAEME' software. These are licensed software's and cannot be copied.

Introduction:
The software 'Computer Applications in Electromagnetics Education (CAEME)', is a well known software for understanding and simulating basic EM problems. In this demonstration laboratory, CAEME software will be used to introduce the basic concept of coordinate systems, vector and scalar quantities. Ask your instructor to clarify all your conceptual problems. If required view the 1^{st} part of the software, titled "Vectors and Coordinate systems" several times before you take the class test.
Software navigation techniques: To see the pop-up navigation menu, scroll down the mouse pointer to the bottom of the CAEME screen.

Procedure:
(1) Execute the software "CAEME".

(2) Click the top rectangle with title "Vectors and Coordinate systems".

(3) Then Click on the icon to enter the lesson.

(4) Click on the "Introduction" icon

(5) Click on the icon titled "Basic Concept on Coordinate Systems". This part of the software will explain the basics or advantages of all the coordinate systems.

(6) Next click on the “Scalar and vector” icon to learn about vector and scalar quantities.

(7) Take the interactive practice quizzes.

Trial quiz: Answer the following questions based on the DEMO. Before you take the quiz, ask your instructor to clarify any confusion regarding any of the explained subjects.

(1) Name three 3D coordinate systems and the independent variables use by the coordinate systems:

(a) ____

(b) ____

(c) ____

(2) A Scalar quantity needs ___________________________ to be specified

(3) A Vector quantity needs ___________________________ to be specified

For the following questions find the correct answer:

(4) Outline the steps involved in defining a coordinate system.

(a) An origin and a vector are required in general

(b) Three points in the space are required

(c) An origin and three independent variables are required

(d) None of these

(5) How do we define the base vectors?

(a) Perpendicular to the reference surfaces

(b) Parallel to the reference surfaces

(c) The base vectors are different for every coordinate system

(d) The vase vectors are always three.

(6) How do we define the origin of a coordinate system?

(a) It is where two vectors intersect

(b) It is the point where the three reference surfaces intersect

(c) All the vectors point to it

(d) All the other answers are true.

(7) How do we define the reference surfaces?

(a) As three planes

(b) As a sphere, a plane and a cone

(c) As a cylinder, a plane and a sphere

(d) As surfaces at constant values of the independent variables.

(8) How do we define a vector in a coordinate system?

(a) An origin and a vector are required in general

(b) Three points in the space are required

(c) An origin and three independent variables are required

(d) None of these

(9) Why is it necessary to define an origin to completely specify a vector?

(a) It is not necessary

(b) Well, everything has to have an origin

(c) Because the color of the vector is closely related to its origin

(d) Because the components along the base vectors only define a magnitude and a direction.

King Fahd University of Petroleum and Minerals

Electrical Engineering Department

Software Lab # 2

COORDINATE SYSTEMS and CONVERSION USING 'CAEME SOFTWARE'

Objective:

To understand the coordinate systems, coordinate conversion using the software "CAEME".

Equipment Required:

'CAEME' software. These are licensed software's and cannot be copied.

Introduction:

In this experiment we will use the CAEME (Computer Applications in Electromagnetics Education) software is used to visually and interactively identify the independent variables, reference surfaces, base vectors, differential elements associated with the rectangular, cylindrical and spherical coordinate systems. Go though every step of the software carefully as you may have to take a quiz after completing each part of the software.

Procedure:

(1) Execute the software "CAEME".

(2) Click on the rectangle with title "Vectors and Coordinate systems".

(3) Then Click on the picture-icon to enter the lesson.

(4) Click on the "Rectangular Coordinate Systems" icon

(5) Bring the mouse pointer to the end of the screen and click on the "right arrow" (or continue button) of the pop-up menu.

(6) Next click again on the "right arrow" of the pop-up menu.

(7) Now select one item at a time from the left menu and carefully go through them. Remember at the end of the lecture, you have to take a quiz on this topic.

(8) To exit from any session, use the pop-up menu that appears when you drag the mouse pointer at the end of the CAEME screen.

(9) USING SIMILAR TECHNIQUE, CAREFULLY GO THROUGH THE DETAIL OF,

a. CYLINDRICAL COORDINATE SYSTEM,

b. SPHERICAL COORDINATE SYSTEM,

c. And COORDINATE CONVERSION

(10) Take the quizzes after each session

NOTE:

Remember, the object of these two software labs is to introduce the "CAEME" software to EE 340 students. From now on you can come to this lab (*with the permission of the Lab technician*) and use this software to enhance your understanding of the subject.

Experiment # 1

ELECTRIC FIELD AND POTENTIAL INSIDE THE PARALLEL PLATE CAPACITOR

OBJECTIVE

To verify the relationship between the voltage, the electric field and the spacing of a parallel plate capacitor.

EQUIPMENT

1. Capacitor plate (two).
2. Electric field meter (1 *KV/m* = 1*mA*).
3. Power supply *DC* 12*V* and 250*V* (variable).
4. Multi-meters (two).
5. Plastic ruler (100 *cm*).
6. Plastic and wooden sheets.

INTRODUCTION

Assume one of the capacitor plates is placed in the y-z plane while the other is parallel to it at distance *d* as shown in Figure 1. The effect of the boundary disturbance due to the finite extent of the plates is negligible. In this case, the electric field intensity $\overline{\mathbf{E}}$ is uniform and directed in x-direction. Since the field is irrotational ($\overline{E} = -\overline{\nabla} V = \overline{0}$), it can be represented as the gradient of a scalar field V

$$\overline{E} = -\overline{\nabla} V = -\frac{\partial V}{\partial x} \text{ .... (1)}$$

which can be expressed as the quotient of differences

$$\overline{E} = -\frac{V_1 - V_o}{x_1 - x_o} = -\frac{V_A}{d} \text{ .... (2)}$$

where V_A is the applied voltage and d is the distance between the plates. The potential of a point at position x in the space between the plates is obtained by integrating the following equation

$$\frac{\partial V}{\partial x} = \frac{V_A}{d} \text{ .... (3)}$$

to give

$$V(x) = \frac{V_A}{d} x \text{ .... (4)}$$

EXPERIMENTAL SETUP AND PROCEDURE

1. The experimental setup is as shown in Figure 2. Adjust the plate spacing to d=10 cm. The electric field meter should be zero-balanced with a voltage of zero.

2. Measure the electric field strength at various voltages ranging from 0 to 250 Volts for d=10 cm and summarize the results in a table. Choose a suitable voltage step to produce a smooth curve.

3. Plot a graph of the data of step (2). On the same graph paper, plot the theoretical graph based on equation (2) and compare the theoretical and experimental graphs.

4. Adjust the potential V_A to 200V. Measure the electric field strength as the plate separation is varied from d=2 cm to d=12 cm. Summarize your results in a table.

5. Plot a graph of the data of step (4). On the same graph paper, plot the theoretical graph based on equation (2) and compare the theoretical and experimental graphs.

6. With a different medium (sheet) inserted between the plates, measure the electric field strength at various voltages ranging from 0 to 30V. The separation between the plates is fixed at d=1 cm. Repeat for all sheets.

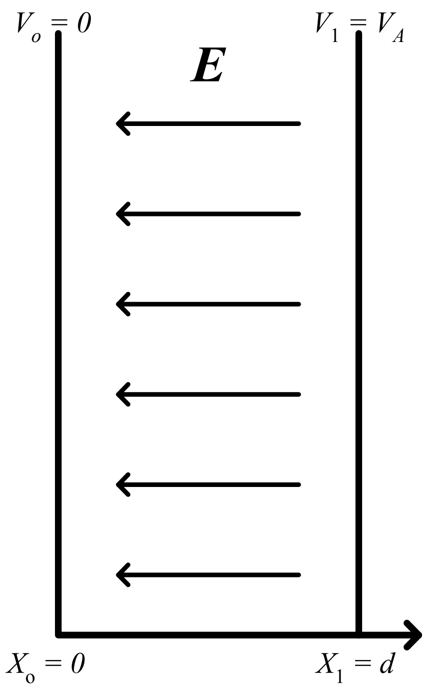


Figure 1: A parallel plate capacitor placed in the yz-plane

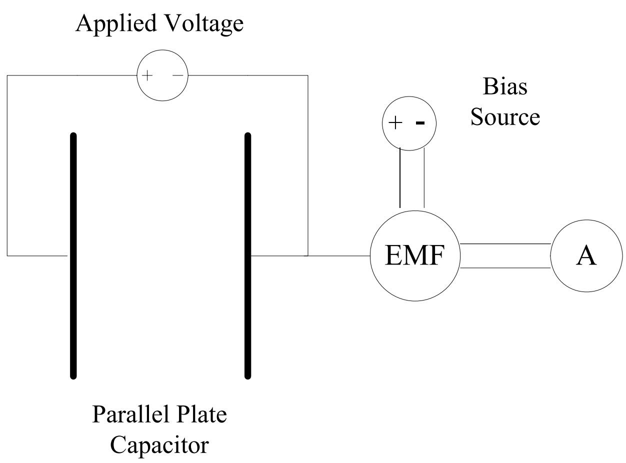


Figure 2: Experimental set-up

Calibration ➔ ____

Table 1: Electric field variation with Voltage (d = 10cm)

Voltage (Volts)	Current, 'I', (mA)	Experimental Electric Field Strength 'E' (V/m)	Theoretical 'E' from Eq(2) E=V/d
0			
25			
50			
75			
100			
125			
150			
175			
200			
225			
250			

Table 2: Electric field variation with Plate Separation "d" (V = 200 Volts)

Plate Separation, 'd' (cm)	Current, 'I', (mA)	Experimental Electric Field Strength 'E' (V/m)	Theoretical 'E' from Eq(2) E=V/d
2			
4			
6			
8			
10			
12			

Table 3: Electric field variation with Voltage when Plastic Sheet is used (d = 1 cm)

Voltage (Volts)	Current, 'I', (mA)	Experimental Electric Field Strength 'E' (V/m)
0		
5		
10		
15		
20		
25		
30		

Table 4: Electric field variation with Voltage when Wooden Sheet is used (d=1cm)

Voltage (Volts)	Current, 'I', (mA)	Experimental Electric Field Strength 'E' (V/m)
0		
5		
10		
15		
20		
25		
30		

QUESTIONS FOR DISCUSSION

1. What are the assumptions and simplifications in this experiment? Discuss their effects on the experimental results.

2. Plot theoretical relation between the potential and distance (equation 4) inside a parallel plate capacitor with d=10 cm and V_A =100 V.

