11. TRI-PHASE TRANSFORMERS:

Tri-phase systems are constructed using tri-phase transformers with different voltages. These transformers have three terminals. High and low voltage windings for each phase are placed in the same terminal. There is a phase difference with a degree of 120 between the current passing through each windings. There are various connection groups for different purposes in tri-phase transformers. These groups will be analyzed.

11.1. Characteristics, Structure and Operation of the Tri-phase Transformer:

The operation of the tri-phase transformer is similar to the operation of the single phase transformer. Tri-phase transformer is constructed by connecting 3 single phase transformers in delta or wye form. It is also constructed by using a core with 3 shells (primary and secondary windings in each shell). The voltage current transformation ratio of the tri-phase transformer is same with the single phase transformer.

The apparent power of the tri-phase transformer is ;

$S_1 = \sqrt{3} . U_1 . I_1$ .....VA (Primary)
$S_2 = \sqrt{3} . U_2 . I_2$ .....VA (Secondary)

In delta connected system ;

$U_h = U_f$
$I_h = \sqrt{3} . I_f$

In Y-connected system ;

$U_h = \sqrt{3} . U_f$
$I_h = I_f$

11.2. The Connection Forms and Properties of the Tri-phase Transformers :

The primary and secondary of the tri-phase transformer can be connected either in star (Y) form or in delta (△) form. As an alternative connection there is zigzag connection form (there are just two windings in the secondary of each phases with equal voltages).

In tri-phase transformers, the connection terminals of the primary winding are shown by capital letters. For the first phase U is used for input, and X is used for output. For the second phase V is used for input, and Y is used for output. For the third phase W is used for input, and Z is used for output. The secondary windings are represented by lower case letters. For the first phase u is used for input, and x is used for output. For the second phase v is used for input, and y is used for output. For the third phase w is used for input, and z is used for output. If there are more than one groups in the windings they are denoted with the numbers 1.2..... Respectively.

Star (λ) Connection :

It is used for primary and secondary windings. One terminal of each phase windings in the primary winding are connected to each other (Star bridge). Three phases L1,L2,L3 are applied to the other terminals (R,S,T). Neutral terminal is connected to star point. The terminals of the phases are connected similarly in secondary winding. The load is connected to the other remaining terminals.

Figure 1 : Star(λ) connection

Delta (△)Connection :

It is used for primary-secondary windings. The input of each phase is connected to the output of another phase.

The tri-phases (L1,L2,L3)are applied to the winding input terminals (R,S,T) in the primary.

The same operation is held in secondary winding. The winding input terminals are connected to the tri-phase load. There is no neutral line in delta connection.

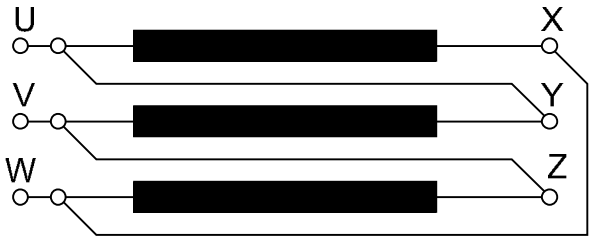


Figure 2: Delta (△) connection

Zigzag (⩚) Connection :

This connection form is applicable only if the secondary of the transformer has two windings with equal voltage in the same phase. In zigzag connection one winding of each phase is connected the other winding of the other phase in series. There is a neutral line.

