22-Sept

Unit-4

Graph Theory

To find out shortest path

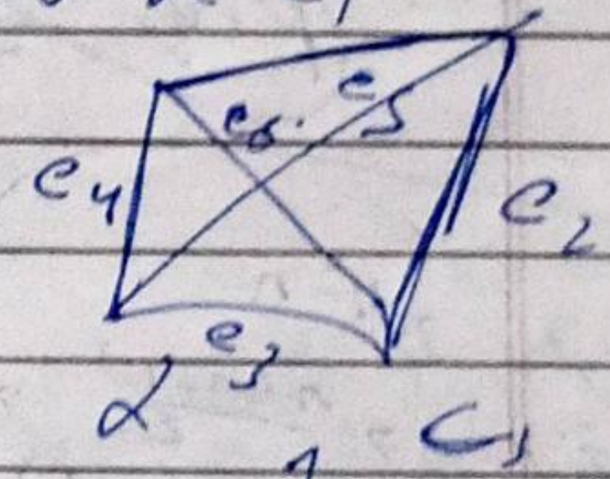
Numerical & Theoretical part also

MJ-16, 20

Graph is set of vertices & edges

$G = (V, E)$

set of vertices, set of edges a e, $\to (a,b)$ In d

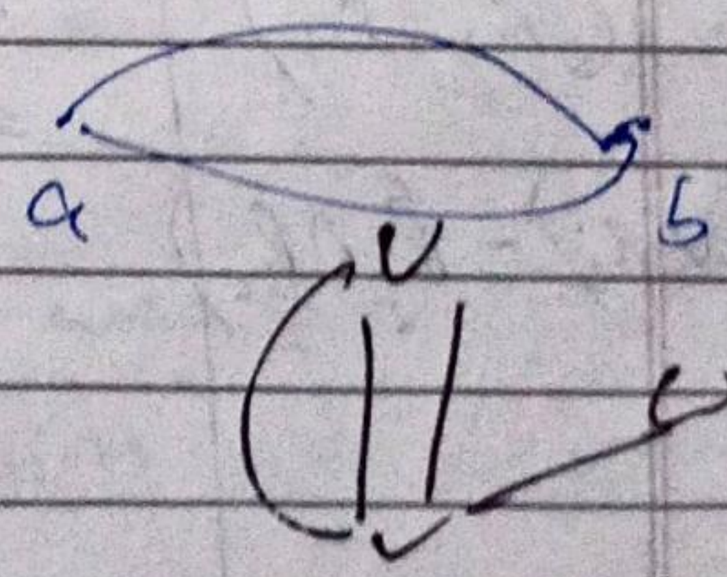


$V(G)$ or $V = \{a, b, c, d\}$

$E(G)$ or $E = \{e_1, e_2, e_3, e_4, e_5, e_6\}$

$\Rightarrow$ Directed ordered pair [Directed graph]
Undirected graph

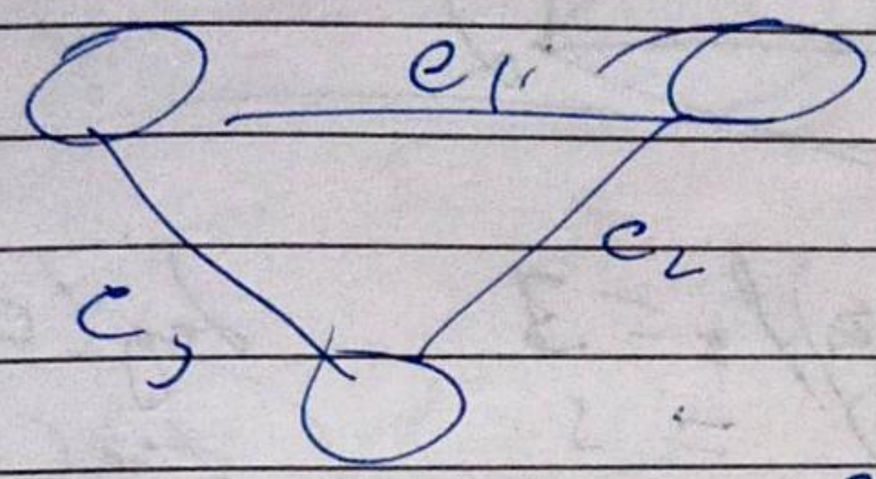
Multiple edges :



Simple (undirected graph)

a

$V = \{u, v, w\}$, set of nodes



$E = \{e_1, e_2, e_3\}$

Loithen

Infinite Graph , then it is simple undirected graph

Pseudo graph = Multiple edges & loops.

No. of edges originating from u

Degree of u = 2

2 vertex Incident on u

" " v = 1

k = isolated vertex

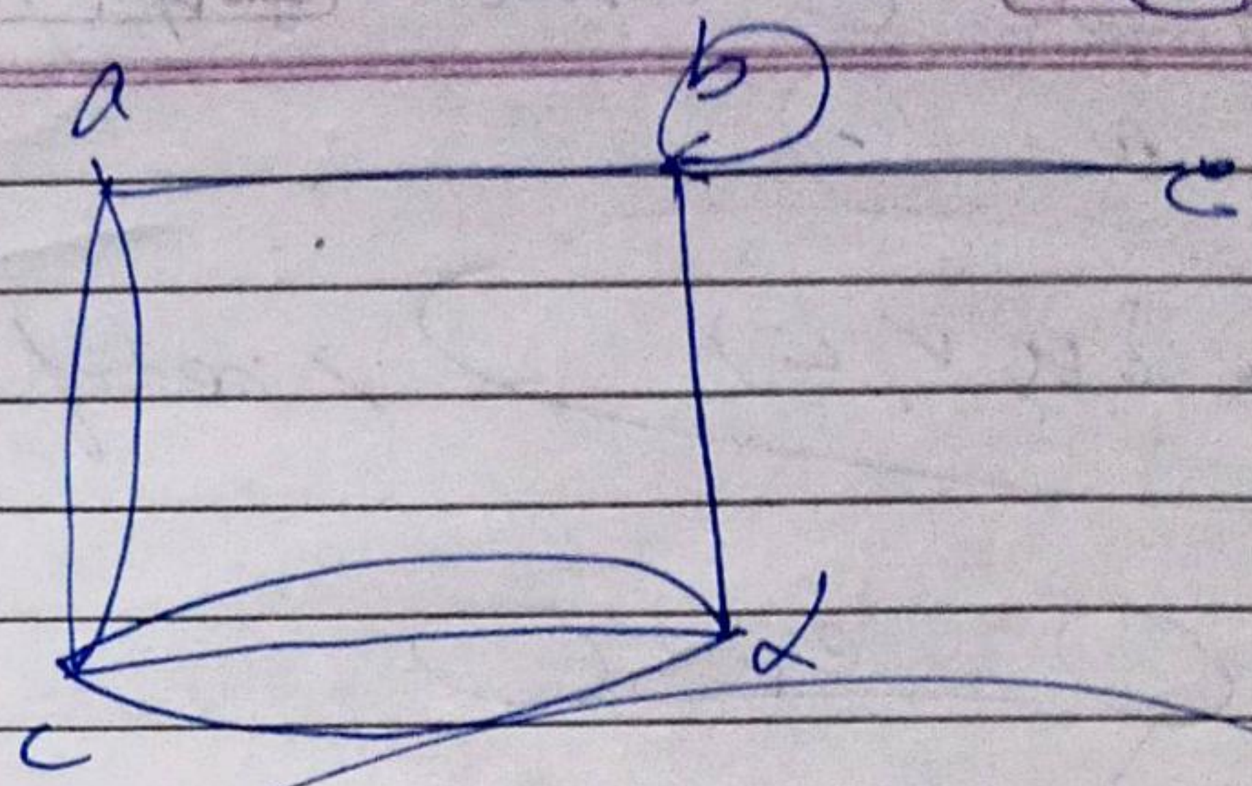
pendant = 1 then deg = 1

multigraph → Graph having multiple edges or parallel edges

→ It is not necessary that b/w every pair u should have more than 2 edges.

Directed graph = (u,v)

$u \rightarrow v$



pendant vertex

no. of edges ⇒ 9

deg (a) = 3
deg (c) = 5
deg (d) = 4

deg (e) = 1
deg (b) = 5

deg (loop) = 2

see at 11 to 14

sum of deg ⇒ 18

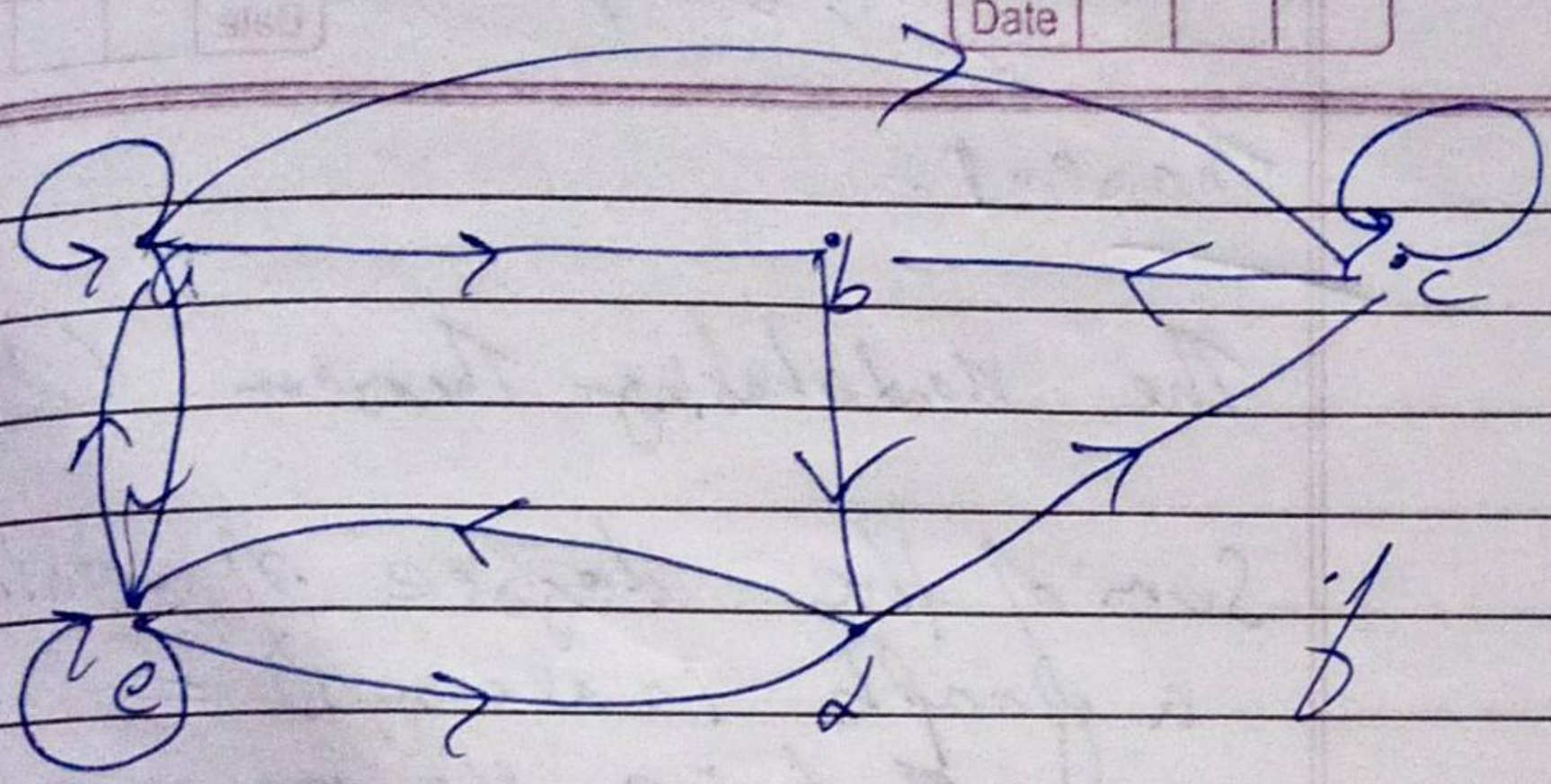
$\frac{18}{2} \Rightarrow 9$

one is originating
one is ending at b

line

Directed graph

Sum of in degree = sum of out degree



In degree of "a" = 2
out " " "a" = 4 ⇒ $deg^+(a) = 4$

$deg^-(b) = 2$ $\quad$ $deg^+(b) = 1$

no. of edges that end at b

$deg^-(c) = 3$ $\quad$ $deg^+(c) = 2$

$deg^-(d) = 2$ $\quad$ $deg^+(d) = 2$

$deg^-(e) = 3$ $\quad$ $deg^+(e) = 3$

$+$ $\quad$ $+$

12 $\quad$ 12

G, sum always equal

&

if not equal then

there is error.

Theorem 1:

The Handshaking Theorem (HST)

Sum of the degree of vertices in a graph is always = twice the no. of edges

Q: How many edges are there in a graph with 10 vertices each of degree 6?

(a) 10 (b) 20 (c) 30 (d) 40

sum of deg of vertices = 10 × 6 = 60

HST ⇒ 60 = 2e

e = 30

Q: Draw a graph with 15 vertices each of degree 5 → graph not possible

sum of deg of vertices = 15 × 5 = 75

no. of edges = 75/2 = 37.5 → graph does not exist

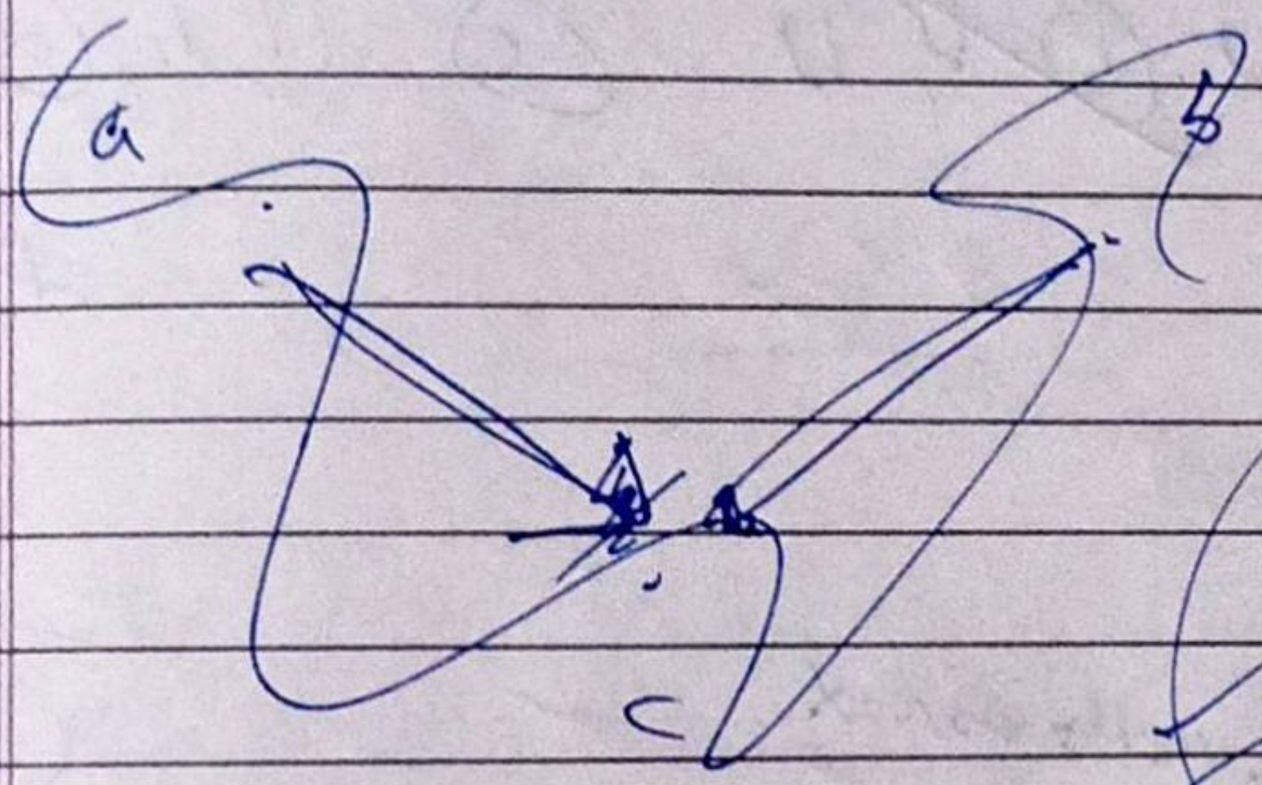
not possible

Page No.
Date

22 Sept

Q2: How many edges are there in the graph with 2 vertices of deg 1 and one vertex of deg 2. Draw the graph.