Experiment # 2

CAPACITANCE AND INDUCTANCE OF TRANSMISSION LINES

OBJECTIVE
The capacitance and inductance per unit length of commonly used transmission lines are measured and compared to the theoretically calculated values and to manufacturer's supplied data.

EQUIPMENT
1. LCR meter (Digital).
2. A length of coaxial transmission line.
3. A length of twin-wire transmission line.
4. Caliper.
5. Meter stick.

INTRODUCTION
The two types of transmission lines to be studied in this experiment are the coaxial and the twin-wire transmission lines. The cross-section of these transmission lines are shown in Figures l-(a) and l-(b) respectively. The value of the capacitance C of any given structure can be analytically obtained by solving Laplace's equation. For the inductance L, analytical relations are obtained by calculating the magnetic flux linkage. For the coaxial transmission line, the capacitance per unit length and the inductance per unit length are given, respectively, by:

$$C/l = \frac{2\pi\varepsilon}{\ln\left(\frac{b}{a}\right)} \quad \text{.......... (1)}$$

$$L/l = \frac{\mu}{2\pi}\ln\left(\frac{b}{a}\right) \quad \text{.......... (2)}$$

For the twin-wire transmission line:

$$C/l = \frac{\pi\varepsilon}{\ln\left(\frac{h}{a}+\sqrt{\frac{h^2}{a^2}-1}\right)} \quad \text{.......... (3)}$$

$$L/l = \frac{\mu}{\pi}\ln\left(\frac{2h}{a}\right) \quad \text{.......... (4)}$$

where l is the total length of the line and a, b, and h are as shown in Figure 1. The constants ε and μ are the permittivity and the permeability of the material of the line respectively.
The characteristic impedance Z_o is related to L and C by

$$Z_o = \sqrt{\frac{L}{C}} \quad \text{.......... (5)}$$

EXPERIMENTAL SETUP AND PROCEDURE

The available transmission lines are the following:

Coaxial line:

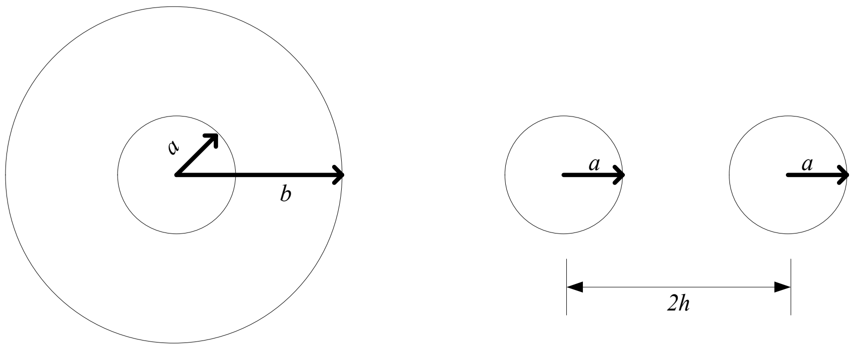
Type	RG 59 B/U
Characteristic impedance	75 Ω
Capacitance/meter	68 *pF/m*
Maximum voltage	6 *kV*

Twin-wire line:

Characteristic impedance	300 Ω
Capacitance/meter	13.2 *pF/m*

In all of the measurements, make sure that the lines are fully extended (no loops). Also, avoid areas of electromagnetic interference inside the lab.

1. Measure the capacitance of the coaxial transmission line using the universal bridge. The far end of the line should be open-circuited.
2. Measure the length of the coaxial line, then find the capacitance per unit length (C/l) of the line.
3. Measure the relevant dimensions of the coaxial line using the caliper.
4. Repeat steps (1)-(3) for the inductance (L/l) of the coaxial transmission line. In this case, the far end of the line should be short-circuited.
5. Repeat all previous steps for the twin-wire line.



(a) (b)

Figure 1. Cross sections of the transmission lines: (a) coaxial (b) twin wire

Table 1: <u>Measured data</u> of Coaxial and Twin-wire lines.

	Coaxial Line	**Twin-Wire Line**
Length '***l***' (m)		
Inner radius '***a***' (mm)		
Outer radius '***b***' (mm)		-------
h (mm)	-------	
Measured Capacitance '***C***' (pF)		
Measured Inductance '***L***' (μH)		

Inductance per unit length '***L/l***' (μH/m)		
Capacitance per unit length '***C/l***' (pF/m) (Experimental)		
Z_0 (Ω) (Experimental)		
C/l (pF/m) (Theoretical)		
Z_0 (Ω) (Theoretical)		
C/l (pF/m) (Manufacturer)		
Z_0 (Ω) (Manufacturer)		

QUESTIONS FOR DISCUSSION

1. Calculate (*C/l*) using equation (1). The dielectric occupying the space between the conductors of the coaxial line is made of polyethylene (ε=2.3 ε_o, μ= μ_o).
2. Compare the theoretical, experimental and the manufacturer's data values of (*C/l*).
3. Calculate Z_o of the coaxial line from the experimental values of *L* and *C* and compare to the theoretical and manufacturer's values.
4. Repeat for the twin-wire line.
5. What is the effect on the characteristic impedance of the transmission line when it is not fully extended?
6. Explain the dependence of your measurements on frequency.

Experiment # 3

SIMULATION OF ELECTRIC FIELD AND POTENTIAL INSIDE CAPACITORS

OBJECTIVE

The electric field and potential inside capacitors of different shapes are obtained numerically. The finite-difference method is used to solve Laplace's equation in two dimensions.

INTRODUCTION

The electric potential distribution inside any given structure can be analytically obtained by solving Laplace's (or Poisson's) equation subject to some boundary conditions. If we assume no volume charge inside the structure, Laplace's equation is given by:

$$\nabla^2 V = 0 \quad \text{.......... (1)}$$

In two dimensions (rectangular coordinates), equation (1) becomes:

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} = 0 \quad \text{.......... (2)}$$

The ability to solve equation (2) depends in a great deal on the nature of the structure under consideration. In some cases, a closed-form (analytical) solution to equation (2) is difficult to obtain. Alternatively, numerical methods can be used, especially for large structures. Numerical methods utilize the speed of computers and the flexibility of programming.

In this experiment, the Finite-Difference (*FD*) method will be used. The *FD* method is one of the most popular numerical methods in the field of electromagnetics. Its main advantages are the following:
1. Easy to formulate.
2. Suitable for many structures.
3. Flexible for modifications.

The most serious disadvantage of the *FD* method is its computational intensity relative to other methods. However, this is becoming less of a disadvantage with the advent of powerful computers.

The *FD*-based solution is performed in the following steps:
1. Discretize the given structure (gridding) using a suitable step size in both dimensions (Δx and Δy). The accuracy of the results improves with smaller step sizes.
2. Approximate the partial derivatives in equation (2) by the following:

$$\frac{\partial^2 V}{\partial x^2} = \frac{V(i+1,j) - 2V(i,j) + V(i-1,j)}{(\nabla x)^2} \quad \text{..............................} \; (3)$$

$$\frac{\partial^2 V}{\partial y^2} = \frac{V(i,j+1) - 2V(i,j) + V(i,j-1)}{(\nabla y)^2} \quad \text{..............................} \; (4)$$

where i and j are the indices along the x-axis and the y-axis respectively. Substituting equations (3) and (4) in equation (2), we get

$$V(i,j) = \frac{1}{4}\left[V(i+1,j) + V(i-1,j) + V(i,j+1) + V(i,j-1)\right] \; ... \; (5)$$

3. Solve the resulting linear system of equations.

Example

Find the potential distribution inside the structure given in figure 1. Take a step size of 5*cm* in both dimensions. The boundary conditions are as shown in the figure.