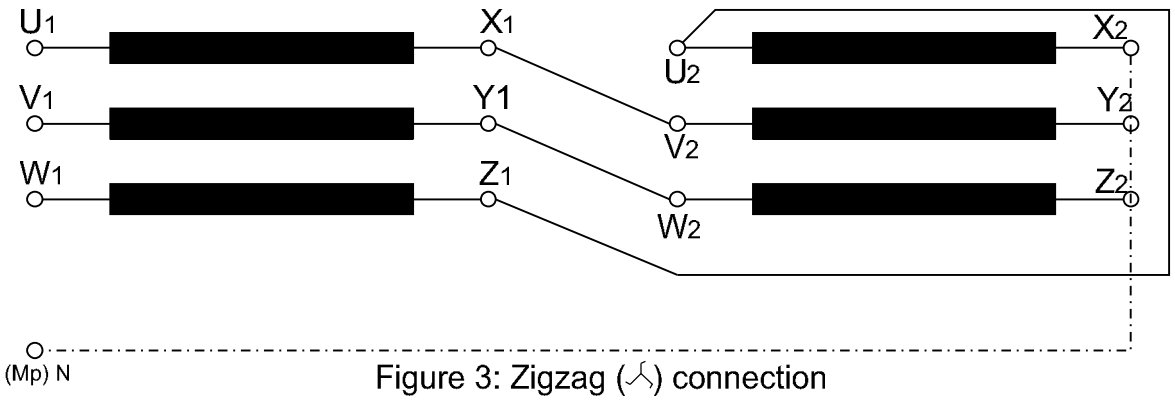


Figure 3: Zigzag (⩚) connection

11.3. Connection Groups and Properties of the Tri-phase Transformers :

Connection groups of tri-phase transformers are formed according to the connection forms and phase differences of the primary and secondary windings. Each connection has different properties and different purposes. These connections are realized according to the structure, protection and property of the transformers and the structure of the system supplied.

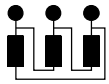
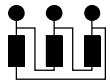
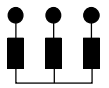
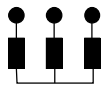
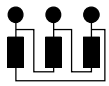
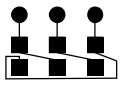
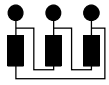
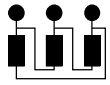
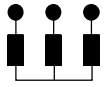
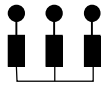
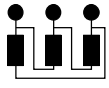
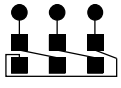
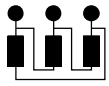
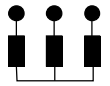
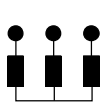
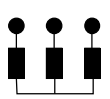
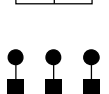
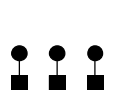
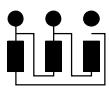
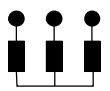
GROUP		VECTOR VOLTAGE		CONNECTION VOLTAGE		SYMBOL
		PRIMARY	SECONDARY	PRIMARY	SECONDARY	
A_0	A_1					D_{do}
A_0	A_2					Y_{yo}
A_0	A_3					D_{zo}
B_6	B_1					D_{bo}
B_6	B_2					Y_{y6}
B_6	B_3					D_{z6}
C_5	C_1					D_{y5}
C_5	C_2					Y_{d5}
C_5	C_3					Y_{z5}
D_{11}	D_1					D_{y11}
D_{11}	D_2					Y_{d11}
D_{11}	D_2					Y_{z11}

Figure 1.4 : Table for connection group and properties of tri-phase transformers

Group A : Dd_0 Delta –delta connection with phase difference 0° .
Group B : Yy_6 Star – star connection with phase difference 6x30° = 180°
Group C : Yd_5 Star –delta connection with phase differencel 5x30° = 150°.
Group D : Yz_{11} Star – Zigzag connection with phase difference 11x30 = 330°.

Experiment 26: LOADED OPERATION OF THE TRI-PHASE TRANSFORMER

Purpose: Using the tri-phase transformer with various loads (resistive, inductive, and capacitive), getting the knowledge about finding regulation and efficiency.

Equipments:

-Experiment board with energy unit	Y-036/001
-Energy analyzer	Y-036/004
-A.C measurement unit	Y-036/005
-Tri-phase transformer	Y-036/029
-Tri-phase switch with fuses	Y-036/051
-Bus	Y-036/053
-Tri-phase variable ohmic load	Y-036/056
-Tri-phase variable inductive load	Y-036/058

-Jagged cable, cable with IEC plug, Multimeter

*Connection diagram for the experiment is given in the following pages!

Procedure :

Note:*The experiment can be adapted to your laboratory conditions. If your transformer has more than secondary output, use the highest level.

-Connect the circuit shown in figure 26.1 and 26.2.
-Connect the tri-phase transformer in λ/λ form. The output of the secondary is at the highest level.
-Apply nominal voltage to the primary winding of the transformer while the switch of the load circuit at the secondary is open.
-Take note of all the parameters(U,I,cosφ,W,VA,VAR etc.) in the energy analyzer of the primary-secondary circuits.
-Close the switch of the load circuit at the secondary and load the transformer step by step up to 1.2 times the nominal power. Take note of all the parameters in the energy analyzer of the primary-secondary circuits.
-Repeat the steps above after replacing the resistive load with an inductive load. Take note of all the parameters in the energy analyzer of the primary-secondary circuits.
-Calculate the efficiency (η) and the regulation (Reg %) of the transformer for different loads and steps.
-Turn of the energy and finish the experiment.