(a) 1 (b) 2 (c) (5) (d) 4

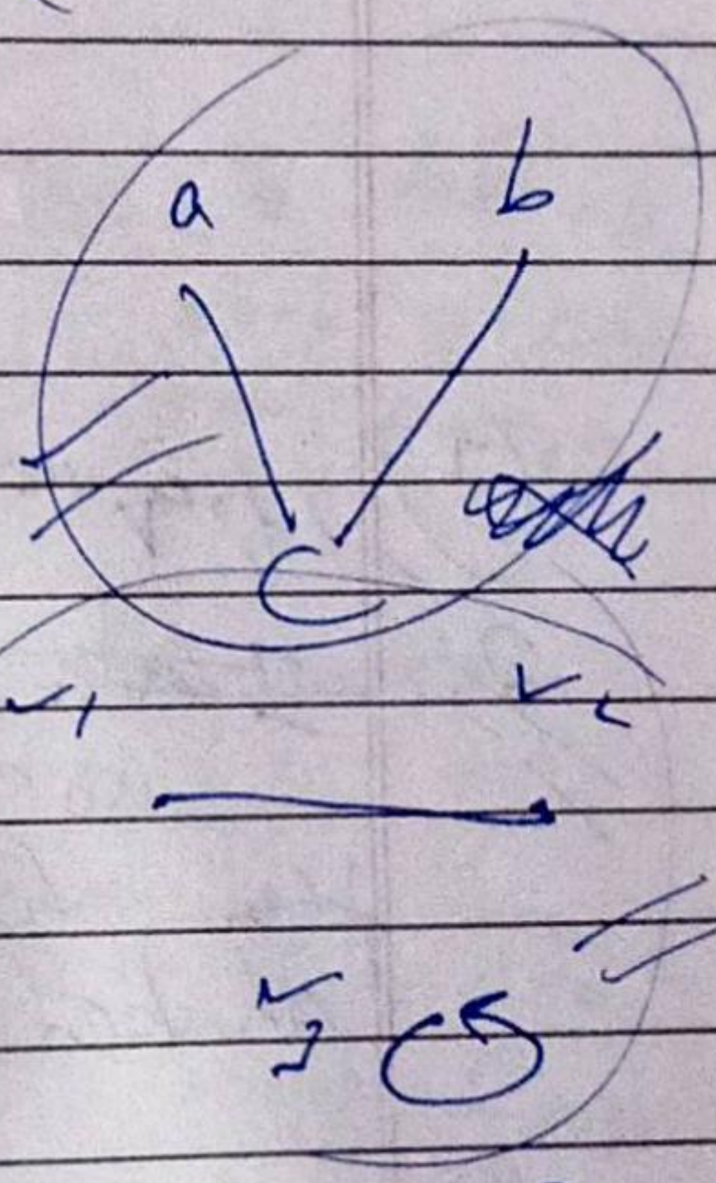


v_1 — 1

v_2 — 1

v_3 — 2

4



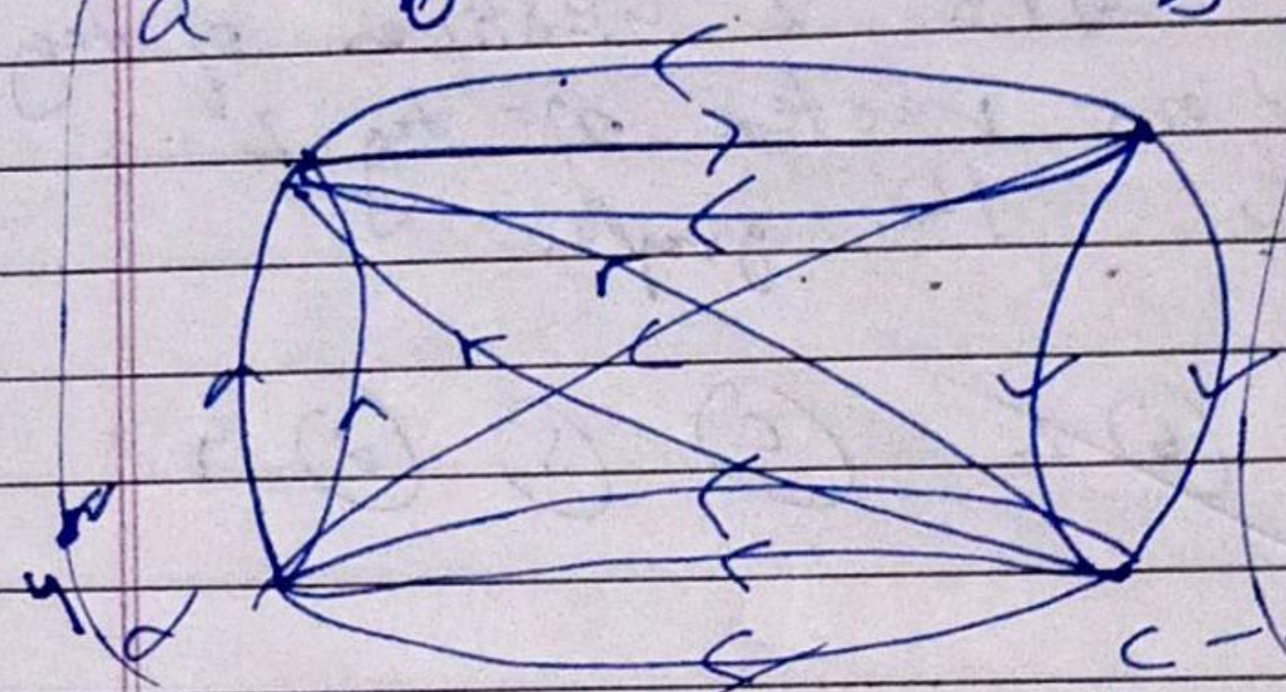
4/2 => 2

Ans

(8)

2. Find the sum of the in deg & out deg for the ~~dis~~ directed graph

a - 6 b - 1



c - 2

(a) 15, 17 (b) 15, 17 (c) 11, 11, (d) 7, 9

#7

7
6
6
20

(7) frequently asked

2. ~~In a~~ In a party, if there are a total of 45 handshakes, then how many people have shaken hands?

(a) 45 (b) 30 (c) 20 (d) 10

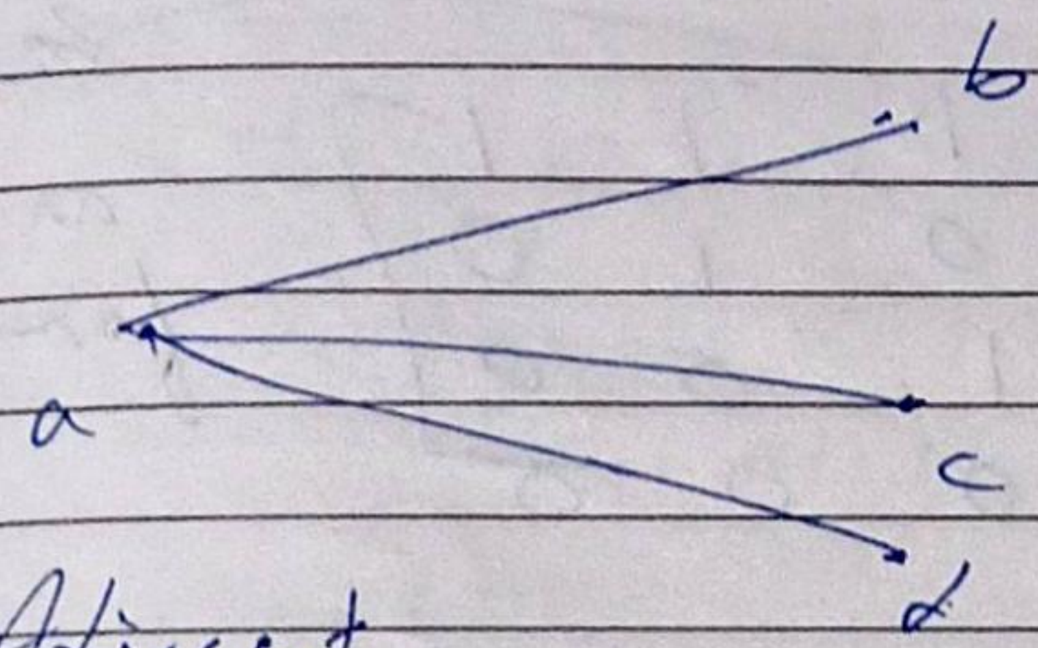
$\frac{n(n-1)}{2} = 45$

n people shake hands with n-1 people

$\boxed{n = 10}$

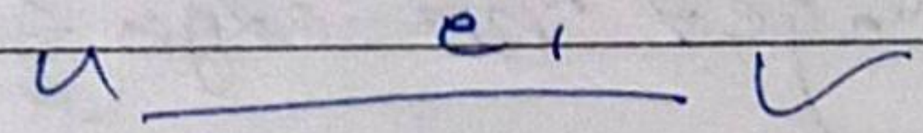
14
12
2 6

Page No.
Date



Adjacent

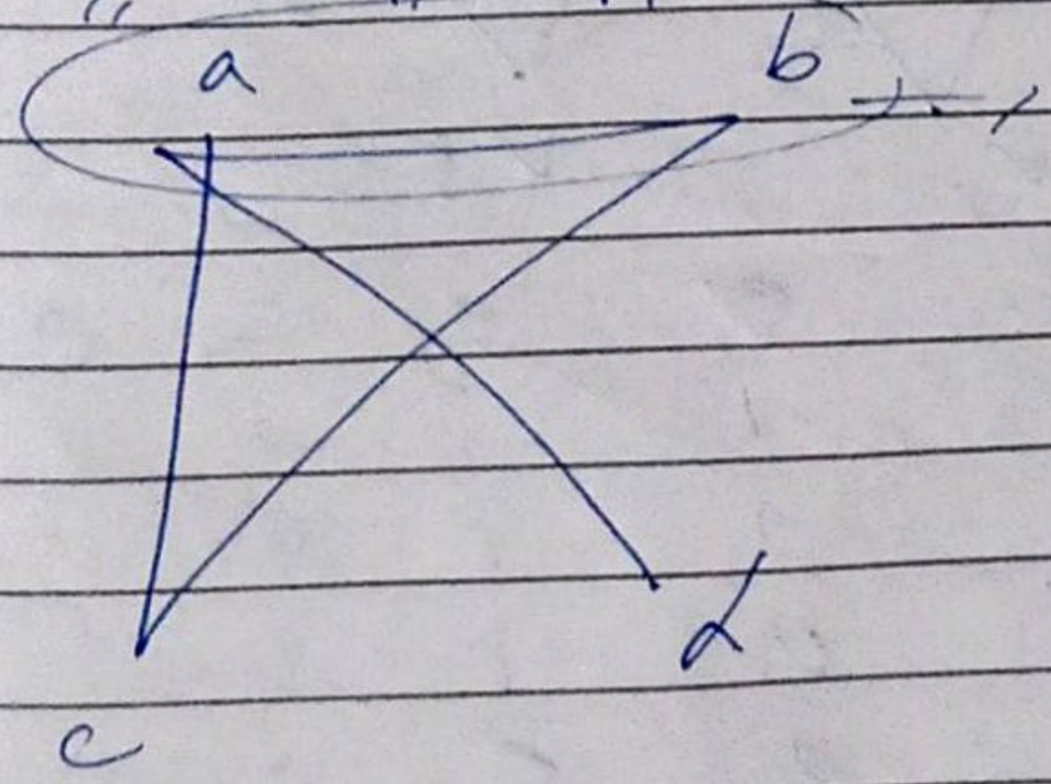
~~The~~ 2 ~~edge~~ vertices, sharing a common edge ~~to~~ are adjacent



e_1 — u
e_1 — v

e is talking about an edge and a vertex

e_1 is incident to vertex u
" " " " v



a & b are neighbours and sharing a common edge
∴ a & b are adjacent

~~but~~ b & d are not adjacent

vertices neighbour to each other

Adjacency matrix

$$\begin{array}{c|cccc} & a & b & c & d \\ \hline a & 0 & 1 & 1 & 1 \\ b & 1 & 0 & 1 & 0 \\ c & 1 & 1 & 0 & 0 \\ d & 1 & 0 & 0 & 0 \end{array}$$

there is an edge from a to b

no edge from a to a (i.e. loop)

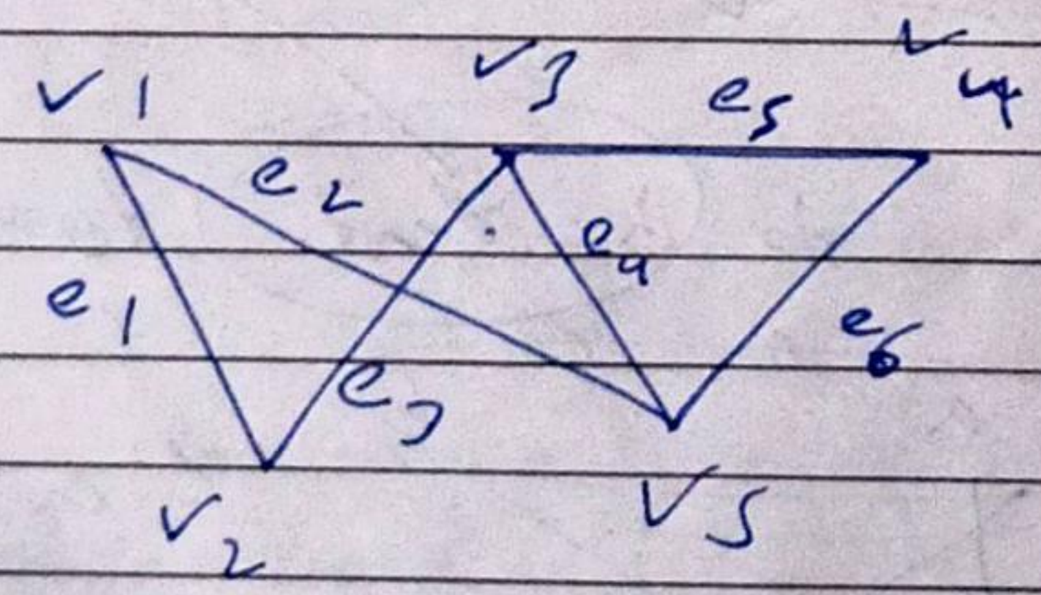
NOTE: In undirected graph adjacency matrix is a symmetric matrix.