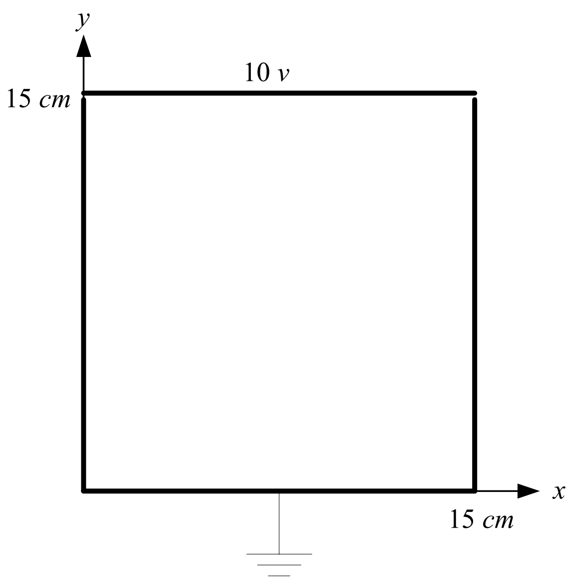


Figure 1: The structure of the example

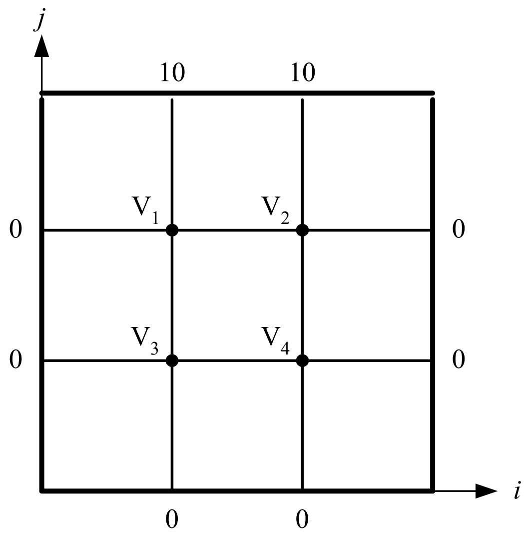


Figure 2: The grid used for solution

The gridding is shown in figure 2. At each node in the figure, the value of the potential is labeled. Only four unknown values (V_1, V_2, V_3 and V_4) are to be determined; all other potentials are given as boundary conditions.

Applying the algorithm of equation (5), we get the following system of linear equations:

$$\begin{aligned}
+4V_1 - V_2 - V_3 - 0V_4 &= 10 \\
-V_1 + 4V_2 - 0V_3 - V_4 &= 10 \\
-V_1 - 0V_2 + 4V_3 - V_4 &= 0 \\
-0V_1 - V_2 - V_3 + 4V_4 &= 0
\end{aligned}$$

The solution of the above system can be obtained using different methods (e.g., matrix formulation in MA TLAB). The result is:

$$V_1 = 3.75\text{ V},\quad V_2 = 3.75\text{ V},\quad V_3 = 1.25\text{ V},\quad V_4 = 1.25\text{ V}$$

PROCEDURE

1. Solve Laplace's equation using the *FD* method for the structure given in figure 3. The dimensions of the structure are 20 *cm* x 30 *cm*. Use a step size of 5 *cm* in both dimensions.

2. Decrease the step size to 2.5 cm and repeat part (1).

3. Compare the results obtained in parts (1) and (2) at some points inside the structure.

4. Produce contour plots for the equi-potential lines inside the structure (If you are using MATLAB, there is a function for contouring).

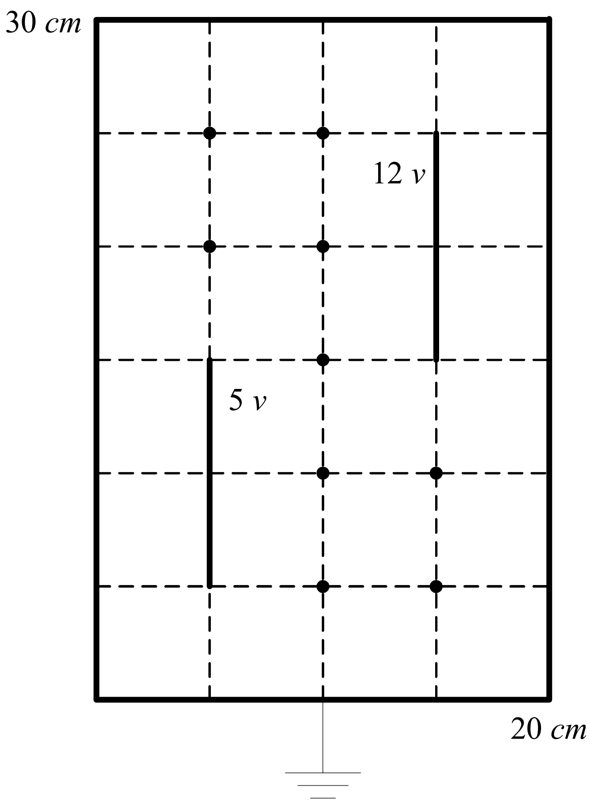


Figure 3: The structure used in the experiment

Experiment # 4

MAGNETIC FIELD OUTSIDE A STRAIGHT CONDUCTOR

OBJECTIVE

To obtain the magnetic field due to current in a straight conductor as a function of the current and as a function of the normal distance from the conductor. Also the magnetic field due to current passing through two straight conductors is to be obtained.

<u>WARNING:</u> THIS EXPERIMENT INVOLVES HIGH CURRENT (100A) AND HIGH TEMPERATURE. <u>DO NOT TOUCH</u> THE CONDUCTOR OR THE TRANSFORMER.

EQUIPMENT REQUIRED

1. A straight conductor.
2. Teslameter with an axial probe.
3. Ammeter.
4. Multimeter.
5. Transformer.
6. Current transformer (100:1 ratio).
7. Power supply.

INTRODUCTION

It is known that the current passing through a long straight conductor (see figure 1) produces a magnetic flux density given by:

$$\left|\overline{B}\right| = \frac{\mu_o I}{2\pi r} \quad \text{.......... (1)}$$

It can also be easily shown that ***B*** due to current in two long and parallel straight conductors is given by:

$$\left|\overline{B}\right| = \frac{\mu_o I}{2\pi x} + \frac{\mu_o I}{2\pi(x-a)} \quad \text{.......... (2)}$$

$$\left|\overline{B}\right| = \frac{\mu_o I}{2\pi x} - \frac{\mu_o I}{2\pi(x-a)} \quad \text{.......... (3)}$$

where *a* is the distance between the conductors. Equation (2) applies to the case when the currents flow in the same direction and equation (3) applies when the currents flow in the opposite directions as shown in figures 2 (a) and (b) respectively.

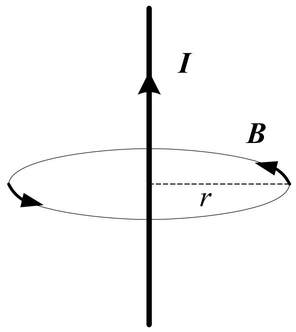


Figure 1: Magnetic field around a straight conductor

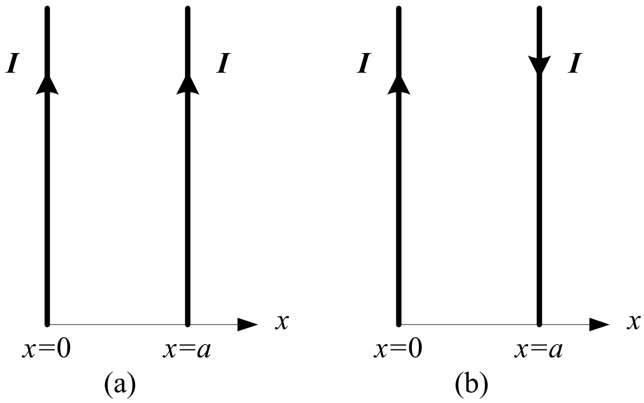


Figure 2: Two parallel straight conductors with
(a) currents in same directions
(b) currents in opposite directions

EXPERIMENTAL SETUP AND PROCEDURE

The experimental set up is shown in figure 3. The magnetic field readings will be taken from the voltmeter which is connected to the teslameter with appropriate calibration.

The teslameter must first be calibrated. For calibration it does not matter if a magnetic field is present or not. The calibration procedure is as follows:

a) *Adjust the multimeter knob to the 3V position (choose AC).*
b) *Push the DC button of the teslameter.*
c) *Push the "Eichen" button of the teslameter.*
d) *Turn the "Eichen" knob unth the multimeter reads exactly 3 volts.*
e) *Release the "Eichen" button. The teslameter is now calibrated.*

Turn the knob of the teslameter to the $3mT$ position and keep it set at this position throughout the experiment. This makes $3mT$ equivalent to $3V$ or $1mT = 1\ V$. Push the AC button of the teslameter.

The power supply output ($0\ldots15V\sim$, $5A$) is connected to the upper most and lower most ports of the transformer for maximum power output.