-Optional: Repeat the experiment for $\lambda/\triangle$, $\triangle/\triangle$, $\triangle/\lambda$ connection forms.
-Analyze the efficiency and regulation values for different connection forms.
-Analyze the difference of the connection forms considering the values recorded in the experiment.
-Analyze the efficiency and regulation for different loads according to the connection forms.
-Turn of the energy and finish the experiment.

Connection diagram for the experiment : Y-036/001

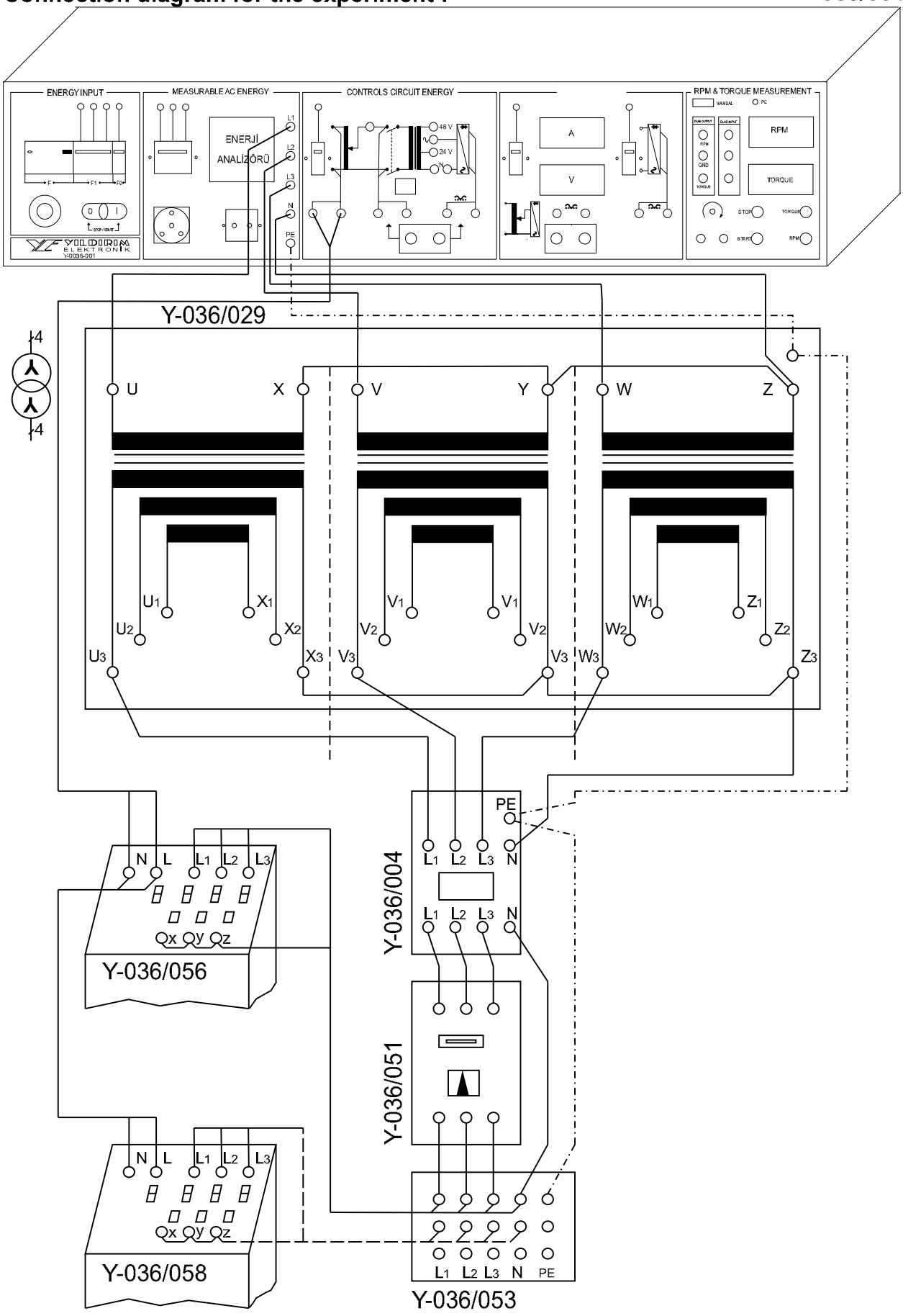


Figure 26.1 Connection diagram for the loaded operation of the tri-phase transformer.