↳ In directed there is no such relationship condition

Incidence → edges & vertices

Incidence matrix –

e_1 is incident on v_1 & v_2



$$\begin{array}{c|cccccc} & e_1 & e_2 & e_3 & e_4 & e_5 & e_6 \\ \hline v_1 & 1 & 1 & 0 & 0 & 0 & 0 \\ v_2 & 1 & 0 & 1 & 0 & 0 & 0 \\ v_3 & 0 & 0 & 1 & 1 & 1 & 0 \\ v_4 & 0 & 0 & 0 & 0 & 1 & 1 \\ v_5 & 0 & 1 & 0 & 1 & 0 & 1 \end{array}$$

Page No.
Date

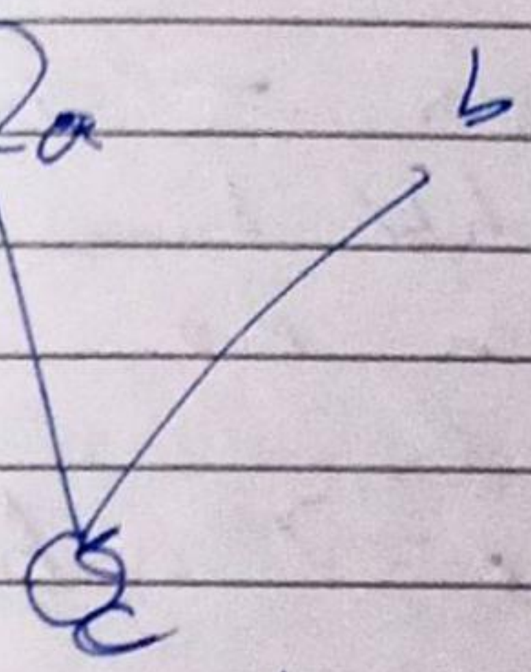
Q: adjacent matrix

$$\begin{array}{c|ccc} & a & b & c \\ \hline a & 1 & 0 & 1 \\ b & 0 & 0 & 1 \\ c & 1 & 1 & 1 \end{array}$$

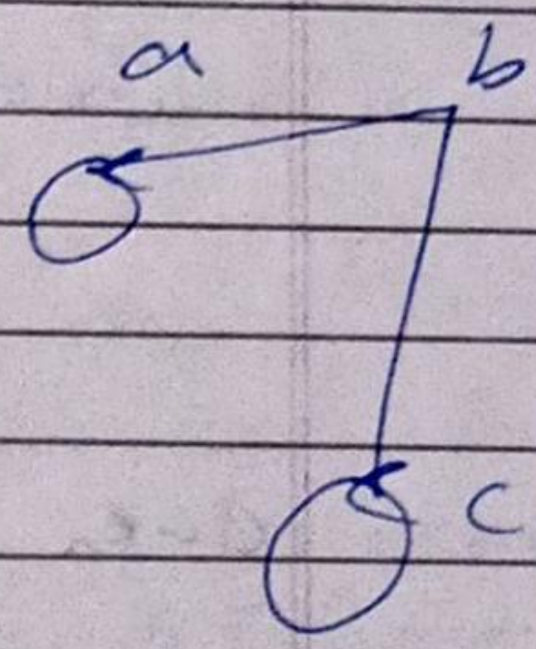
symmetric matrix

Draw graph:

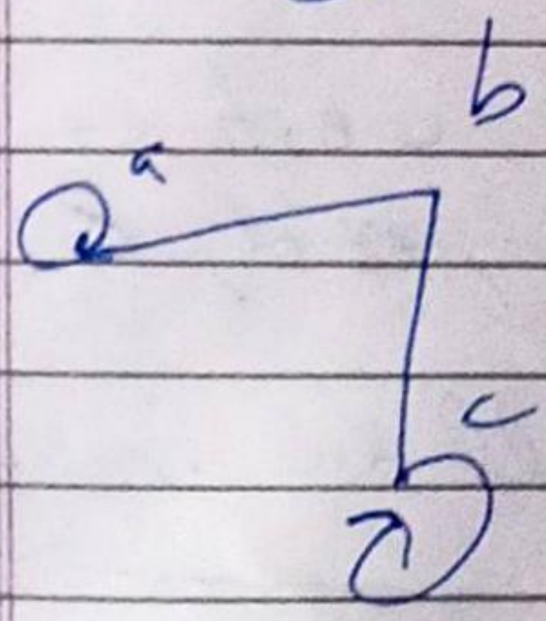
(a)



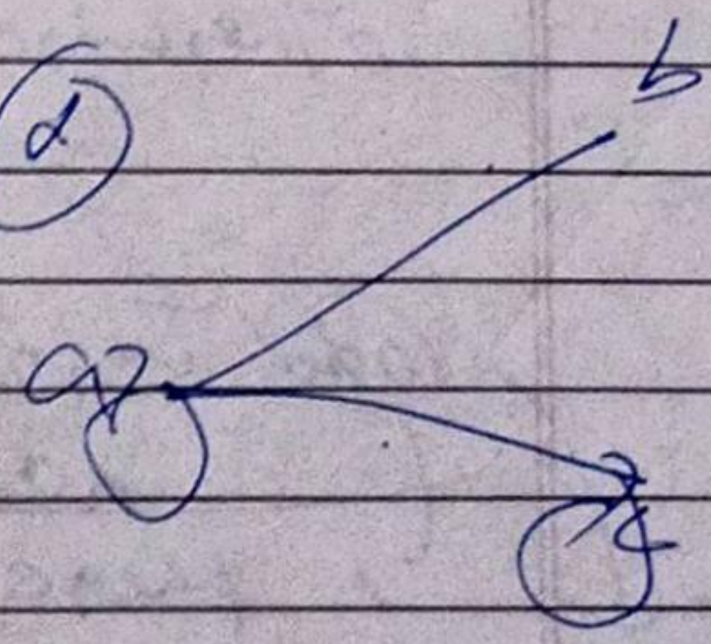
(b)



(c)

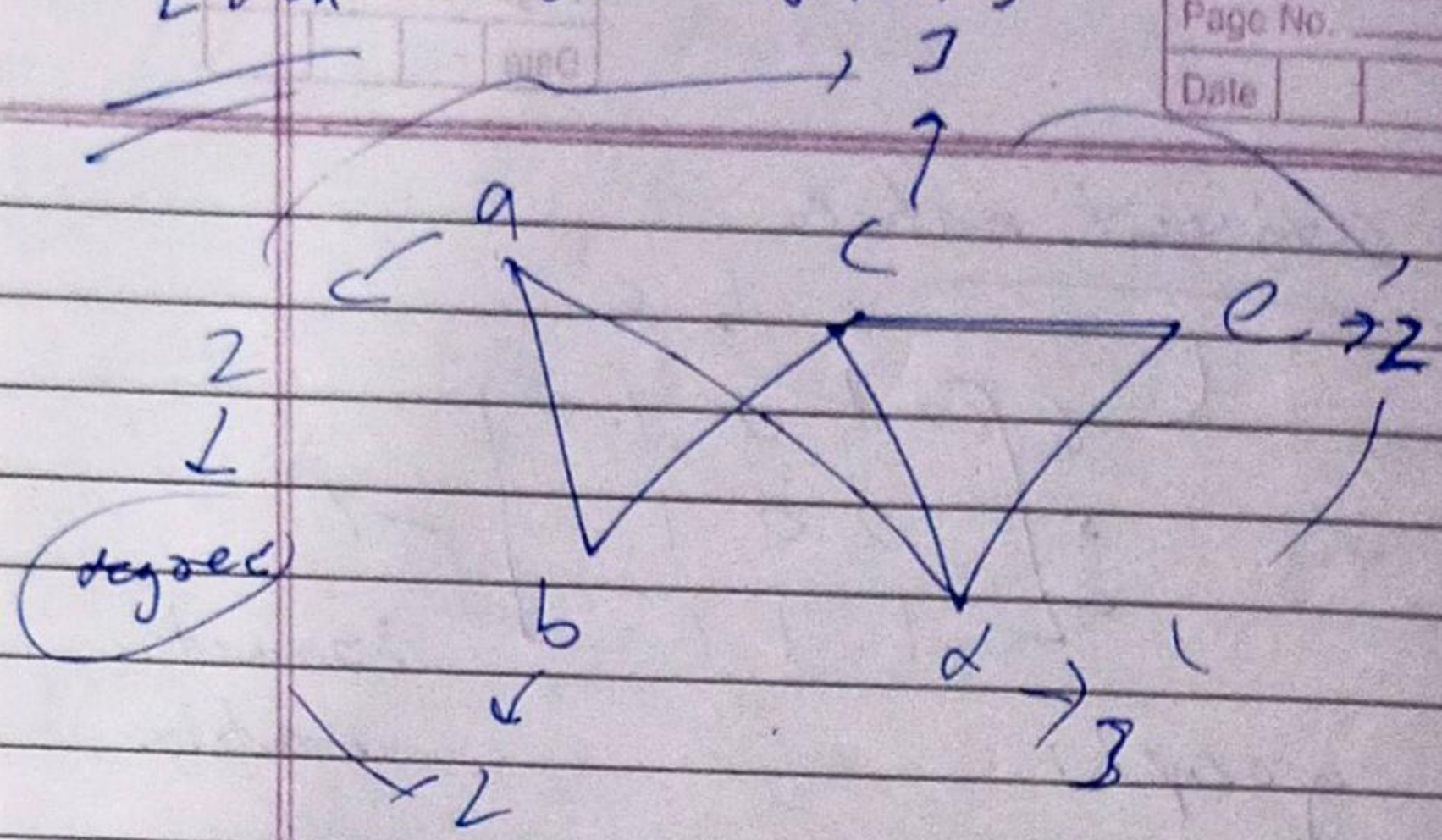


(d)



Theorem: 4

Even & odd vertices



Even vertices → all vertices which have deg as even no.

even vertices ⇒ a, b, e

otherwise odd vertices c, d, e

odd vertices will be in even no.

theorem-2 ⇒ there will be even no. of odd vertices always.

from

$\sum \deg(v) = 2e$ (Even no.)

Sum of degree of vertices = twice no. of edges

$v = v_e + v_o$ → odd vertices

even vertices

$\sum \deg(v_e) + \sum \deg(v_o) = 2e$

↳ Even no.

(8) -
(4) -
(3) -

$15 + 1 = 16$

Page No.
Date

(1) (3) even no. + Σ deg (v_o) = (2e) even

even

• sum of odd nos, odd no of times is odd not even

• If I. add odd no. of times, then it is even.

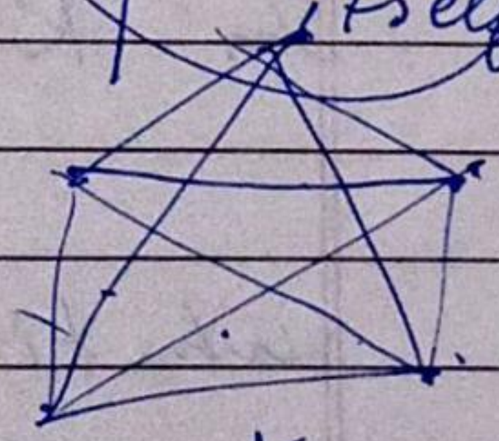
odd vertices should be present in an even no.

Complete graph

every vertex is connected to every other vertex except itself

2:

No. of edges in K_5 → n



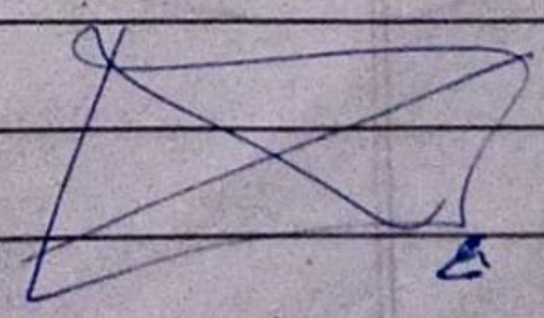
K_5

(a) 20

(b) 40

(c) 5

(d) 16



K_4

Every vertex has same degree = n-1

$\therefore 5 \times 4 = \frac{20}{2} = 10$

$$\sum \deg(v) = 2e$$

$$n(n-1) = 2e$$

$$e = \frac{n(n-1)}{2}$$

$$\Rightarrow \frac{5 \times 4}{2} \Rightarrow 10$$

Theorem: for directed Graph
sum of in-degree = sum of out degree
= No. of Edges

In $K_{10} \Rightarrow \frac{10 \times 9}{2} \Rightarrow 45$ edges

what is the degree of every vertex in complete graph $\Rightarrow (n-1)$

overx

MTH 401

Date:
Page:

28-Sept

Cycle Graph = starts from s (C_n)

graph in the form of cycle

closed form of str.

$n \geq 3$ no. of vertices

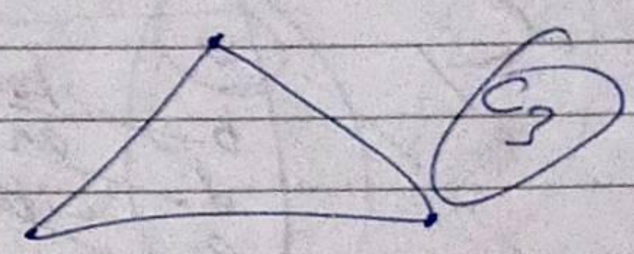
26:32
29:30

- u come back from where v have started

vertices = n

edges = n

$n = 2$ ✗



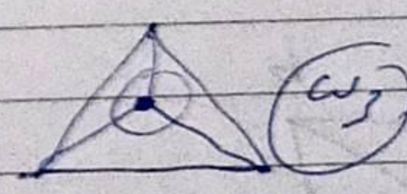
C_3

$n = 3$ $V = 3$

$E = 3$

✗ not a cycle graph

Wheel graph: → extension of cycle graph



W_3 → as extension of C_3

- add a vertex in cycle graph and join it to all other vertices.

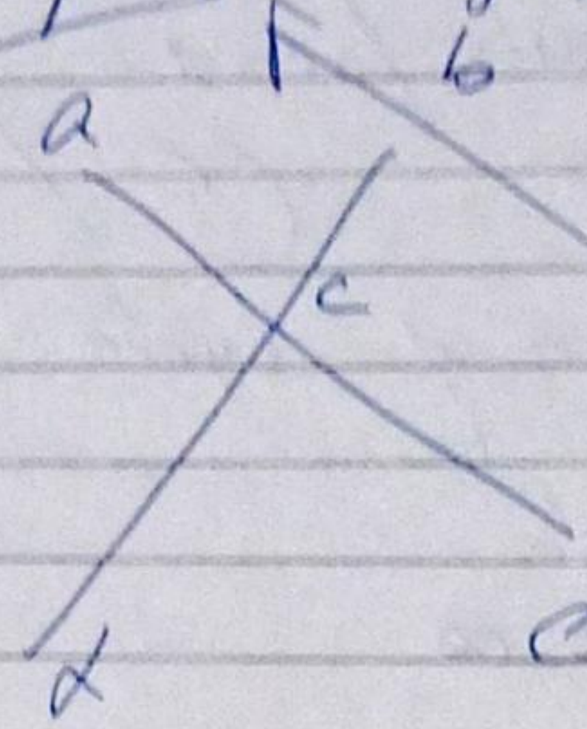
for no values of n this is impossible

Date:
Page:

— Imp

Bipartite graph

(1)

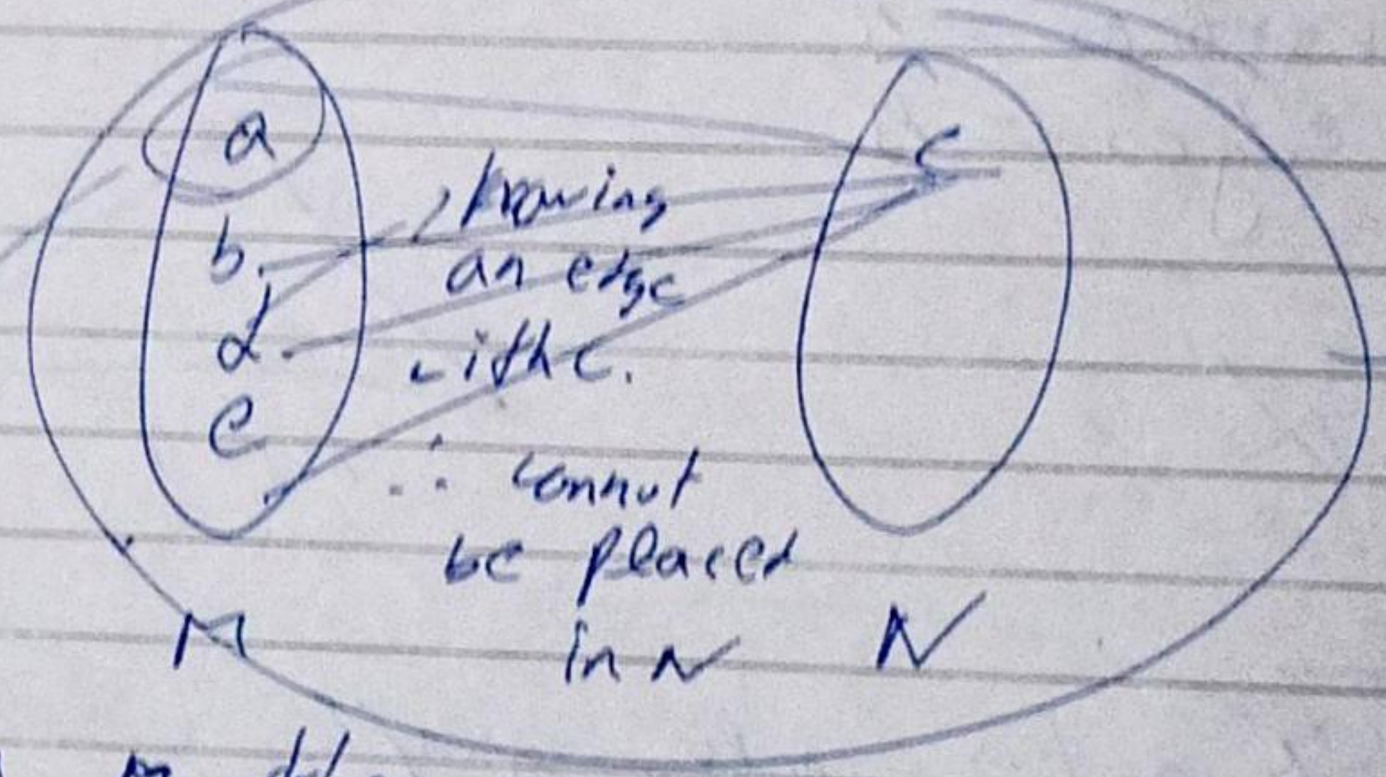


vertex set

$V = \{a, b, c, d, e\}$

This can be drawn as

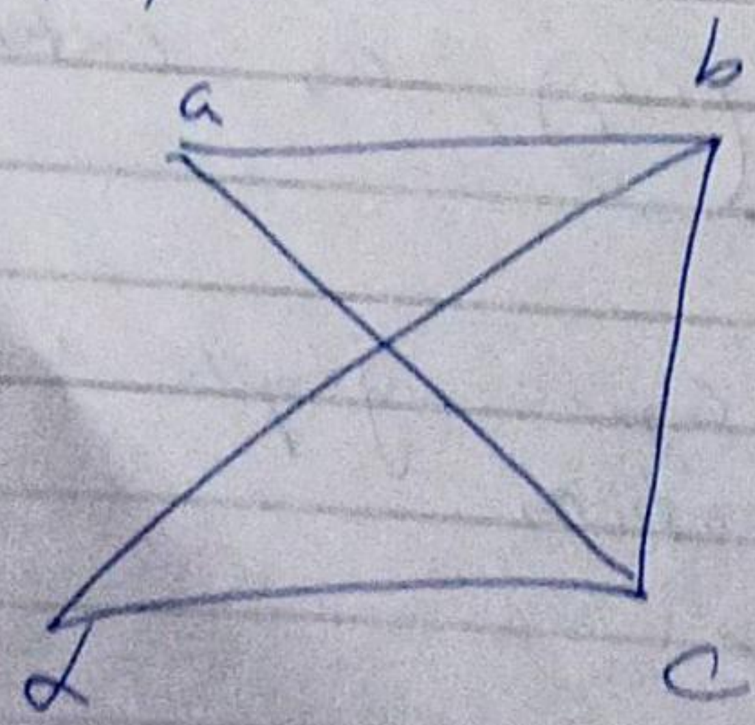
Divide this vertex set into 2^ subsets



If I write 'a' in M then

I write vertices that are not connected to a & b,

(2)