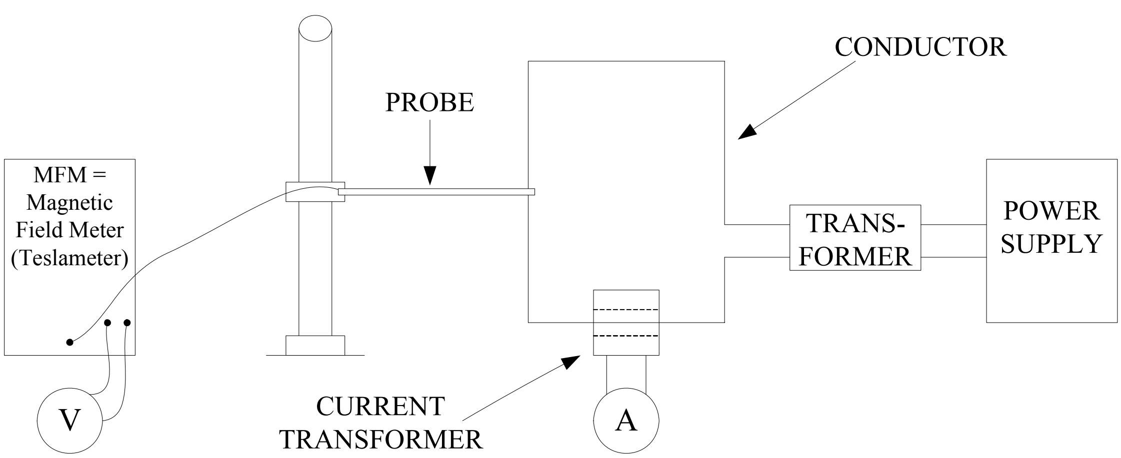


Figure 3: Experimental set-up

1. Fix the distance between the tip of the probe and the conductor to 1 *cm* (keep the probe tip near the middle of the vertical conductor). Change the current through the conductor and measure the resulting ***B*** field. (Keep the tip of the probe in the plane of the conducting loop. Also keep the probe perpendicular to the plane of the loop throughout this experiment).
2. Fix the current to 100*A* and change the distance between the probe and the conductor. Record the magnetic field at several distances to produce a smooth curve.

Calibration ➔ ________________________________

Table 1: Magnetic Field variation with Current (r = 1 cm)

Current '*I*' (A)	**Magnetic Field '*B*' (mT)**		**Percentage Error**
	Experimental	**Theoretical**	
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			
100			

Table 2: Magnetic Field variation with Distance (I = 100 A)

Distance '*r*' (cm)	**Magnetic Field '*B*' (mT)**		**Percentage Error**
	Experimental	**Theoretical**	
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

QUESTIONS FOR DISCUSSION

1. Plot a graph of the experimental relation between the current in the wire and the resulting magnetic field. Compare with the theoretical results based on equation (1). (Note: plot both results on top of each other).

2. Plot a graph of the experimental relation between the magnetic field of the wire and distance. Compare with the theoretical results based on equation (1). (Note: plot both results on top of each other).

3. Based on your experimental curve for a single wire, sketch the expected field from the structures in figures 2 (a) and (b).

4. How can you experimentally determine the direction of the magnetic field due to the straight line?

Experiment # 5

MAGNETIC FIELD OF COILS

OBJECTIVE
To measure the magnetic field at the center of wire loops and along the axis of a coil and verify the analytical expressions.

EQUIPMENT REQUIRED
1. Ammeter l*A*/5*A DC*.
2. Universal power supply.
3. Teslameter with an axial probe.
4. Induction coils.
5. Digital meter.
6. Conducting circular loops.
7. Meter scale.

INTRODUCTION
The magnetic flux density ***B*** at a point on the axis of a circular loop of radius *b* that carries a direct current *I* (see Figure 1) is given by:

$$\left|\overline{B}\right| = \frac{\mu_o I b^2}{2(z^2 + b^2)^{3/2}} \quad \text{.......... (1)}$$

If there is a number of identical loops close together, the magnetic flux density is obtained by multiplying by the number of turns *N*. At the center of the loop (z=0), equation (1) becomes:

$$\left|\overline{B}(0)\right| = \frac{\mu_o N I}{2b} \quad \text{.......... (2)}$$

To calculate the magnetic flux density of a uniformly wound coil of length *L* and *N* turns (see figure 2), we multiply the magnetic flux density of one loop by the density of turns, *N/L* and integrate over the length of the coil. The resulting magnetic flux density is given by

$$\left|\overline{B}(z)\right| = \frac{\mu_o N I}{2L}\left(\frac{a}{\sqrt{b^2 + a^2}} - \frac{c}{\sqrt{b^2 + c^2}}\right) \quad \text{.......... (3)}$$

where $a = z + L/2$ and $c = z - L/2$.
If the length of the coil is much larger than its radius, the magnetic flux density near the center of the coil axis can be obtained by approximating equation (3), yielding:

$$\left|\overline{B}(z)\right| \cong \frac{\mu_o N I}{L} \quad \text{.......... (4)}$$

(provided that $b << L$ and z is smaller than $L/2$).

PROCEDURE

Calibration and measurement of the teslameter

The calibration steps are as follows

f) *Adjust the multimeter knob to the 3V position (choose AC).*
g) *Push the DC button of the teslameter.*
h) *Push the "Eichen" button of the teslameter.*
i) *Turn the "Eichen" knob unth the multimeter reads exactly 3 volts.*
j) *Release the "Eichen" button. The teslameter is now calibrated.*

Note: Because part *A* of this experiment involves the measurement of relatively weak *DC* magnetic fields, a procedure must be followed to cancel out the contribution to measurement from the naturally occurring magnetic fields.

1. Set the digital multimeter to read *AC* voltage and choose the 20 *V* setting.
2. Set the knob of the teslameter to 0.3mT (i.e., 0.3mT = 3V or 0.1mT = 1V).
3. Push the *DC* button of the teslameter.
4. Place the tip of the axial probe in the location where the magnetic field is to be evaluated (at the center of the coil) and leave it there. The magnetic field must be parallel to the axis of the axial probe.
5. Switch the current *I* to zero.
6. Turn the "*O* adjust" knob until the multimeter gives minimum reading (for the purpose of this experiment, the reading of the multimeter should be < 0.4 *V*).
7. Switch the current *I* on to +5 *A*. Record the multimeter's reading, call it V_1.
8. Reverse the direction of the current *I* (i.e., *I* = -5*A*), record the multimeter's reading and call it V_2. To reverse the direction of *I* without moving the probe, turn off the power supply, interchange the leads at the output of the power supply, and turn on the power supply again.
9. Take the average of the voltage readings in steps (7) and (8). The average voltage $V=(V_1+ V_2)/2$ is the voltage due only to the magnetic field to be measured.
10. Finally, multiply *V* by the appropriate factor to obtain the value of ***B***.

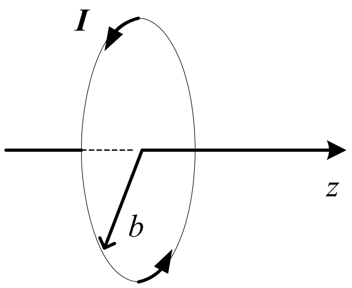


Figure 1: A circular loop of radius *b*.

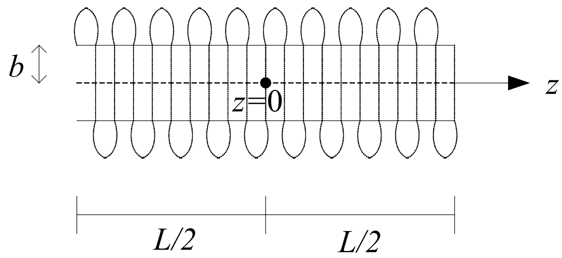


Figure 2: A coil

PART A: Magnetic Field at the Center of a Circular Conductor

1. Connect the *DC* output of the power supply to the single-turn circular conductor of diameter 2*b*=12 *cm*. Connect the ammeter to measure the current in the conductor. Adjust the current to 5 *A*. Using the Teslameter, measure the resulting *DC* magnetic field ***B*** at the center of the circular conductor.

2. Repeat step (1) for the circular conductor of diameter $2b$=12 *cm* and N=2 and N=3 turns.

Table 1: Magnetic Field Measurement at the Center of Conductor.

No. of Turns 'N'	V_1 (Volt)	V_2 (Volt)	$V = (V_1+V_2)/2$ (Volt)	$B_{(experimental)}$ (mT)	$B_{(Theoretical)}$ (mT)
1					
2					
3					

PART B: Magnetic Field inside a Coil

1. Connect the coil of length L=160 *mm*, diameter $2b$=33 *mm* and N=300 turns to the *DC* output of the power supply. Adjust the current I to 1A. Measure $\boldsymbol{B}$ inside the coil at several distances along the axis of the coil.

Table 2: Magnetic Field Measurement inside a Coil.

Distance 'z' cm	V (Volt)	$B_{(experimental)}$ (mT)	$B_{(Theoretical)}$ (mT)
0			
2			
4			
6			
8			
10			
12			
14			
16			

QUESTIONS FOR DISCUSSION

1. Plot the relation between the magnitude of the magnetic field and the number of turns and compare it with the theoretical result based on equation (2). (Note: plot both results on top of each other).
2. Why did we need to eliminate the field of the surrounding in part A of the experiment but not in part B?
3. Plot the magnetic field inside the coil as a function of distance. Compare it with the theoretical graph based on equation (3). (Note: plot both results on top of each other).
4. Plot a curve representing equation (4) on top of the two curves in step (3). Do you think equation (4) is a valid approximation of equation (3) in this case'? Why or why not?

Experiment # 6

MAGNETIC FORCE ON A CURRENT CARRYING CONDUCTOR

OBJECTIVE
To measure the force on a conductor carrying electric current placed in a magnetic field. The force is measured as the current and the length of the conductor are varied. The effect of the magnetic field strength on the resulting force is also studied.