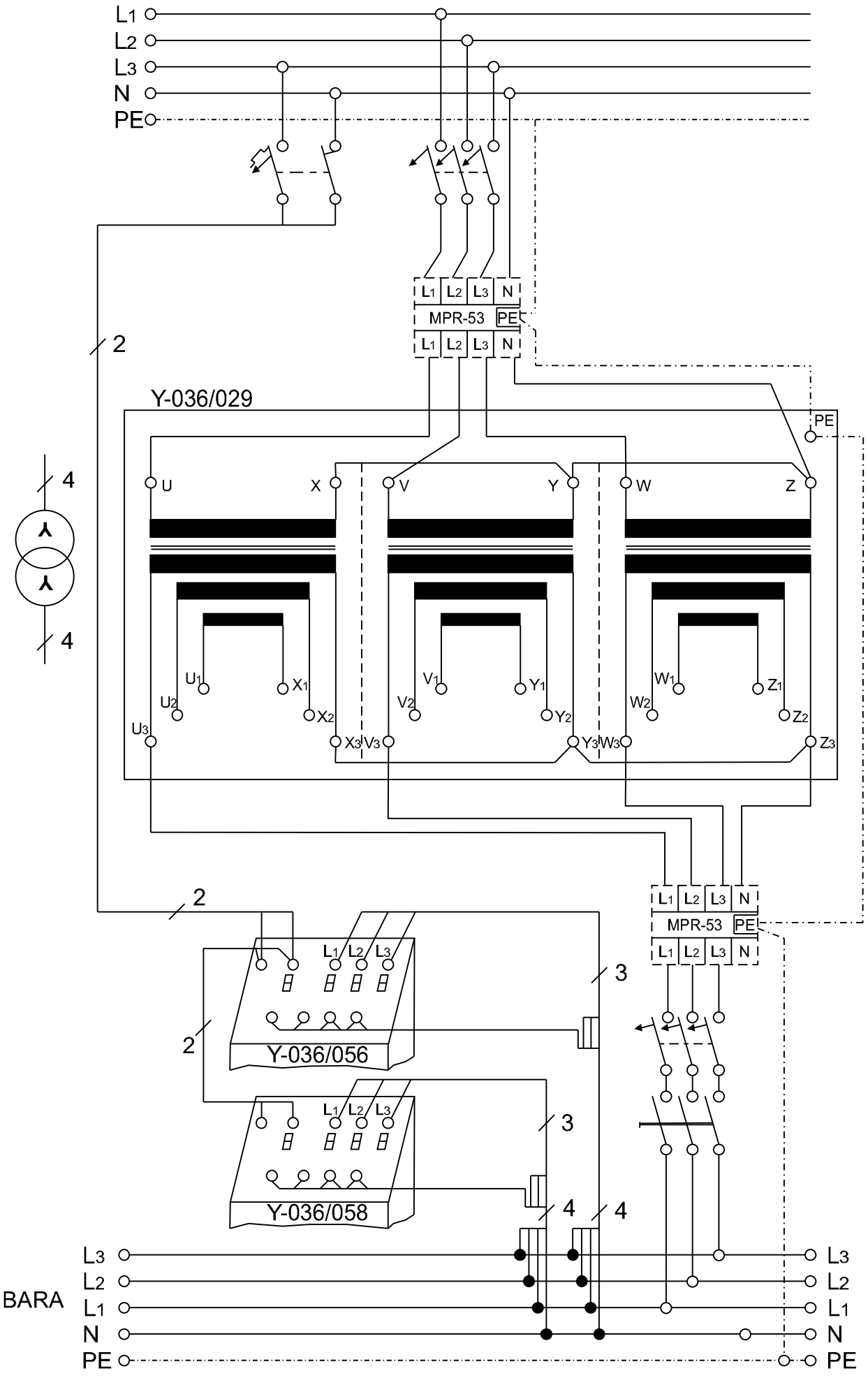


Figure 26.2 Connection diagram for the loaded operation of the tri-phase transformer.

Values recorded in the experiment :

													Explanation
	U	I	cosφ	W	VA	VAR	U	I	cosφ	W	VA	VAR	
R(ohmic)													
L (inductive)													
R-L													

Evaluation :

Question 1:What should be considered while selecting the connection form of the three phase transformer? Explain.
Question 2:Analyze the connection groups applied in the experiment considering the efficiency and regulation values.
Question 3:State your observations about different load types considering efficiency and regulation. Explain.
Question 4:Sketch the graphs (gain) n=f(P1) and U2=f(P1) according to the values recorded.
Question 5:For which load type the efficiency of the transformer takes its maximum value? Explain the reason.
Question 6:State your final observations about the experiment.