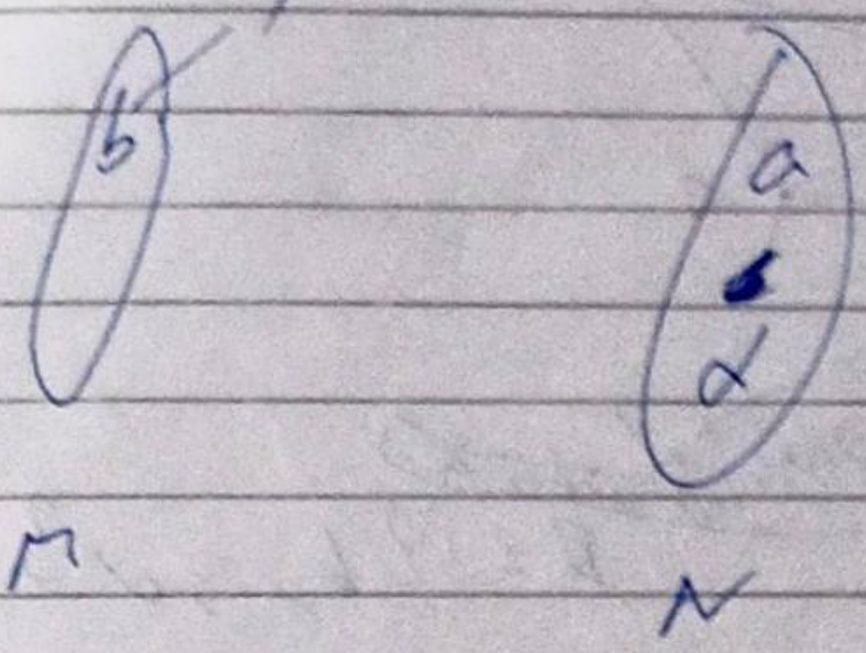


$V = \{a, b, c, d\}$

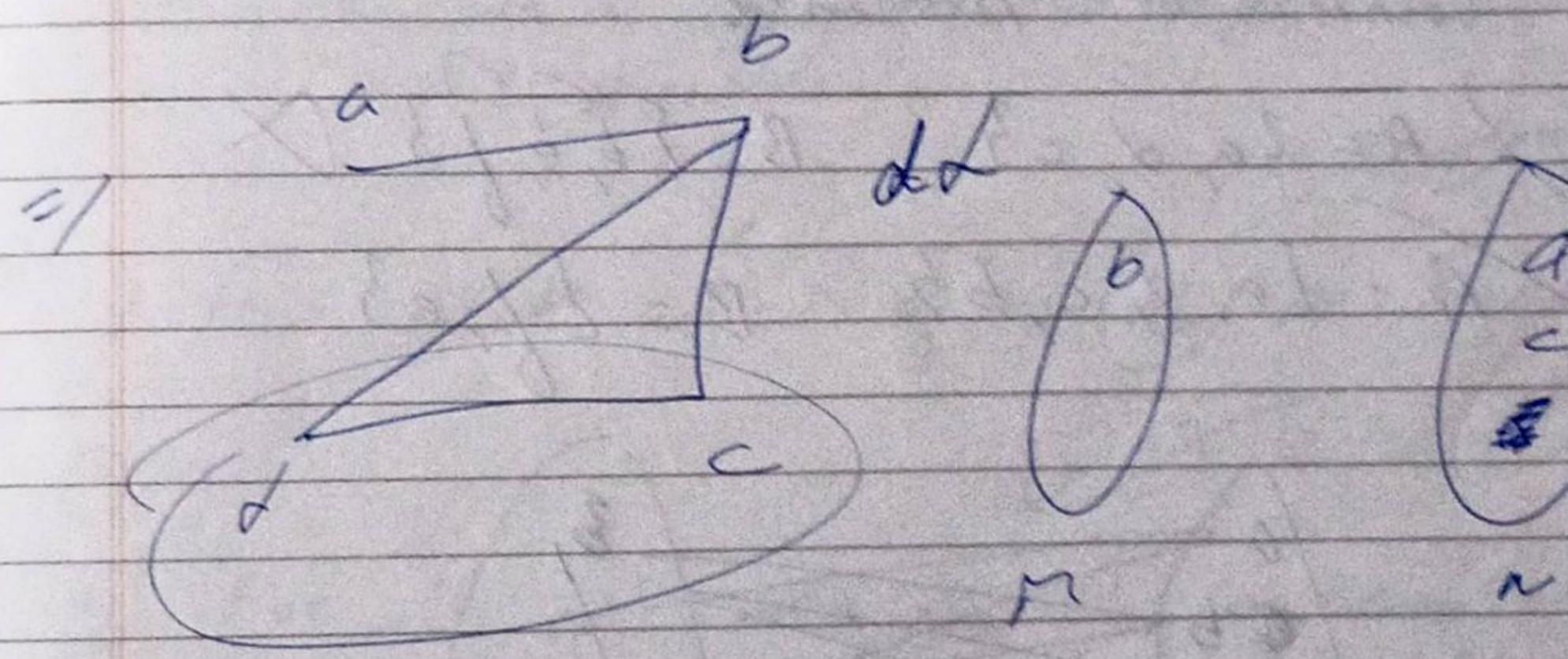
Date:
Page:

constant with any

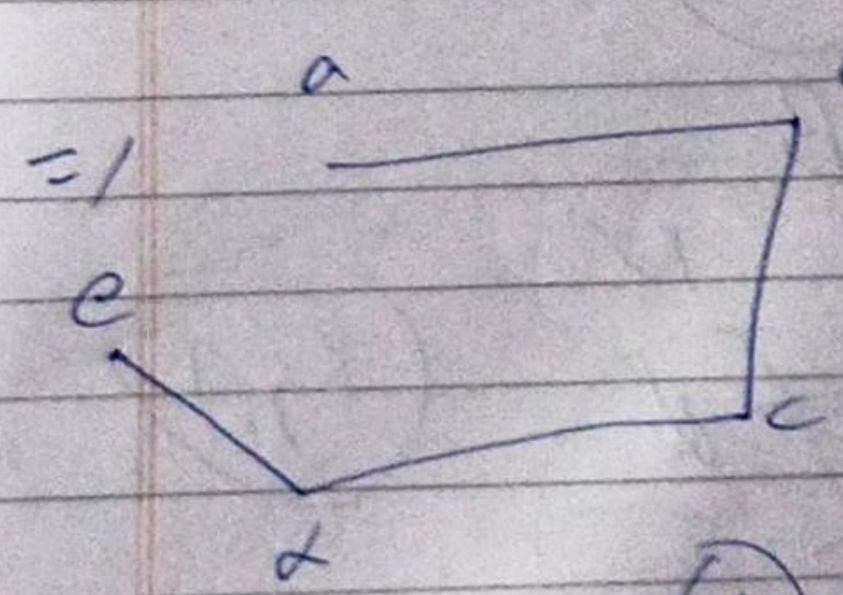
b is connected to a



Not a bipartite graph
because of c

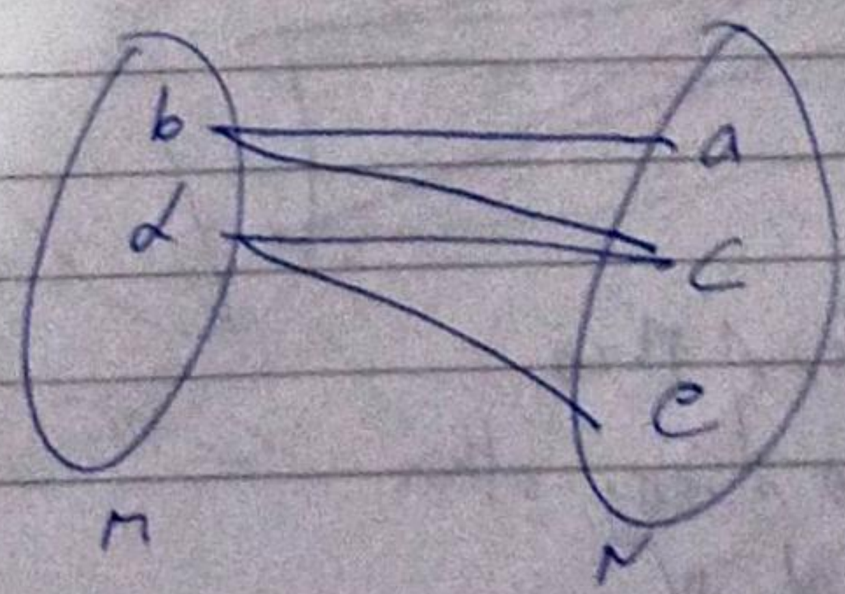


Not a
bipartite graph



$V = \{a, b, c, d, e\}$

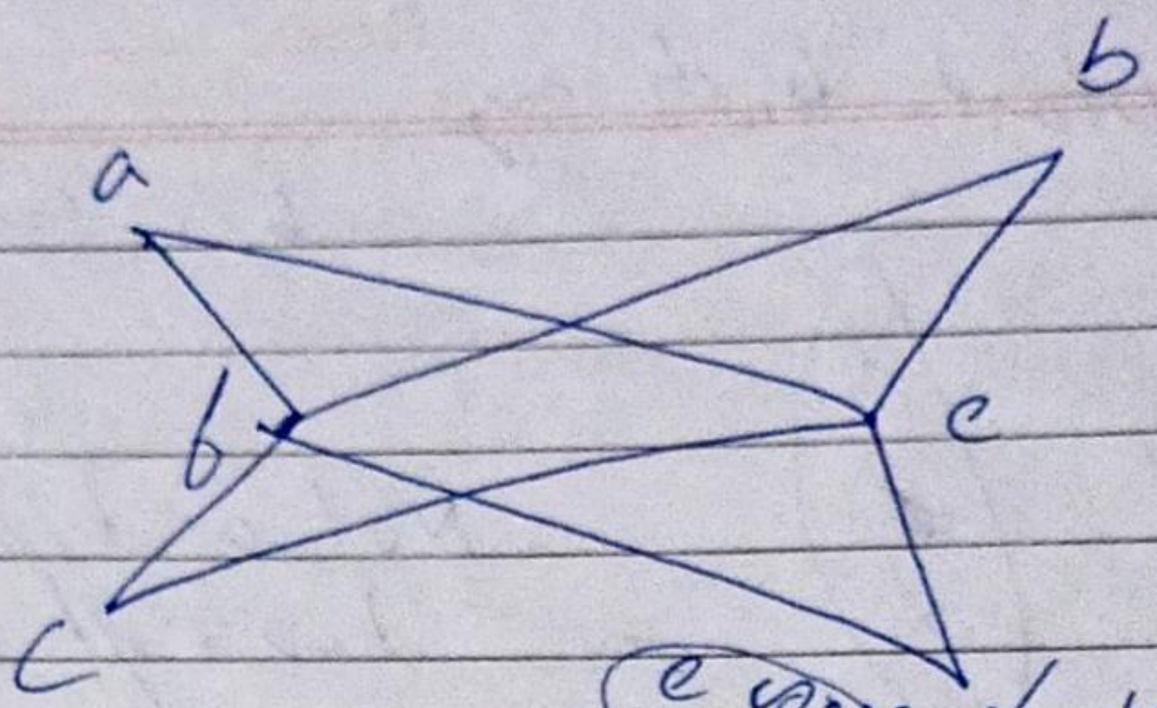
bipartite graph



$M = \{b, d\}$
$N = \{a, c, e\}$

Date:
Page:

Q:



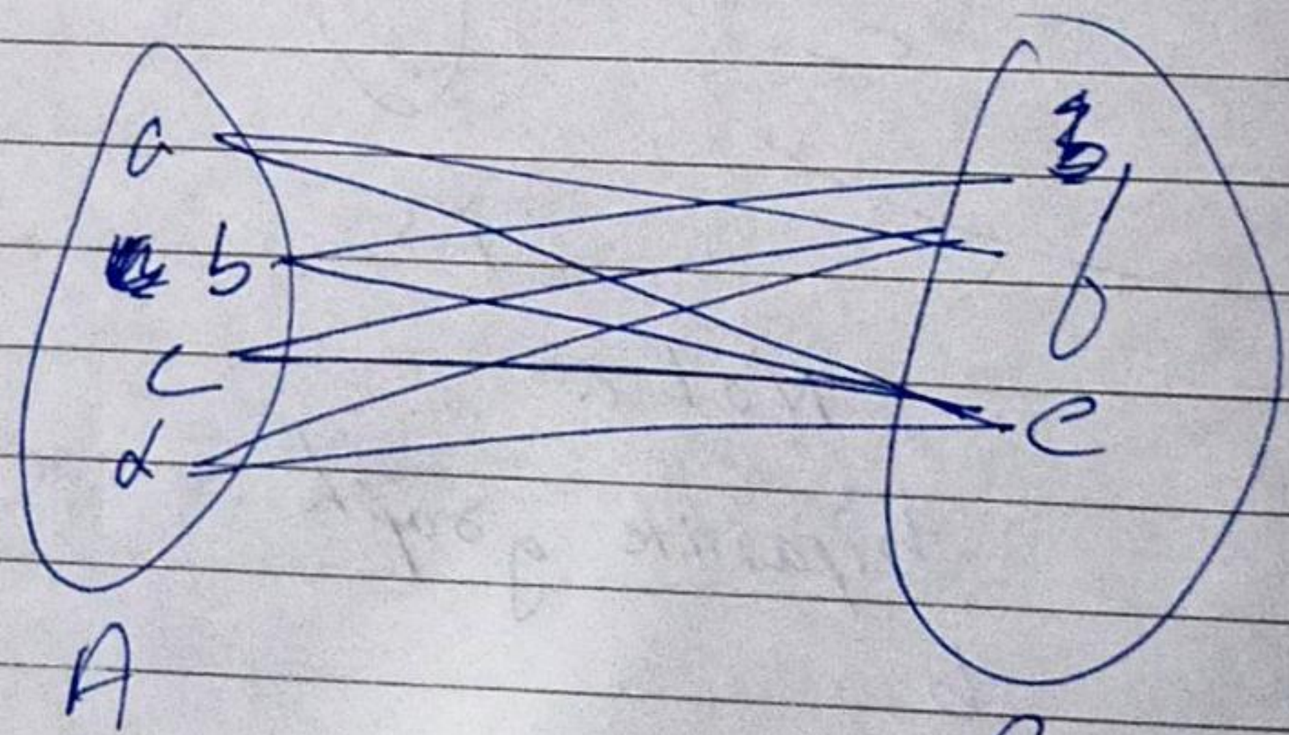
e connected with a

(a) ✗ $A = \{a, e, f\}$ $B = \{b, c, d\}$

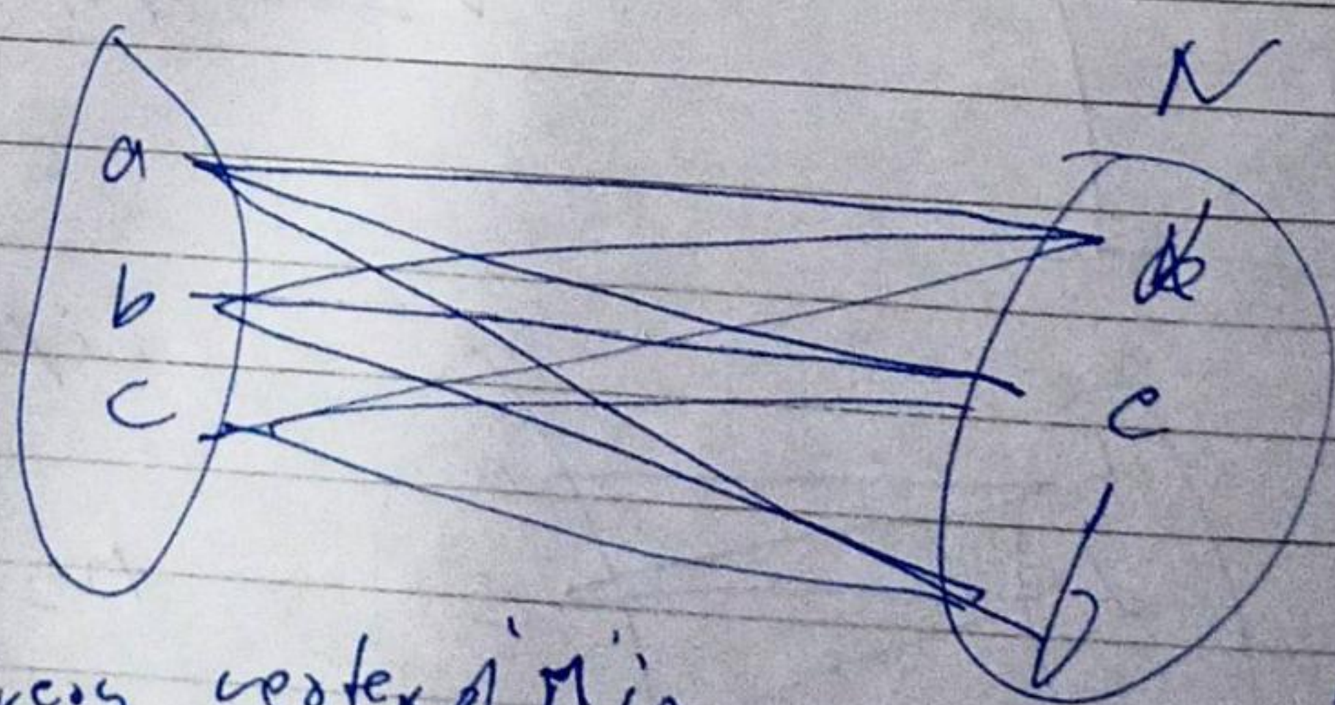
(b) Cannot be partitioned

(c) ✗ $A = \{a, d, c\}$ $B = \{b, e, f\}$ ✗

(d) $A = \{a, d, c, b\}$ $B = \{f, e\}$



Q:



$K_{3,3}$

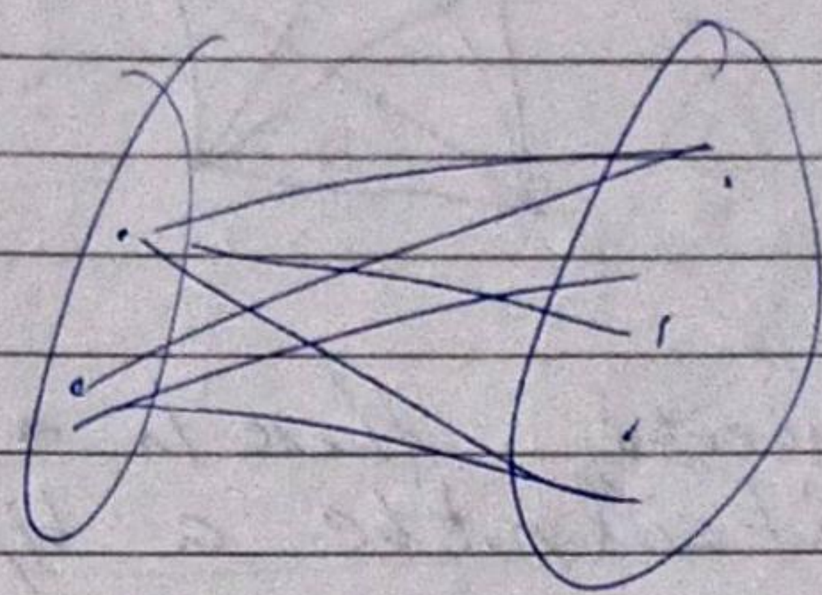
Every vertex of M is connected to every other vertex of N

complete bipartite graph

$K_{M,N}$

Date:
Page:

$K_{2,3}$



- A given can be bipartite or complete bipartite or not a bipartite.

Q: ⇒ For what values of n, (K_n) is bipartite. (complete graph)

(a) 4 (c) 2

(b) For all odd values of n (K_n) can never be a bipartite, not a bipartite graph

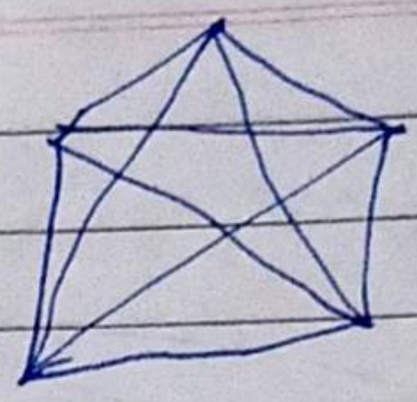
K_1 ✗

K_2 a b ⇒ a b bipartite graph.

K_3 a b c a b ✗

K_4 a b c d a b ✗

$K_3 = C_3$

$K_5 =$ 

- whenever there is a cycle of length 3, it will not be a bipartite

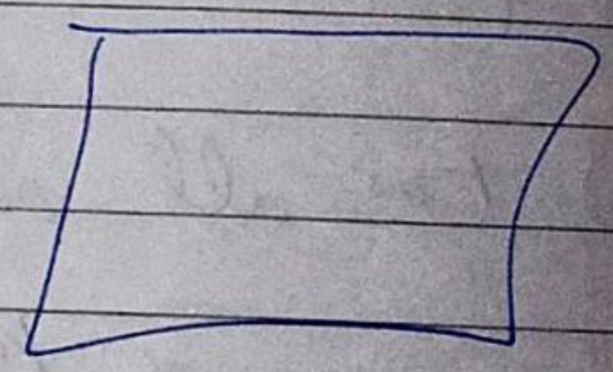
2: for what values of n, C_n is bipartite

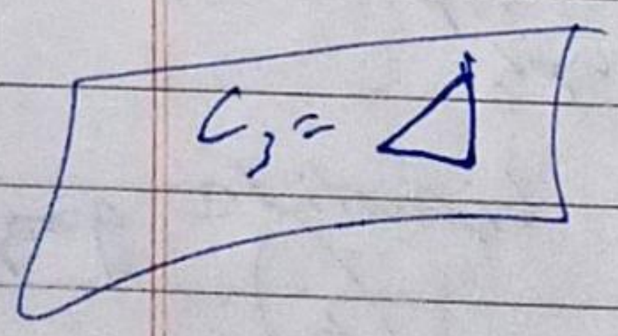
(a) $n=3$

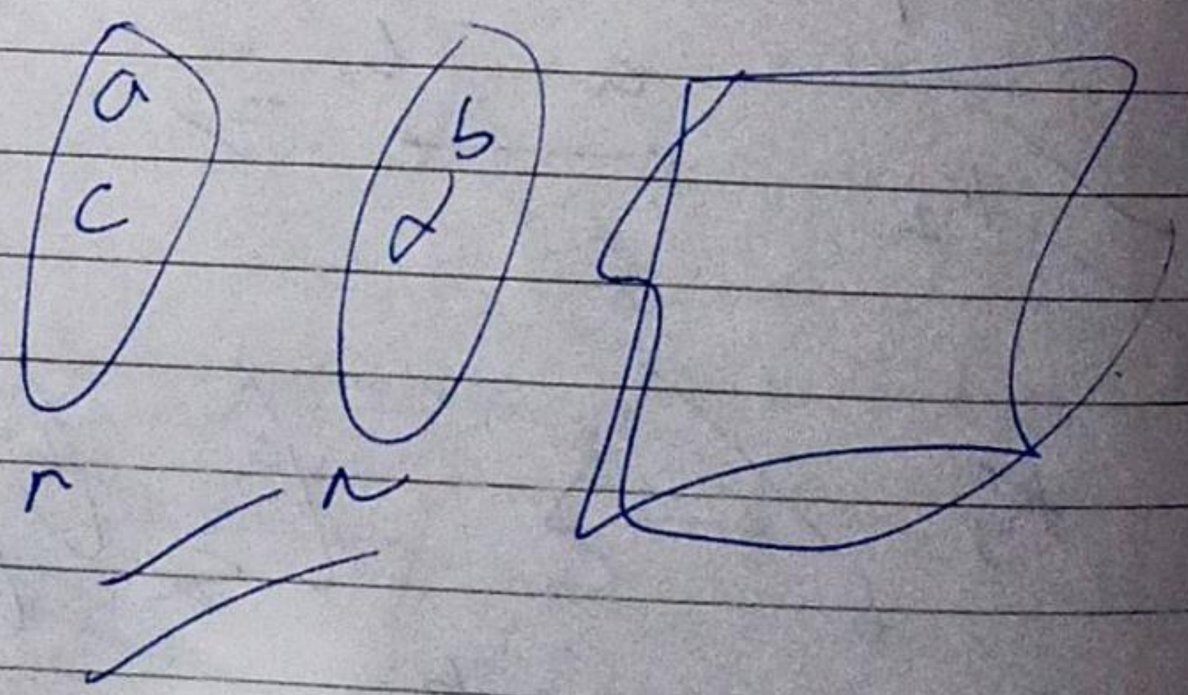
(b) all even values of n

(c) " odd " " "

(d) Cannot be partitioned

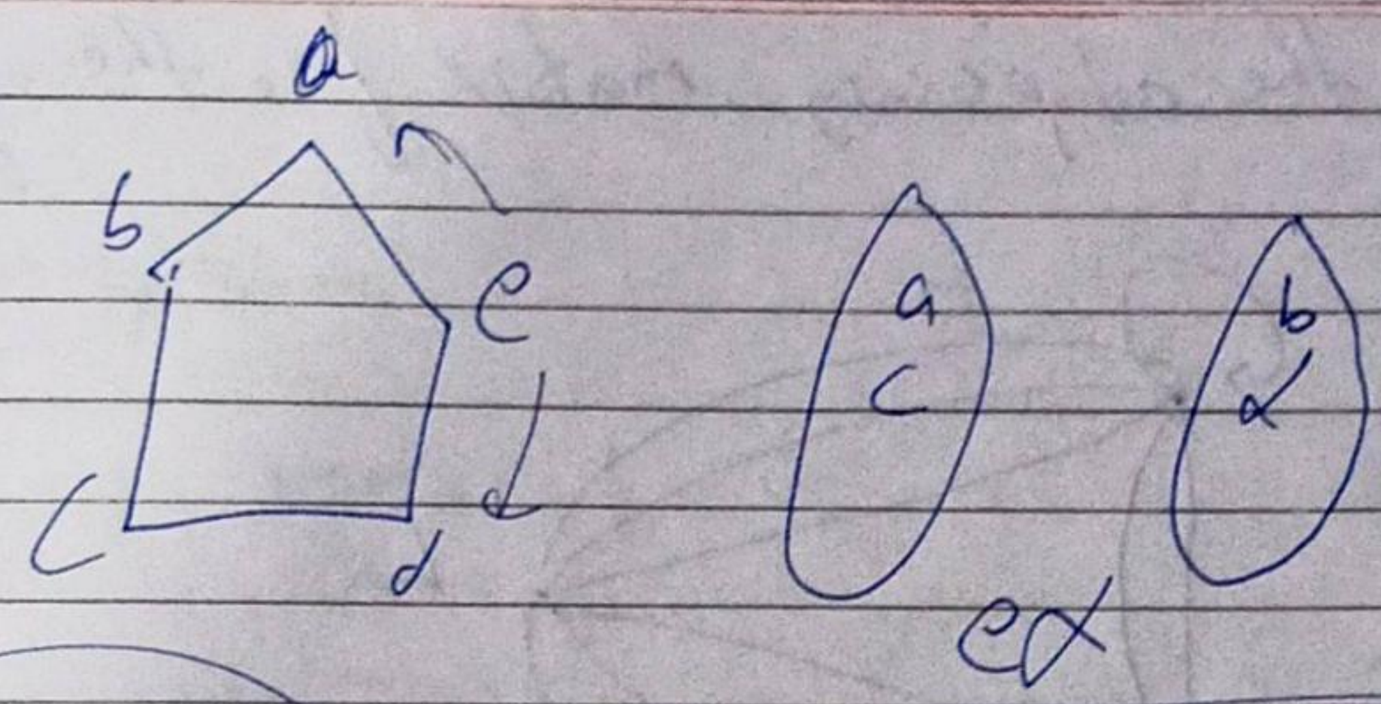






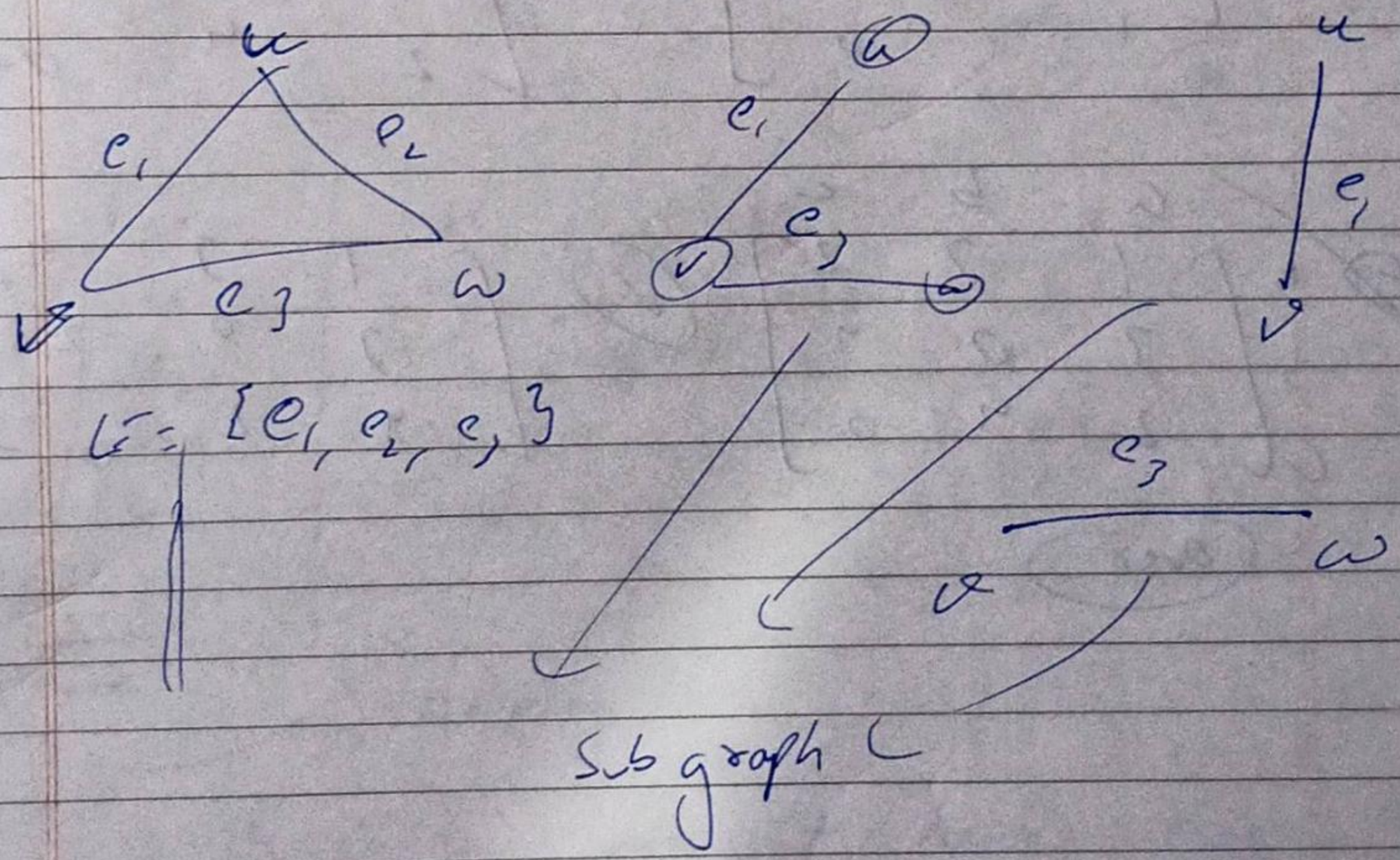
Date:
Page:

C_5



⇒ Subgraph = [a part of the graph]

1. Any subset from the vertex set
2. " " " " edge "

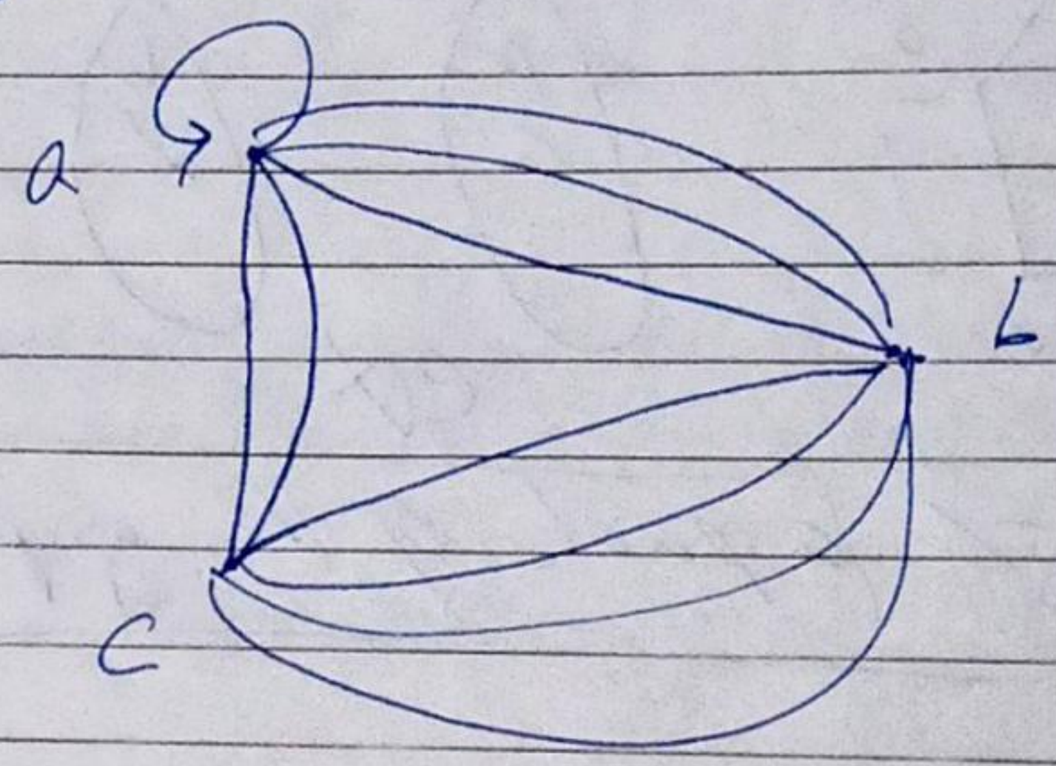


$E = \{e_1, e_2, e_3\}$

Subgraph C

List of vertices adjacent to each other

Q5 Find the adjacency matrix for the following graph



(a) $\begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix}$ (b) $\begin{bmatrix} 0 & 2 & 2 \\ 2 & 0 & 4 \\ 2 & 4 & 0 \end{bmatrix}$

(c) $\begin{array}{c} \\ a \\ b \\ c \end{array} \begin{array}{c} \begin{array}{ccc} a & b & c \end{array} \\ \begin{bmatrix} 1 & 3 & 2 \\ 3 & 0 & 4 \\ 2 & 4 & 0 \end{bmatrix} \end{array}$ (d) $\begin{bmatrix} 1 & 3 & 4 \\ 3 & 0 & 2 \\ 4 & 2 & 0 \end{bmatrix}$

Over

Date:
Page:

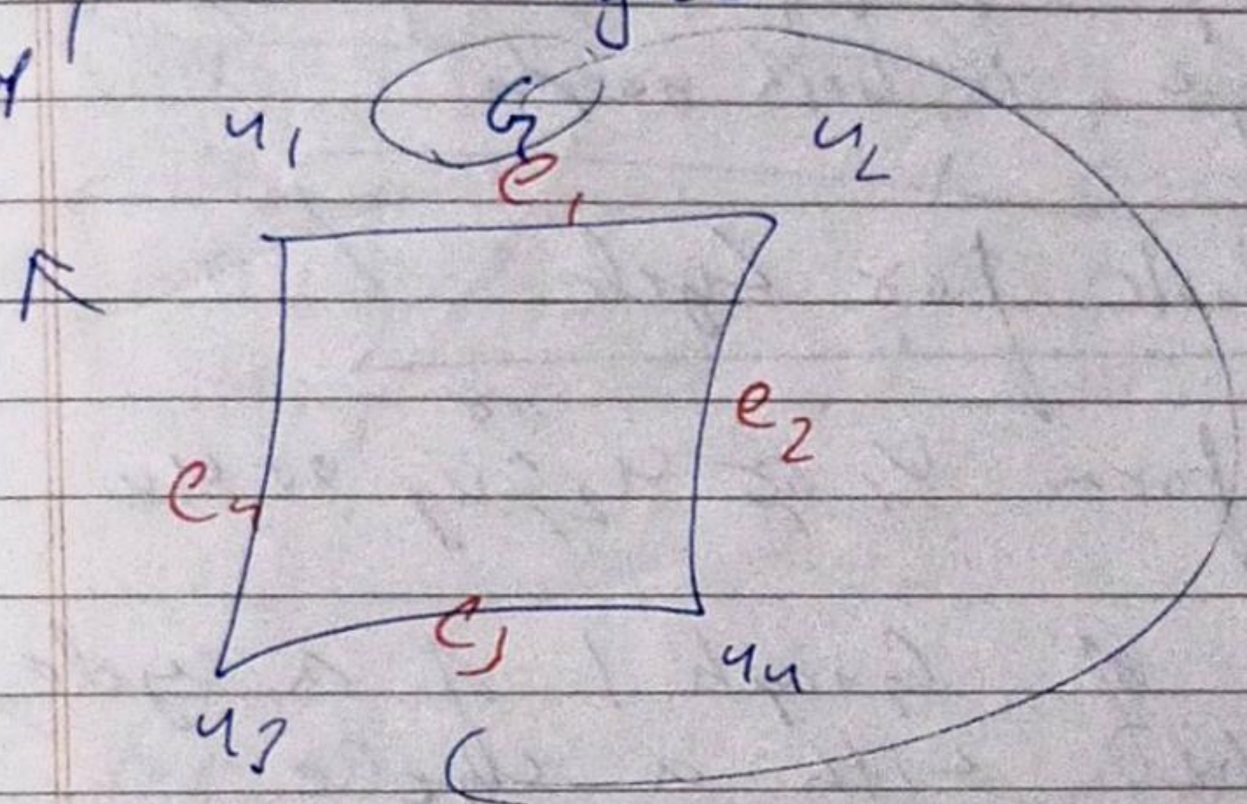
29-Sept

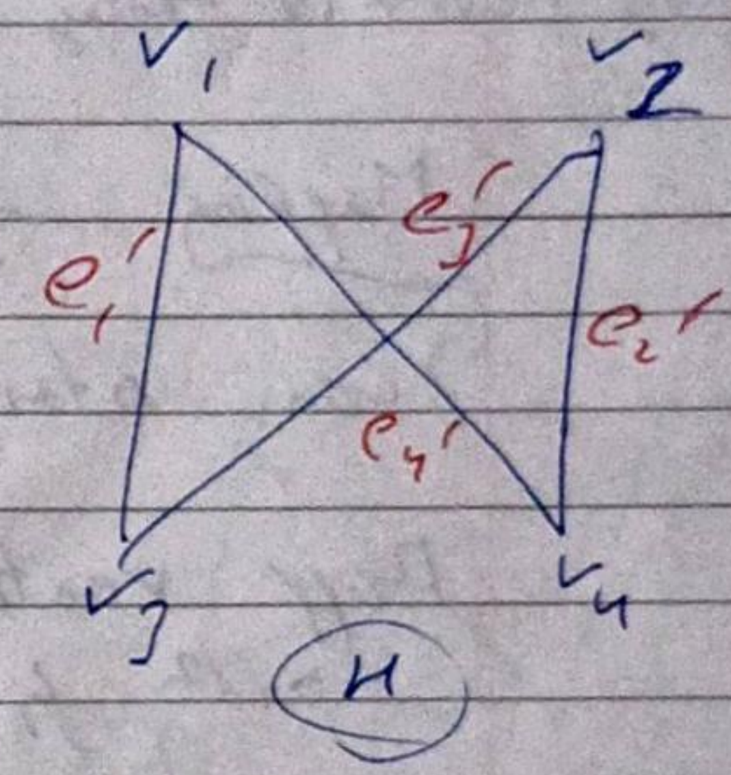
Isomorphism

· vertices
· edges
· degree

} fully I/O 2 graphs

Graph 1 | Graph 2





G	H	OR
u_1	v_3	v_3
u_2	v_2	v_1
u_4	v_4	v_4
u_3	v_1	v_2

Cycle

~~vertex~~ node

→ mapping

u_1 & u_4 are not having edge
∴ v_3 & v_4 should not have edge

see from 4 to 10

① No. of vertices → G (V = 4), H (V = 4)

② No. of Edges → G (E = 4), H (E = 4)

③ Deg of G ($u_1 \to 2$, $u_2 \to 2$, $u_3 = 2$, $u_4 = 2$)

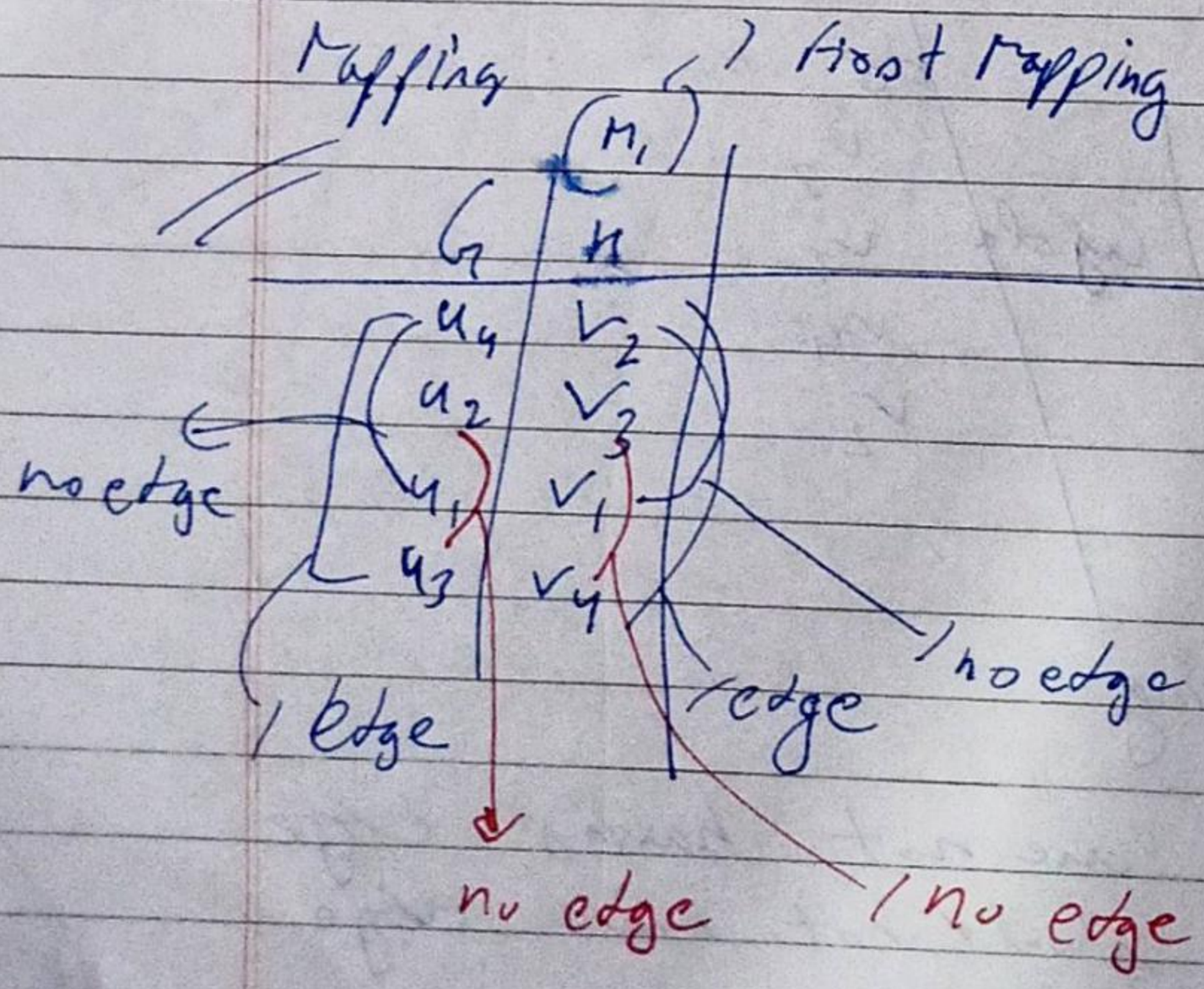
H ($v_1 \to 2$, $v_2 \to 2$, $v_3 = 2$, $v_4 = 2$)

Every vertex is having deg 2 in both graphs

Mapping ⇒ $\boxed{\text{look for Cycle}}$

can start from v_1 or u_2 or v_3 or u_4

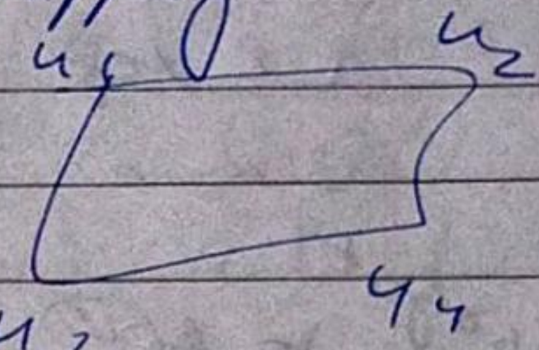
Map vertices of Graph 1 of a cycle with Graph 2 with a cycle



Date:
Page:

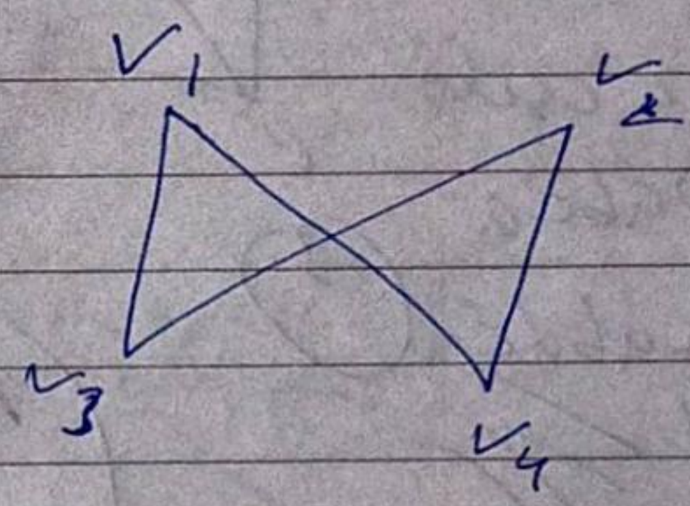
Adjacency Matrix –

For Adj Matrix, order of vertices should be same as taken in mapping



For G

	u_4	u_2	u_1	u_3
u_4	0	1	0	1
u_2	1	0	1	0
u_1	0	1	0	1
u_3	1	0	1	0



For H

	v_2	v_3	v_1	v_4
v_2	0	1	0	1
v_3	1	0	1	0
v_1	0	1	0	1
v_4	1	0	1	0

Isomorphic sign

$G \cong H$ G is Isomorphic to H

Adjacency is a Check to mapping

The orders on the column side, should be same as row side

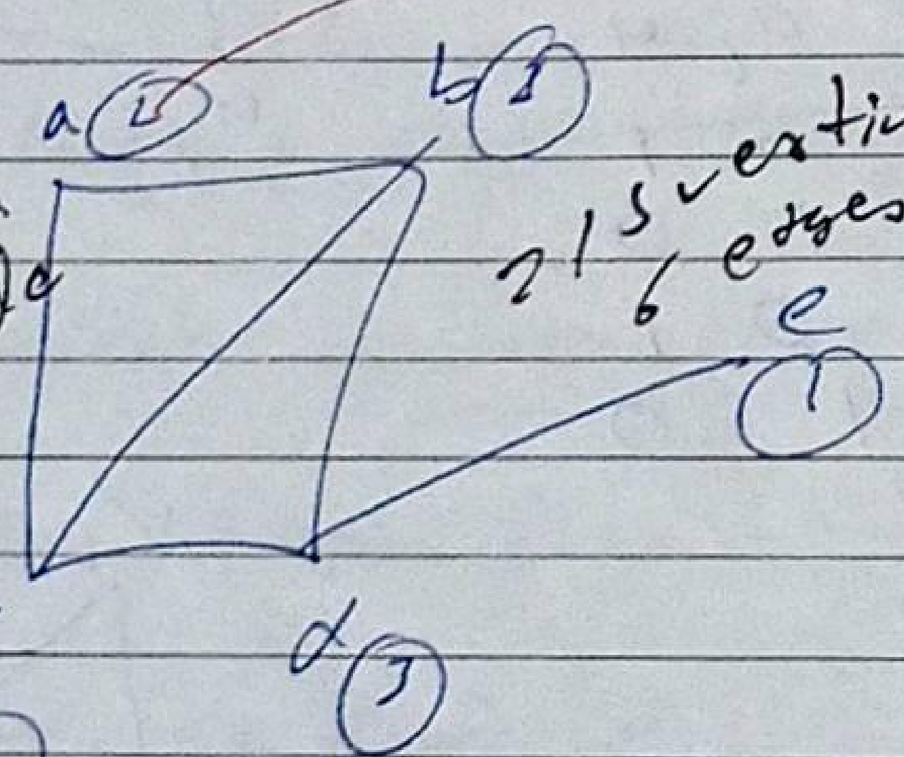
Date:
Page:

from 26

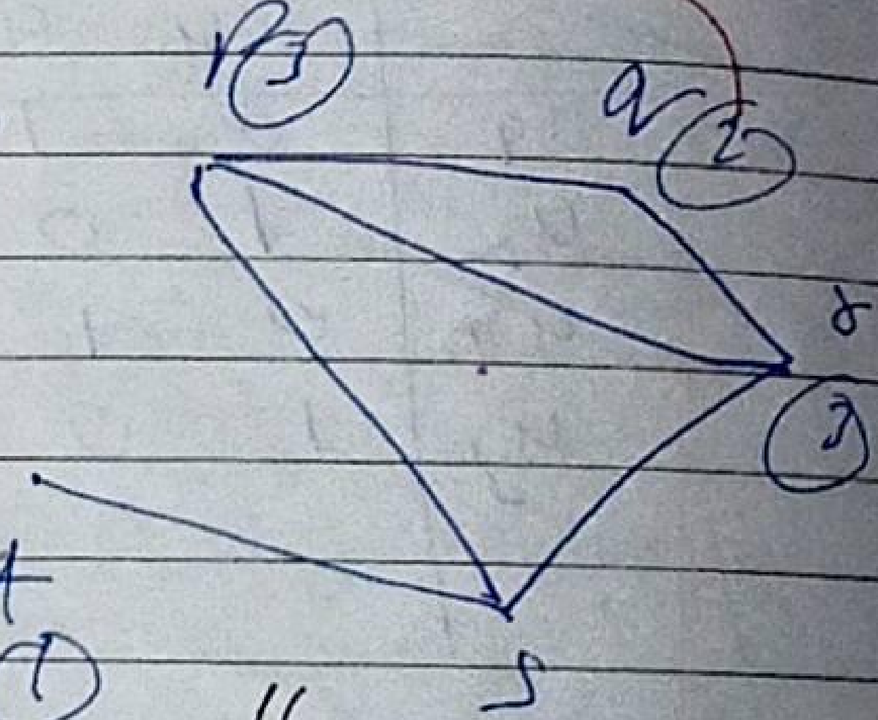
a 3 deg vertex will be mapped with
" " "

a 2 deg " " " " "
2 " " "

I forgot to a
I have to a cycle



2 | 5 vertices
6 edges



2 cycle
(1) abca
(b) abdca

5 vertices
6 edges

A

B

no edge

no edge

A	B
a	q
b	p
d	s
c	r
c	t

2 deg
1 edge
1 edge
1 deg
1 deg
1 deg

q r s p q o r

q p s r q

1 take cycle of max. length (elements)

- Cycle is to mapped with the cycle
- It is not necessary that every edge make a cycle

→ this mapping will be verified by adj. matrix.

(A)

	a	b	d	c	e
a	0	1	0	1	0
b	1	0	1	1	0
d	0	1	0	1	1
c	1	1	1	0	0
e	0	0	1	0	0

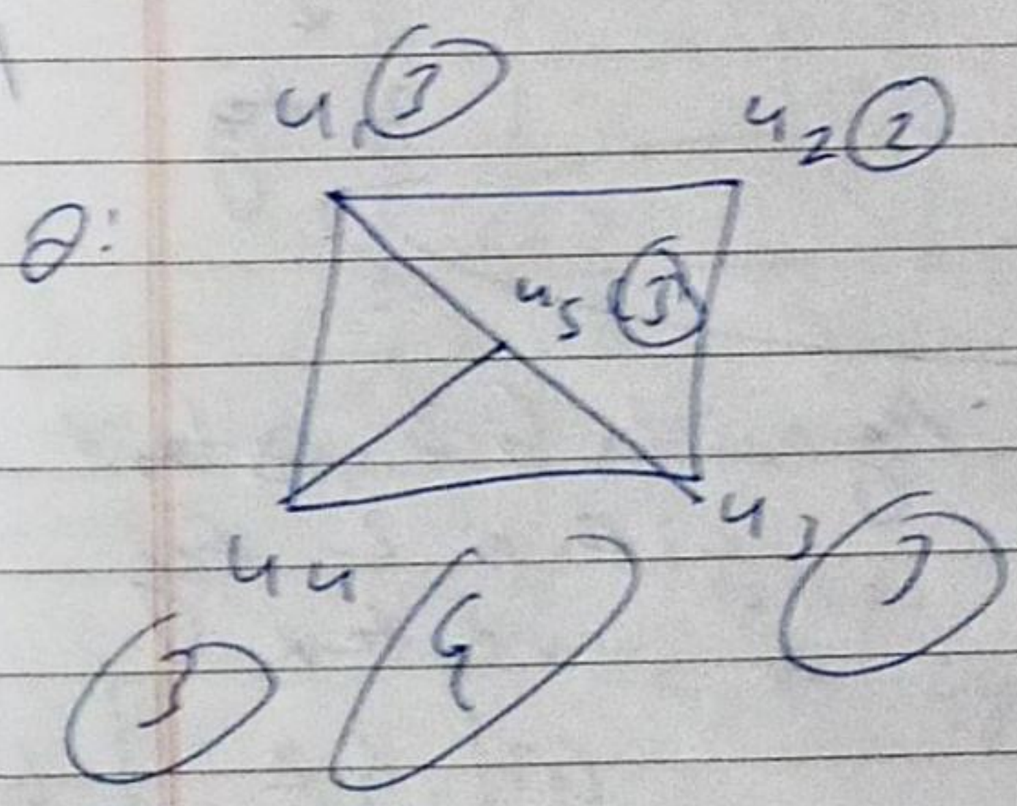
(B)

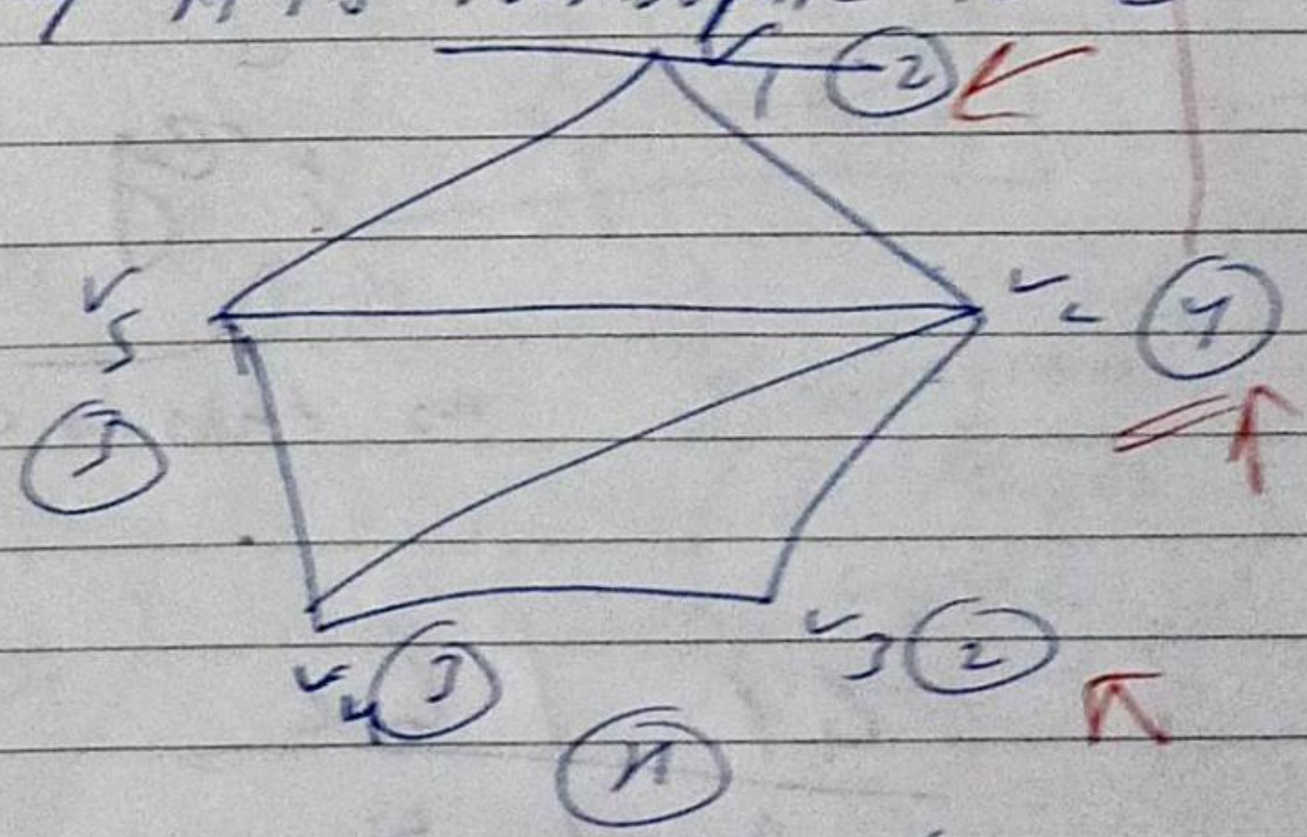
	q	p	s	o	t
q	0	1	0	1	0
p	1	0	1	1	0
s	0	1	0	1	1
o	1	1	1	0	0
t	0	0	1	0	0

$A \cong B$ ∴ Not Isomorphic

Basic condition of deg is not fulfilled.

↳ A is isomorphic to B





cycle ⇒ (1) $G(u_1, u_5, u_2, u_3, u_4) \to H(v_1, v_2, v_3, v_4, v_5)$

✗ (2) $G(u_1, u_2, u_3, u_4, u_5) \to H(v_1, v_5, v_2, v_4, v_3)$

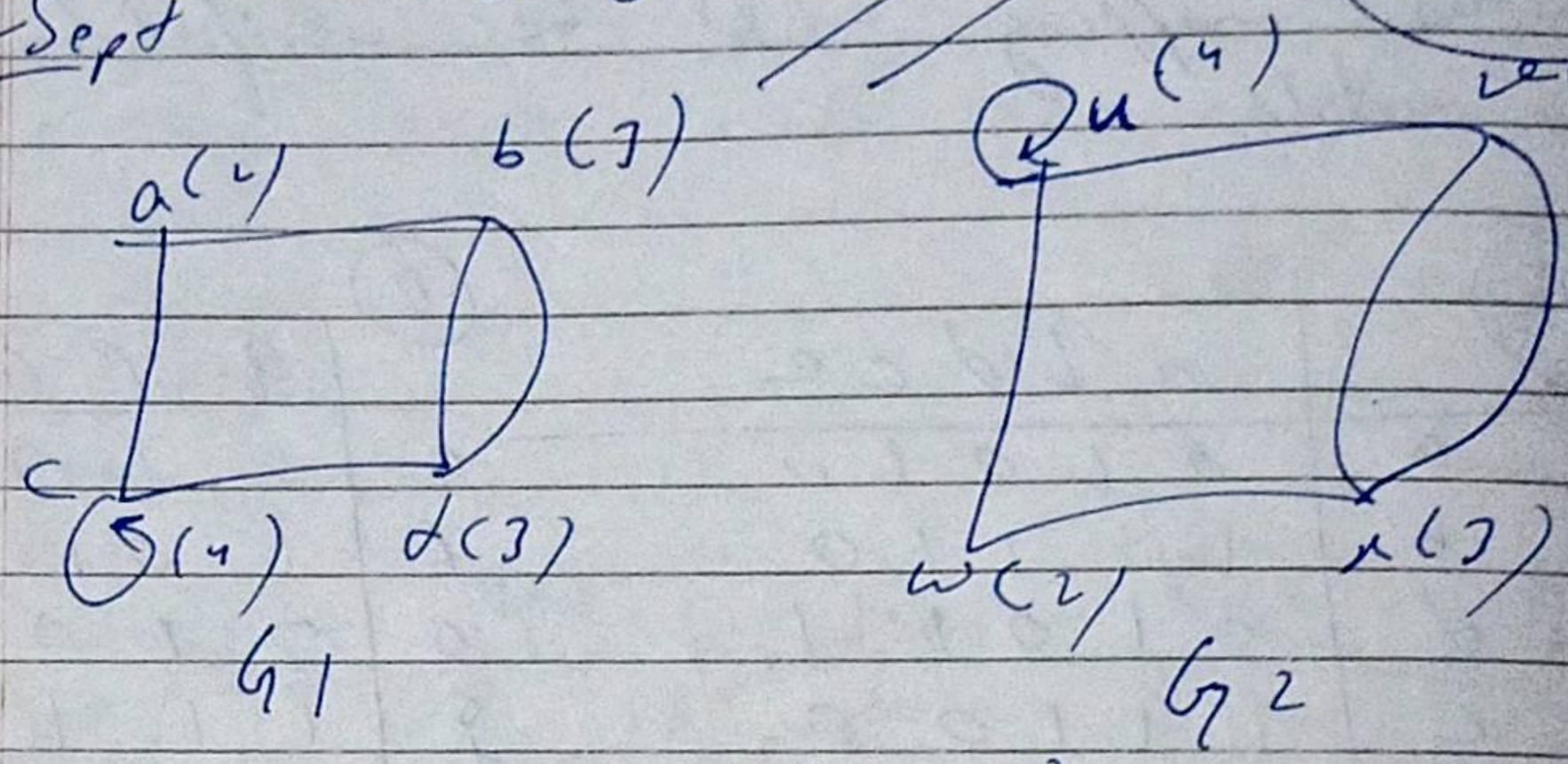
✗ (3) $G(u_3, u_5, u_4, u_1, u_2) \to H(v_4, v_5, v_1, v_2, v_3)$

(4) Not Isomorphic

~~10am to 12~~

30 - Sept

Pseudo graph
loops & multiple edges



No. of vertices → G1 (4) & G2 (4)

No. of edges → G1 (6) & G2 (6)

cycle → G1 (a, b, d, c) → G2 (w, x, v, u)

2 deg

2 deg

as this is 2 deg, in G2 start with a 2 deg vertex.