EQUIPMENT REQUIRED
1. Balance.
2. Wire loop, *L*=50 *mm*.
3. Wire loop. *L*=25 *mm*.
4. Wire loop. *L*=12.5 *mm*.
5. Power supply.
6. Ammeters (two).
7. 900-turn coils (two).
8. Pole pieces (two).
9. Iron core, *U*-shape.
10. Distributor.
11. Right angle clamp.
12. Bridge rectifier.
13. Teslameter with a tangential probe.
14. Multimeter.

INTRODUCTION
Consider a straight conductor of length *L* and carrying current *I* placed in a region of a uniform magnetic field ***B***, where the magnetic field is perpendicular to the conductor. The magnetic force on the conductor is given by:

$$F = IBL \qquad (1)$$

The direction of the force is given by:

$$a_F = a_I \times a_B \qquad (2)$$

PROCEDURE
The experimental set up is shown in Figure 1. The *AC* current out of the power supply is rectified (call it I_F) and passed through the 900-turn coils to produce a constant magnetic field between the pole pieces. The *DC* current out of the power supply is passed through the conductor (call it I_L).

<u>PART A: Force vs. conductor current</u>
1. Attach the 50 *mm* wire loop (*N*=1) to the balance.
2. Set the *AC* output voltage of the power supply to the 12 *V* setting.
3. Adjust the balance to the horizontal position when the switch is off (I_F = 0). Record the reading or the balance dial.

4. Turn the switch on and adjust I_L to 0.5 *A*. Readjust the balance again to the horizontal position. Record the reading of the balance dial.
5. The difference in the balance readings of steps (3) and (4) is the force in grams exerted on the wire. To obtain the force in mille-Newton (*m N*), multiply the force in grams by 9.81.
6. Measure the magnetic field between the pole pieces using the Teslameter and the tangential probe. This value of the magnetic field will be used in the theoretical calculations. (*Remember to calibrate the Teslameter. After calibration, push the DC button and choose the 300mT setting*).
7. Repeat steps (3)-(6) for a range of conductor current between 0.5 and 5 A.

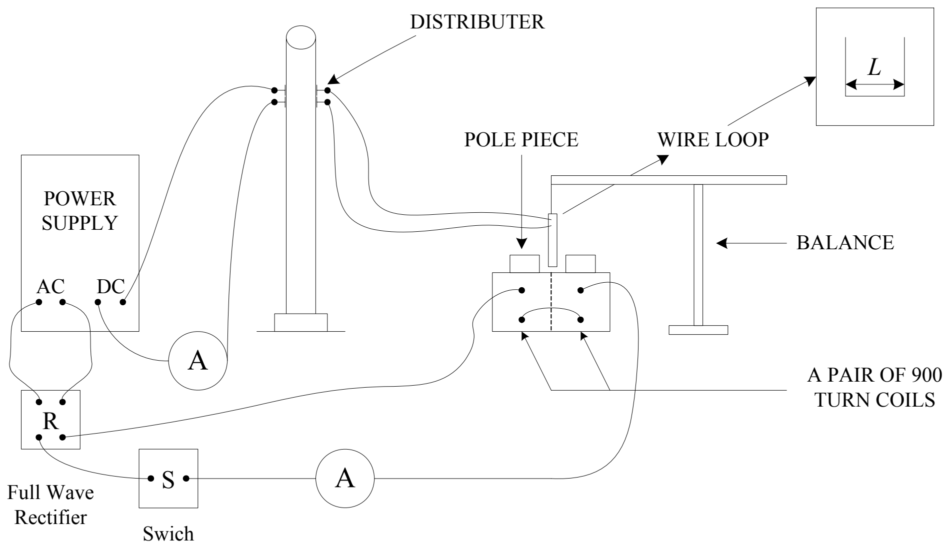


Figure 1: Experimental set-up

Table 1: Force variation with Conductor Current

L = 50 mm, N = 1, $F_{exp} = | M - M_0 |$ x 9.81, where M (mass) in grams., $F_{theo} = I_L BL$

I_L (A)	$B_{(experimental)}$ (mT)	Balance Reading M (gms)	$F_{(experimental)}$ (mN)	$F_{(Theoretical)}$ (mN)
0	0	M_0 =	0	0
0.5		M =		
1.0		M =		
1.5		M =		
2.0		M =		
2.5		M =		
3.0		M =		
3.5		M =		
4.0		M =		
4.5		M =		
5.0		M =		

PART B: Force vs. conductor length

Repeat the steps of *PART A* for different conductor lengths (N=1) with I_L = 5.0 A only.

Table 2: Force variation with Conductor Length

I_L = 5 A, N = 1, F_{exp} = | M – M_0 | x 9.81, where M (mass) in grams., $F_{theo} = I_L BL$

L (mm)	B_{exp} (mT)	Initial Balance M_0 (gms)	Final Balance M (gms)	$F_{(experimental)}$ (mN)	$F_{(Theoretical)}$ (mN)
12.5					
25					
50					

PART C: Force vs. magnetic field

1. Attach the 50 *mm* (N=1) wire loop to the balance.
2. Fix I_L to 5 A.
3. Measure the force as the current I_F is varied. (This is done by choosing different voltage settings on the power supply).
4. Measure the corresponding magnetic field.

Table 3: Force variation with Magnetic Field

I_L = 5 A, L = 50 mm, N = 1, F_{exp} = | M – M_0 | x 9.81, where M (gram), $F_{theo} = I_L BL$

V (Volts)	I_F	B_{exp} (mT)	Balance Reading 'M' (gms)	$F_{(experimental)}$ (mN)	$F_{(Theoretical)}$ (mN)
0	0	0	**M_0 =**	0	0
2			**M =**		
4			**M =**		
6			**M =**		
8			**M =**		
10			**M =**		
12			**M =**		
15			**M =**		

QUESTIONS FOR DISCUSSION

1. Plot the experimental and the theoretical relations between the force on the conductor and the conductor current, the conductor length and the magnetic field.
2. Why did we ignore the effect of the magnetic field of the surroundings?
3. Why did we ignore the effect of the vertical portions of the conductor loop?
4. Plot and explain the relation between the magnetic field and I_F. (Use the results of *PART C*).

Experiment # 7

MAGNETIC INDUCTION

OBJECTIVE
To verify Faraday's law of induction. The induced voltage in the secondary circuit is measured as a function of the amplitude and frequency of the current in the primary circuit. The variation of the induced voltage with the number of turns and the cross-sectional area of the secondary circuit is also studied.

EQUIPMENT REQUIRED
1. Frequency counter.
2. Function generator.
3. Digital multimeter.
4. Analog multimeter.
5. Voltage transformers 125/220 (two).
6. Field coil 485 turns/meter, 750 *mm* long.
7. Induction coil, 300 turns, 41 *mm* diameter.
8. Induction coil, 300 turns, 33 *mm* diameter.
9. Induction coil, 300 turns, 26 *mm* diameter.
10. Induction coil, 200 turns, 41 *mm* diameter.
11. Induction coil, 100 turns, 41 *mm* diameter.

INTRODUCTION
According to Faraday's law of induction, voltage can be induced in a circuit due to current passing through a nearby circuit. In this experiment, a large solenoidal field coil (item 6 in the equipment list) is used to generate a time-varying magnetic field by passing an *AC* current (I_1) through it. Smaller coils (items 7-11 in the equipment list) are used for induction (see Figure 1).
The *AC* current I_1 passing through the field coil produces a time-varying magnetic field given by:

$$\overline{B} = \mu_o n I_1 \quad \text{.......} (1)$$

where n is the turns density (turns/meter) of the coil. If the current I_1 is sinusoidal and given by:

$$I_1 = I_o \cos(\omega t) \quad \text{.......} (2)$$

then, the induced voltage, v, in the induction coil is given by:

$$\boxed{v = \mu_o n \pi a^2 N \omega I_o \sin(\omega t) \quad \text{.......} (3)}$$

where a and N are the radius and the number of turns of the induction coil, respectively.

PROCEDURE
<u>PART A: Induced voltage vs. current</u>
1. Connect the function generator to the field coil and to the frequency counter.
2. Adjust the frequency to 10.7 *kHz*.
3. Measure the amplitude of I_1, using the analog multimeter.

4. Insert the 300-turn, 41 *mm* diameter coil into the field coil. Insure that the coil is well into the field coil. Measure the induced voltage in the coil using the digital multimeter.
5. Repeat for a range of I_1 from 0 to 30mA.

Table 1: Induced Voltage vs. Current

f = 10.7 kHz, N = 300 turns, diameter = 2a = 41 mm

Current I_1 (mA)	**Induced Voltage '*v*' (Volts)**	**Theoretical '*v*' (Volts)**
0		
5		
10		
15		
20		
25		
30		

PART B: Induced voltage vs. number of turns

1. Fix the current I_1 to 30mA and the frequency to 10.7 *kHz*. Measure the induced voltage across the 300-tum, 41 *mm* diameter coil.
2. Repeat step (1) for the 200-turn, 41 *mm* diameter and the 100-turn, 41 *mm* diameter coils.
3. Repeat step (1) for a 400-turn, 41 *mm* diameter coil (not provided but a combination can be used).
4. Repeat step (1) for a 500-turn, 41 *mm* diameter coil.

Table 2: Induced Voltage vs. Number of Turns

f = 10.7 kHz, I_1 = 30 mA turns, diameter = 2a = 41 mm

No. of Turns N	**Induced Voltage '*v*' (Volts)**	**Theoretical '*v*' (Volts)**
200		
300		
400		
500		

PART C: Induced voltage vs. coil diameter

1. Fix the current I_1 to $30mA$ and the frequency to $10.7kHz$. Measure the induced voltage across the 300-tum, 41 *mm* diameter coil.
2. Repeat step (1) for the 300-tum coils of diameters 33 *mm* and 26 *mm*.

Table 3: Induced Voltage vs. Coil Diameter

f = 10.7 kHz, I_1 = 30 mA turns, N = 300 turns

Diameter mm	**Induced Voltage '*v*' (Volts)**	**Theoretical '*v*' (Volts)**
26		
33		
41		

PART D: Induced voltage vs. frequency

1. Fix the current I_1 to $30mA$ and the frequency to 1 *kHz*. Measure the induced voltage across the 300-turn, 41 *mm* diameter coil.
2. Repeat step (1) for a frequency range from 1 to 12 *kHz* (make sure that the current is maintained at $30mA$ each time you change the frequency).

Table 4: Induced Voltage vs. Frequency

I_1 = 30 mA turns, N = 300 turns, Diameter = 2a = 41 mm.

Frequency kHz	**Induced Voltage '*v*' (Volts)**	**Theoretical '*v*' (Volts)**
1		
2		
4		
6		
8		
10		
12		

QUESTIONS FOR DISCUSSION

1. Plot the experimental and the theoretical relations between the induced voltage and current, number of turns, coil diameter and frequency.

2. From your experimental curves, find the induced voltage for the case: N=350, a= 15 mm, I_1= 10mA and f=10 kHz.

3. Use equation (3) to find a theoretical value of the induced voltage for the case in question (2). Compare with your answer of question (2). This is a good measure of the accuracy of your experimental results.

4.

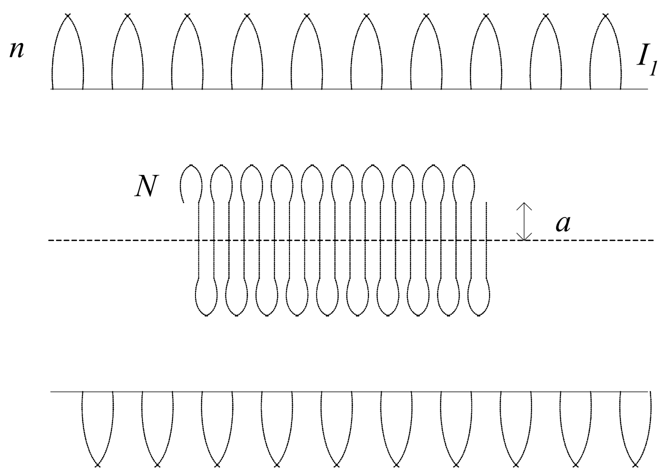


Figure 1: Field and induction coils

Experiment # 8

EM WAVE RADIATION AND PROPAGATION OF A HORN ANTENNA

OBJECTIVE

To acquaint the students with the idea of polarization of electromagnetic (*EM*) waves and to introduce some microwave components. Also, the radiation patterns of a horn antenna will be measured.

EQUIPMENT REQUIRED

1. Microwave oscillator.
2. Attenuator.
3. Horn radiators (two).
4. Oscilloscope.

INTRODUCTION

Linearly polarized waves are radiated by a waveguide horn antenna, the direction of polarization being parallel to the narrow dimension of the waveguide feeding the antenna. The reason is that the waveguide field has only one electric field component parallel to the narrow wall of the guide. Because of this and by virtue of the principle of reciprocity such a horn can only receive waves of the same polarization as that it radiates, and so if the incident field is arbitrarily polarized the horn selects the components of the field aligned with its direction of polarization. If the only field component is perpendicular to the horn's direction of polarization, then the horn does not receive the incident field.

PROCEDURE

<u>PART A: Demonstration of microwave components and EM wave radiation</u>

1. The instructor will explain the different components of a microwave transmission and receiving components. This includes the oscillator, the attenuator, the waveguide, the horn antenna and the detector.
2. The instructor will also explain the basic concept of polarization.

<u>PART B: EM wave polarization</u>

1. Connect the circuit shown in Figure 1.
2. Align the two antennas for maximum reception. Adjust the received power to maximum reading on the meter.
3. Rotate the receiving antenna about its center (Figure 2) from –90 degrees to +90 degrees in steps of 10 degrees. In each setting, read the received power from the meter or the oscilloscope. (*Note: The oscilloscope may provide a finer resolution*).
4. Readjust the receiving antenna for maximum reception and repeat step (3) using the polarizing screen.

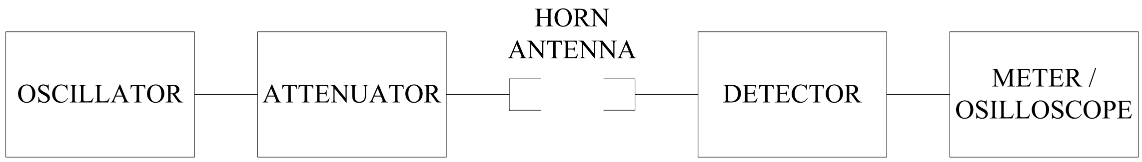


Figure 1: Experimental setup

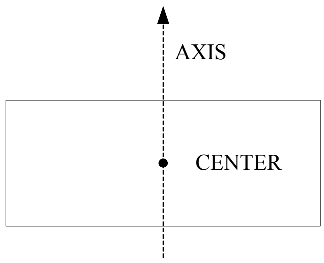


Figure 2: Front view of the receiving horn antenna

Table 1: Rotating Receiver about its Center

Angle (degree)	**V_{pp} (mV)**	**I (mA)**	**P (µW)**
-30			
-25			
-20			
-15			
-10			
-5			
0			
5			
10			
15			
20			
25			
30			

Table 2: Rotating Receiver about its Center using the Polarizing Screen

Angle (degree)	V_{pp} (mV)	I (mA)	P (µW)
-30			
-25			
-20			
-15			
-10			
-5			
0			
5			
10			
15			
20			
25			
30			

PART C: Radiation patterns

1. Connect the circuit shown in Figure (1).
2. Align the two antennas for maximum reception. Adjust the received power to maximum reading on the meter.
3. Rotate the receiving antenna about its axis (Figure 2) from –90 degrees to +90 degrees in steps of 10 degrees. In each setting, read the received power from the meter or the oscilloscope. (*Note: The oscilloscope may provide a finer resolution*).
4. Move the receiving antenna in a semicircle around the transmitting antenna from –90 degrees to +90 degrees in steps of 10 degrees. In each setting, obtain maximum reception and read the received power from the meter or the oscilloscope. (*Note: The oscilloscope may provide a finer resolution*).

Table 3: Rotating Receiver about its axis

Angle (degree)	V_{pp} (mV)	I (mA)	P (µW)
-90			
-80			
-70			
-60			
-50			
-40			
-30			
-20			
-10			

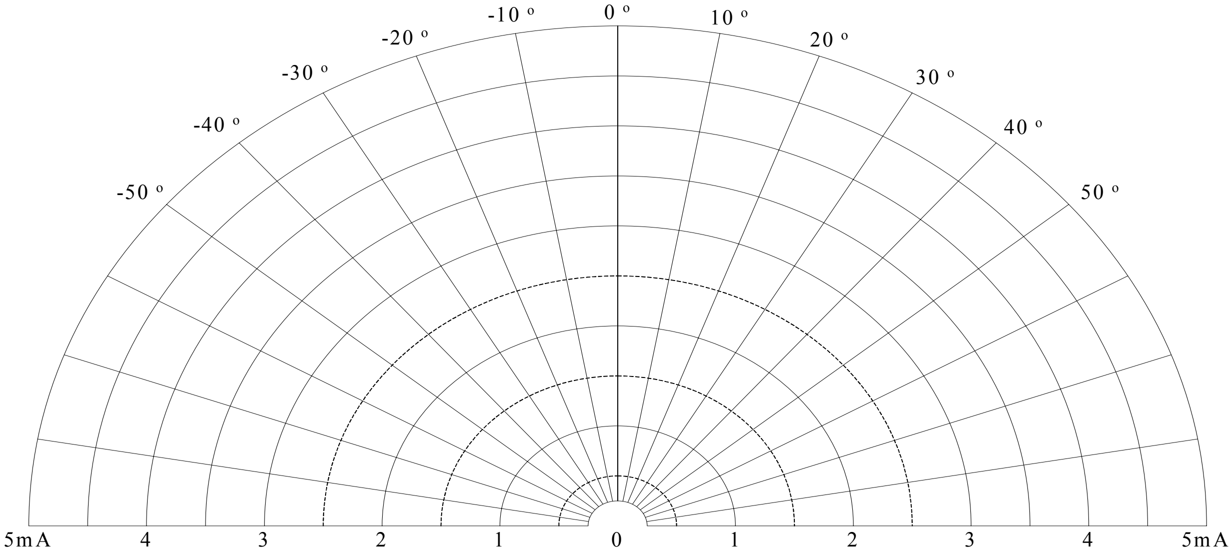
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			

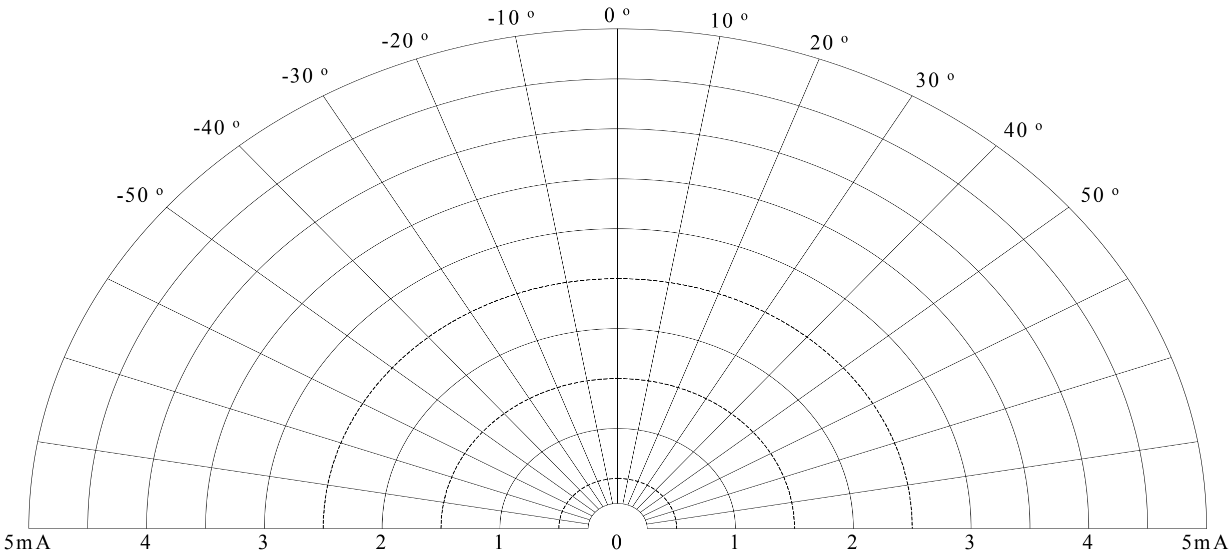
Table 4: Rotating Receiver in a semicircle around the tranmitter

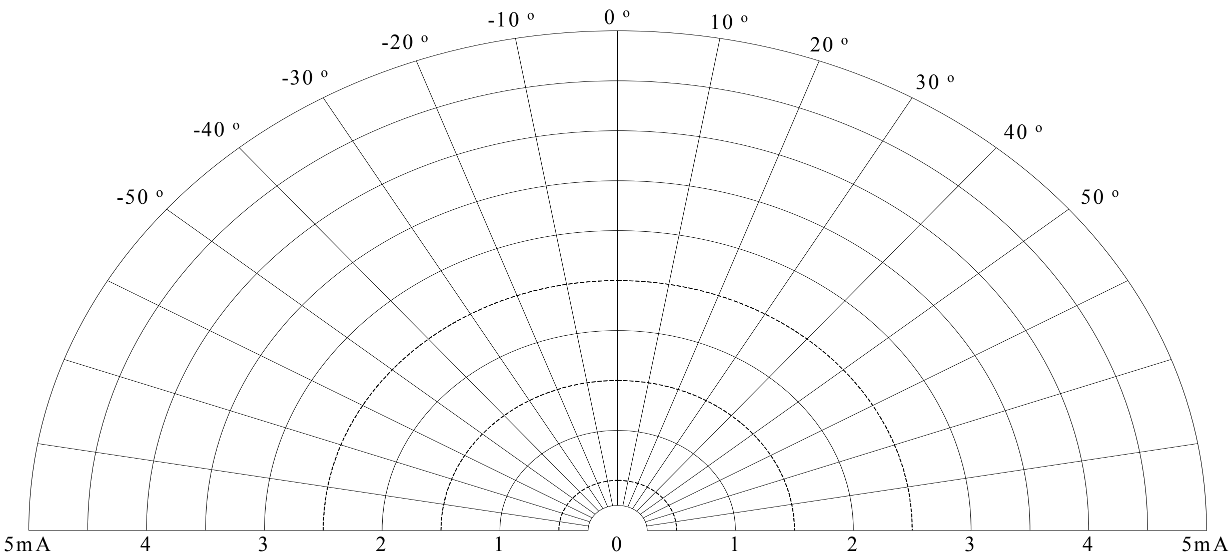
Angle (degree)	**V_{pp} (mV)**	**I (mA)**	**P (µW)**
-90			
-80			
-70			
-60			
-50			
-40			
-30			
-20			
-10			
0			
10			
20			
30			
40			
50			
60			
70			
80			
90			

QUESTIONS FOR DISCUSSION

1. Draw a normalized curve of your results in *PART B* on a polar plot (*provided)*.
2. Explain the results with relation to polarization.
3. Draw normalized radiation patterns of the antenna using your results in *PART C* on a polar plot (*provided*). Discuss these curves.







Polar Plots for the Questions

Experiment # 9

EM WAVE TRANSMISSION AND REFLECTION

OBJECTIVE
To demonstrate the phenomena of reflection and transmission of electromagnetic fields.

EQUIPMENT REQUIRED
1. Signal Generator, with square wave modulation.
2. Directional Coupler and matched termination.
3. Oscilloscope.
4. Detectors (two).
5. Horn antennas (two).
6. Waveguide sections.
7. Several sheets of different materials.

INTRODUCTION
When a time-varying electromagnetic wave propagating in one medium encounters another medium of different electric parameters, part of the energy will reflect back at the interface and part will continue to propagate. Further, some of the field characteristics may change (for example, the direction of the power flow, the field polarization, etc.). These changes in the field characteristics and the ratio of the reflected field to the incident field (the reflection coefficient) depend on the electromagnetic parameters of the materials (μ and ε).
In this experiment, the effect of μ and ε on the value of the reflection coefficient and the transmission coefficient will be studied for the case of normal incidence.

The reflection and transmission coefficients are related to the material parameters in the case of normal incidence by the following relations:

$$\text{Reflection coefficient} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \quad \text{..} (1)$$

$$\text{Transmission coefficient} = \frac{2\eta_2}{\eta_2 + \eta_1} \quad \text{.....................................} (2)$$

where η_1 and η_2 are the characteristic impedances of the media at the interface.

PROCEDURE

PART A: Demonstration of microwave components
The instructor will explain the function of some microwave components used in this experiment This include the directional coupler and matched termination. The instructor will also explain the basic concept of reflection and transmission.

PART B: EM wave reflection and transmission

1. Bring the transmitting and the receiving antennas in close proximity with a separation small enough to insert a sheet between them.
2. Align the two antennas for maximum reception. Adjust the received power to maximum reading on the meter. Record this value.
3. Insert a sheet between the two antennas and adjust it such that best transmission can be obtained. Record the transmitted value.
4. Repeat step (3) for different sheets (A mix between dielectric and metallic sheets).

Table 1: Rotating Receiver in a semicircle around the transmitter

Material	**Transmitter V_{pp} (mV)**	**Receiver V_{pp} (mV)**
Air		
Glass		
Black Plastic		
White Plastic		
Steel		

Ask your lab instructor to show the demonstration video related to this topic.

QUESTIONS FOR DISCUSSION

1. From the results of *PART B* obtain a rough estimate of the permittivity of the material of the dielectric sheets (Note: μ_r = 1 and $\sigma \approx 0$ for most dielectric materials). Compare with textbook values.
2. What is tile main reason for the discrepancy in the answers of question (1)?
3. Suggest another method to measure reflection and transmission coefficients.

Appendix A

Guidelines for Formal Report Writing

A formal report is expected to include the following sections

Cover Page
Contains experiment number and title, student name, partners' names, date and abstract.

Abstract
A few statements that summarize the work done in the experiment, the general procedure and results and observations.

Introduction
A brief summary of the theoretical background needed to understand the experiment. This background may include laws and formulas, models, equivalent circuits, block diagrams, etc. A clear statement of objective should also be included in this section.

Procedure
A list of steps done in the experiment. Each step should be briefly explained and outlined. The circuit connections, block diagram and/or modifications to the handout procedure should be included in the appropriate step. All components in the circuit connections should be marked clearly. (Do not copy the lab manual; write your own statements)

Results
The experimental results obtained from each of the steps in the procedure. All data should be tabulated.

Discussion of Results
A comprehensive evaluation of the results. This evaluation includes the following:
- Calculation of theoretical values.
- Plots of experimental and theoretical values.
- Error analysis (calculation of % error associated with each data set).
- Discussion of errors and ways to reduce them.
- Any specific observations and comments.

Conclusions
A few statements discussing the following:
- A general statement about the experiment and how close it accomplishes the objectives. Problems and Conclusions of the experiment regarding procedure, equipment, accuracy, learning benefits, etc.
- Answer to questions (those in the lab manual and those given by instructor).

Important notes
- Submitting identical or even similar reports will be considered as act of cheating.
- All pages should be numbered.
- All figures (including circuits diagrams, plots, block diagrams, etc.) should be numbered and given meaningful captions and legends (see examples on next page).
- tables should be numbered and given meaningful captions (see examples on next page).
- Landscape figures or tables should be oriented correctly.
- Report grade will be based on the quality of the above sections and on correct format.
- Use of computers in word setting and plotting is highly encouraged.

King Fahd University of Petroleum and Minerals

Electrical Engineering Department

Appendix B: PROBLEM SESSIONS

PROBLEM SESSION I

Part (1): Visualization of surfaces in *3D* coordinate systems

Describe the following surfaces separately:

a) $x=-5$, $z=2$.
b) $\rho=3$, $\Phi=3\pi/2$.
c) $\rho=\sqrt{5}$, $z=-2$.
d) $r=5$, $\Phi=\pi/3$.
e) $\theta=\pi/2$, $\Phi=\pi/2$.
f) $r=2$, $\Phi=0$.
g) $y=5$.

Part (2): Visualization of surfaces in *3D* coordinate systems

Describe the intersection of surfaces (1) and (2):

Surface (1)	Surface (2)
$\Phi=45$	$z=5$
$x=-2$	$z=3$
$\rho=5$	$\Phi=45$
$r=1$	$\theta=60$

Part (3): Vector Algebra

Problems 1.5 and 1.10 from the text book.

1.5 For $\mathbf{U} = U_x\,\mathbf{a_x} + 5\,\mathbf{a_y} - \mathbf{a_z}$, $\mathbf{V} = 2\,\mathbf{a_x} - V_y\,\mathbf{a_y} + 3\,\mathbf{a_z}$, and $\mathbf{W} = 6\,\mathbf{a_x} + \mathbf{a_y} + W_z\,\mathbf{a_z}$, obtain U_x, V_y, and W_z such that **U**, **V**, and **W** are mutually orthogonal.

1.10 Verify that

(a) $\mathbf{A} \cdot (\mathbf{A} \times \mathbf{B}) = 0 = \mathbf{B} \cdot (\mathbf{A} \times \mathbf{B})$

(b) $(\mathbf{A} \cdot \mathbf{B})^2 + |\mathbf{A} \cdot \mathbf{B}|^2 = (AB)^2$

(c) If $\mathbf{A} = (A_x, A_y, A_z)$, then $\mathbf{A} = (\mathbf{A} \cdot \mathbf{a}_x)\,\mathbf{a}_x + (\mathbf{A} \cdot \mathbf{a}_y)\,\mathbf{a}_y + (\mathbf{A} \cdot \mathbf{a}_z)\,\mathbf{a}_z$.

Part (4): Coordinate transformations

Problems 2.1, 2.2 , 2.3 and 2.15 from the text.

2.1 Convert the following points to Cartesian coordinates:

(a) P_1 (5, 120°, 0)
(b) P_2 (1, 30°, -10)
(c) P_3 (10, 3π/4, π/2)
(d) P_4 (3, 30°, 240°)

2.2 Express the following points in cylindrical and spherical coordinates:

(a) P (1, -4, -3)
(b) Q (3, 0, 5)
(c) R (-2, 6, 0)

2.3 Express the following points in cylindrical and spherical coordinates:

(a) $\mathbf{P} = (y + z)\,\mathbf{a_x}$
(b) $\mathbf{Q} = y\,\mathbf{a_x} + x\,z\,\mathbf{a_y} + (x + y)\,\mathbf{a_z}$
(c) $\mathbf{T} = \left[\dfrac{x^2}{x^2+y^2} - y^2\right]\boldsymbol{a}_x + \left[\dfrac{xy}{x^2+y^2} + xy\right]\boldsymbol{a}_y + \boldsymbol{a}_z$
(d) $\mathbf{S} = \dfrac{y}{x^2+y^2}\boldsymbol{a}_x - \dfrac{x}{x^2+y^2}\boldsymbol{a}_y + 10\boldsymbol{a}_z$

2.15 If $\mathbf{J} = \boldsymbol{r}\sin\theta\cos\phi\,\boldsymbol{a}_r - \cos 2\theta\sin\phi\,\boldsymbol{a}_\theta + \tan\dfrac{\theta}{2}\ln \boldsymbol{r}\,\boldsymbol{a}_\phi$, determine the vector component of **J** at T (2, π/2, 3π/2) that is

(a) Parallel to $\mathbf{a_z}$.
(b) Normal to the surface $\Phi = 3\pi/2$.
(c) Tangential to the spherical surface $r = 2$.
(d) Parallel to the line $y = -2$, $z = 0$.

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PROBLEM SESSION # 2

Problem 1.a) Find the surface integral of $\boldsymbol{F} = 5\ \boldsymbol{a_y}$ over S, where S is a cubical surface 3 units of length of the side with a corner at the origin. One of the faces of the cube lies in the first quadrant of the x-y plane. **(b)** Repeat (a) for $\boldsymbol{F} = x^2\ y^2\ \boldsymbol{a_x}$.

Problem 2.a) Evaluate the surface integral of $\boldsymbol{F} = \frac{a_r}{r^2}$ over the spherical surface of radius 4 centered at the origin. **(b)** Repeat part (a) for $\boldsymbol{F} = \frac{\sin^2\phi}{r^2}a_r + \cos\phi a_\theta$. **(c)** Repeat part (a) for $\boldsymbol{F} = \boldsymbol{a_x}$.

Problem 3. Consider the conical surface S shown in figure 1.
The cone has height h and base radius a. Evaluate the closed surface integral of the following vector fields: **(a)** $\boldsymbol{F} = r\ \boldsymbol{a_r}$. **(b)** $\boldsymbol{F} = r\ \boldsymbol{a_\theta}$. **(c)** $\boldsymbol{F} = \cos\phi \boldsymbol{a}_\phi + r\ \boldsymbol{a_\theta}$.

Problem 4. Consider the closed cylindrical surface of height h and base radius a as shown in figure 2. Evaluate the closed surface integral of $\boldsymbol{F}$ over this surface if:
(a) $\boldsymbol{F} = \rho^2 \boldsymbol{a}_\rho + \rho\sin\phi \boldsymbol{a}_\phi + \rho^2 \sin\phi \boldsymbol{a}_z$. **(b)** $\boldsymbol{F} = x\ \boldsymbol{a_x} + z\ \boldsymbol{a_z}$.

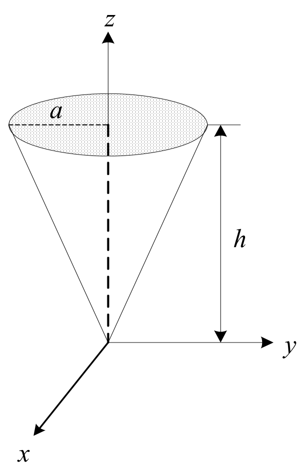

Figure 1: The surface for problem 3

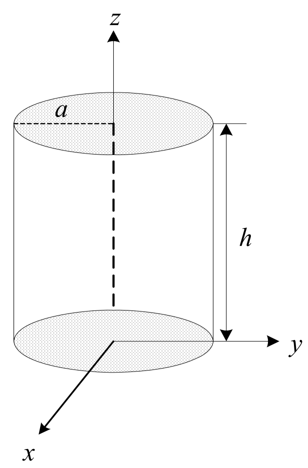

Figure 2: The surface for problem 4

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PROBLEM SESSION # 3

3.15 Determine the gradient of the following scalar fields:

(a) $U = 4xz^2 + 3yz$.

(b) $V = e^{(2x+3y)} \cos 5z$.

(c) $W = 2\rho(z^2 + 1) \cos \varphi$.

(d) $T = 5\rho\, e^{-2z} \sin \varphi$.

(e) $H = r^2 \cos \theta \cos \varphi$.

(f) $Q = (\sin \theta \sin \varphi) / r^3$.

3.18 Find the divergence and curl of the following vector fields:

(a) $\mathbf{A} = e^{xy}\, \mathbf{a_x} + \sin xy\, \mathbf{a_y} + \cos^2 xz\, \mathbf{a_z}$

(b) $\mathbf{B} = \rho\, z^2 \cos \varphi\, \mathbf{a_\rho} + z \sin^2 \varphi\, \mathbf{a_z}$

(c) $\mathbf{C} = \boldsymbol{r} \cos\theta\, \boldsymbol{a}_r - \frac{1}{\boldsymbol{r}} \sin\theta\, \boldsymbol{a}_\theta + 2\,\boldsymbol{r}^2 \sin\theta\, \boldsymbol{a}_\phi$

3.30 Given that $\boldsymbol{E} = \frac{1}{\boldsymbol{r}^4} \sin^2\phi\, \boldsymbol{a}_r$, evaluate

(a) $\oint_S E \cdot dS$

(b) $\int_V (\nabla \cdot E)\, dv$

over the region between the spherical surfaces $r = 2$ and $r = 4$.

3.33 Calculate the total outward flux of vector

$\boldsymbol{F} = \rho^2 \sin\phi\, \boldsymbol{a}_\rho + \boldsymbol{z} \cos\phi\, \boldsymbol{a}_\phi + \rho\, \boldsymbol{z}\, \boldsymbol{a}_z$

through the hollow cylinder defined by $2 \le \rho \le 3$, $0 \le z \le 5$.

3.39 Given the vector field

$R = (2x^2 y + yz)\, a_x + (xy^2 - xz^3)\, a_y + (c\, xyz - 2x^2 y^2)\, a_z$

determine the value of c for **R** to be solenoidal.

3.40 If the vector field

$T = (\alpha xy + \beta z^3)\, a_x + (3x^2 - \gamma z)\, a_y + (3\, xz^2 - y)\, a_z$

is irrotational, determine α, β, and γ. Find $\nabla \cdot \mathbf{T}$ at (2, -1, 0).