G1	G2
a	w
b	x
d	v
c	u

G1	G2	G2
3 - b	x	x
2 - a	v	w
4 - c	u	u
3 - d	w	v

2 deg

3 2 deg

Adjacency matrix

Date:
Page:

two Isomorphic

	a	b	d	c
a	0	1	0	1
b	1	0	2	0
d	0	2	0	1
c	1	0	1	1

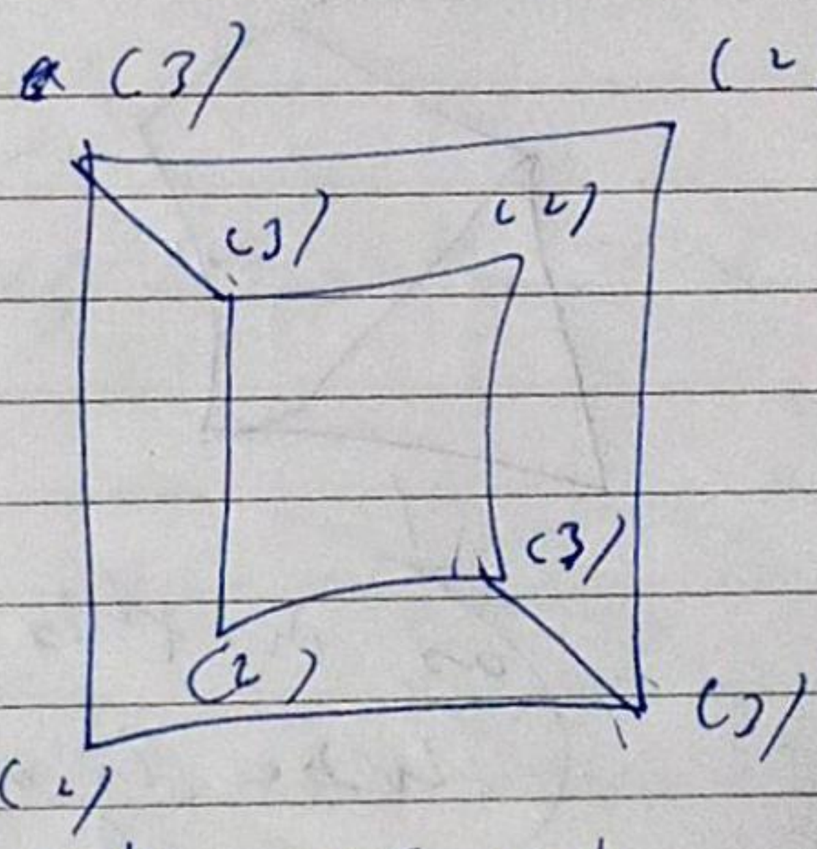
	w	x	v	u
w	0	1	0	1
x	1	0	2	0
v	0	2	0	1
u	1	0	1	1

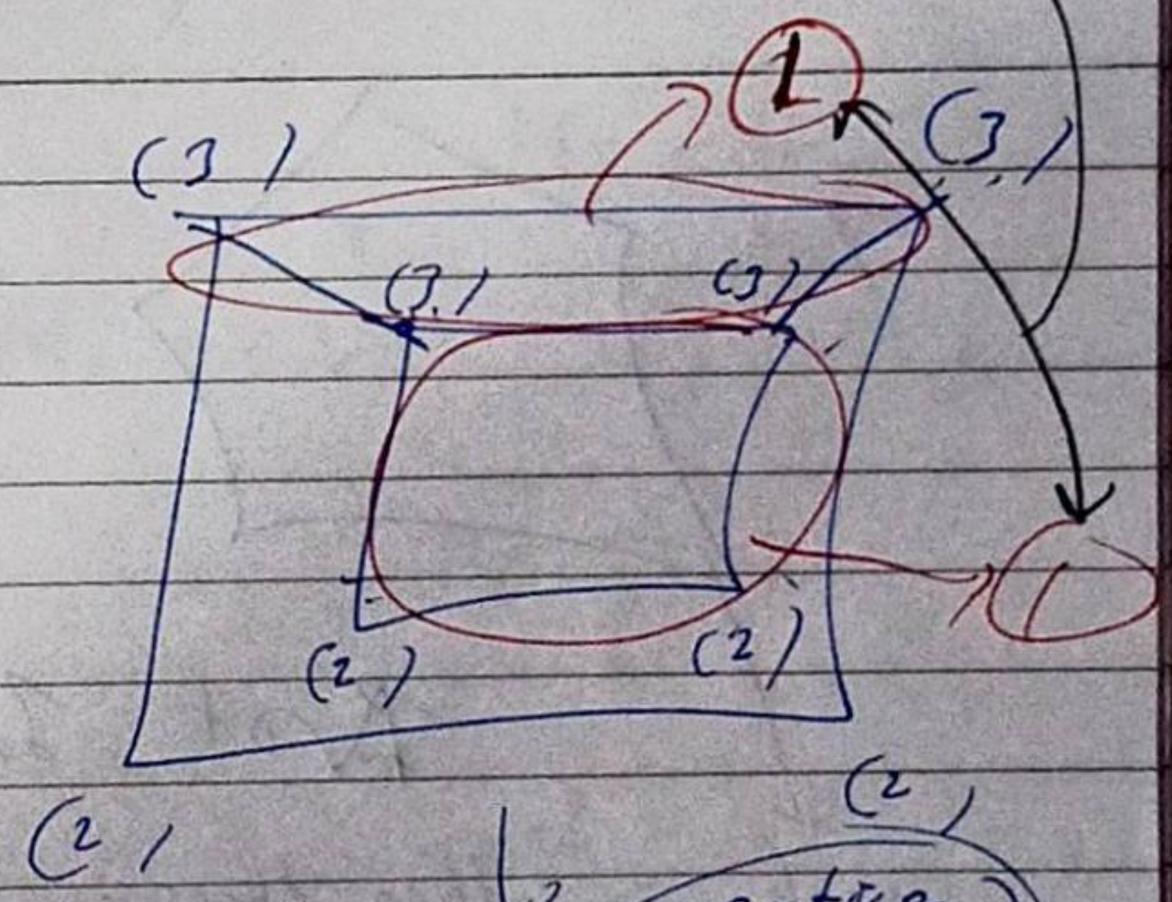
$G \cong H$

deg is 2
edge is
] etc

2, 4 length cycle

Q:





Q: Isomorphic or not

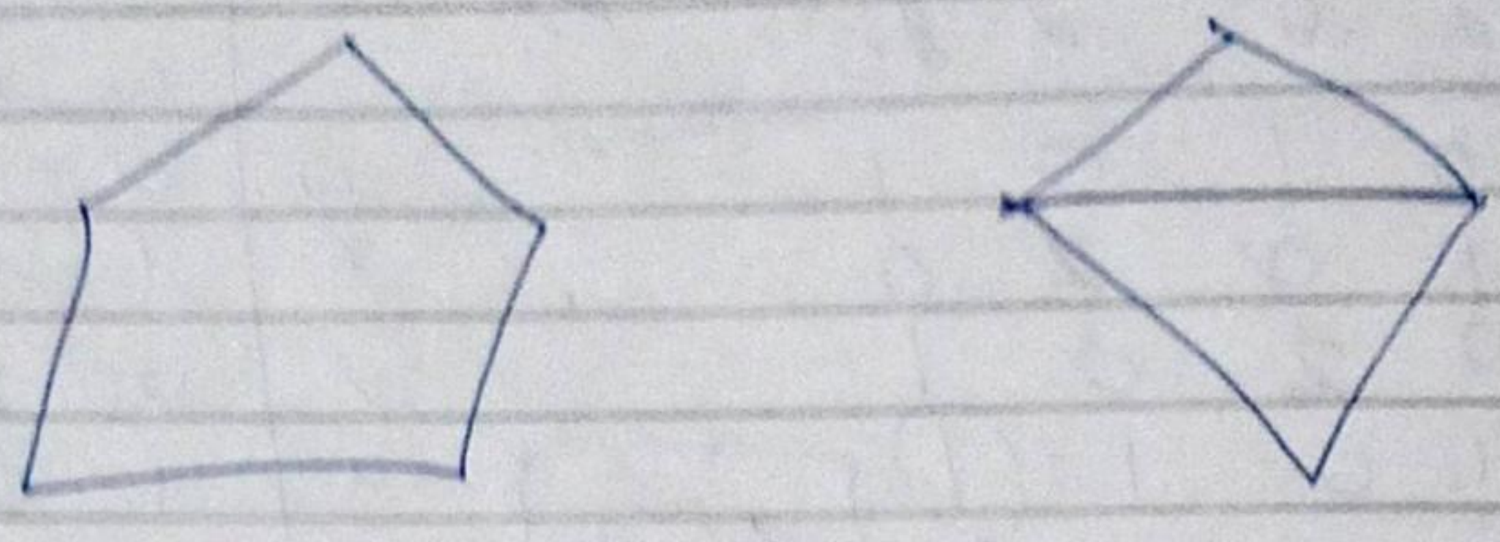
(4 vertices
length cycle)

(4 vertices.
2 length
cycle

→ shoot trick

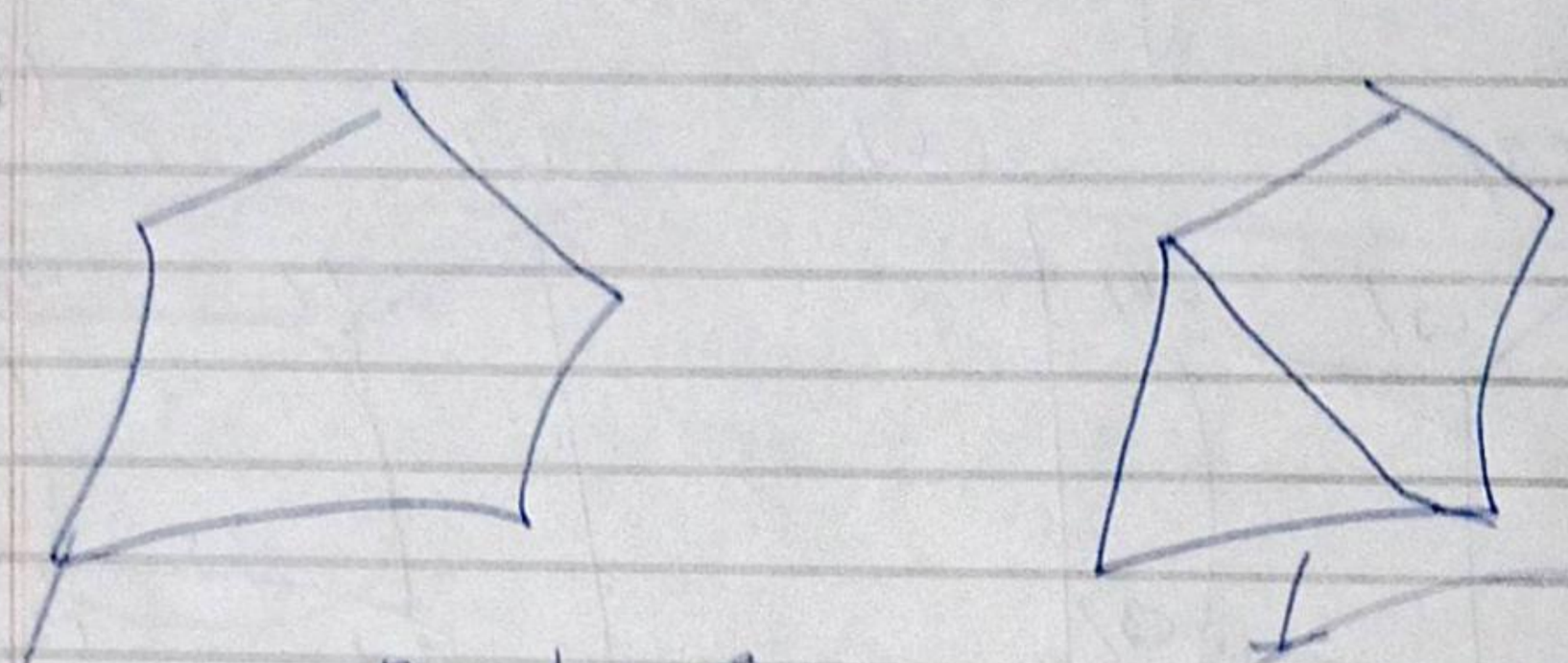
Not Isomorphic

=)



Not Isomorphic

=)

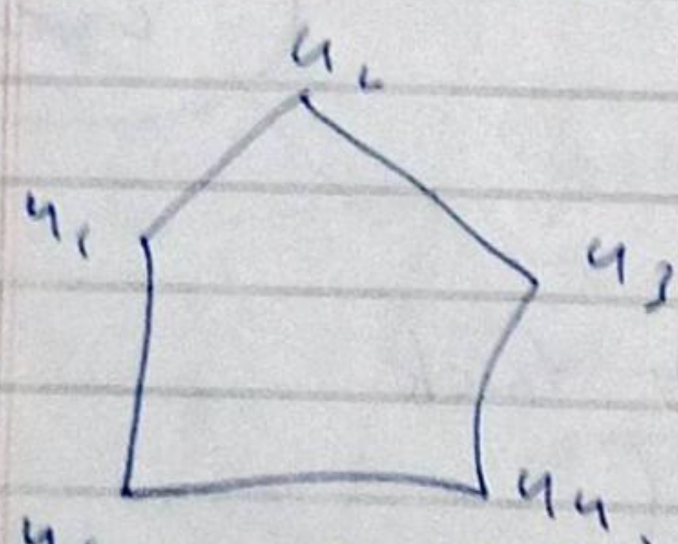


Not Iso

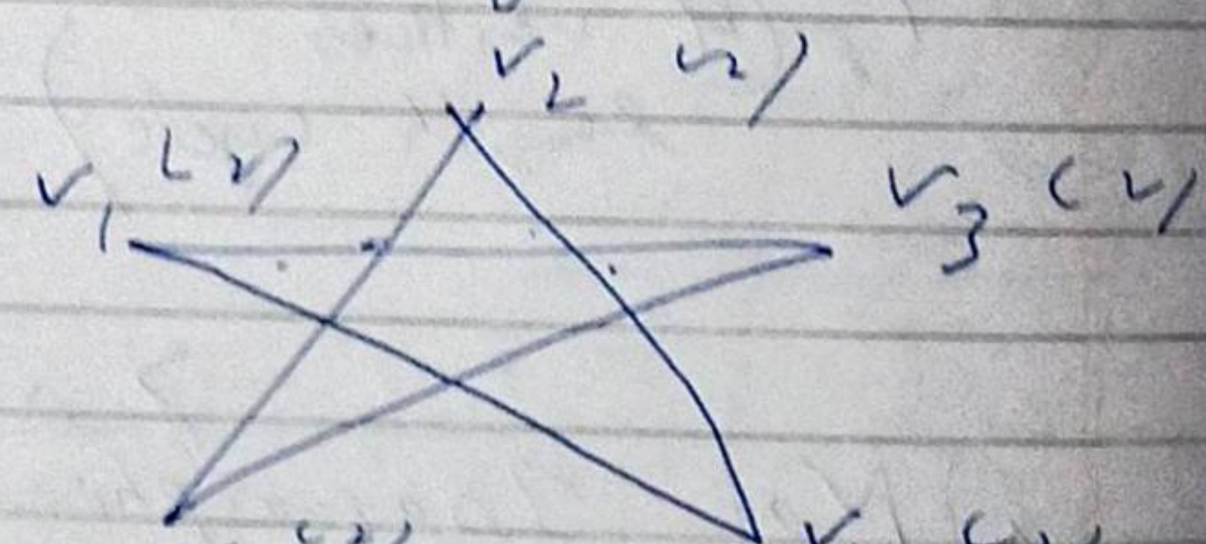
but in this there is no cycle of 3 ele.

as in this there is a cycle of 3 elements

=)



G (V=5) (E=5)



H (V=5) (E=5)

① vertices =5

② Edges =15

① Deg.

② Cycle

③ mapping

Date:
Page:

(a) $u_2 - v_2$, $u_3 - v_3$, $u_4 - v_4$, $u_5 - v_5$, $u_1 - v_1$

(b) $u_1 - v_1$, $u_2 - v_2$, $u_3 - v_3$, $u_4 - v_4$, $u_5 - v_5$

(c) $u_1 - v_5$, $u_5 - v_2$, $u_4 - v_3$, $u_2 - v_4$, $u_3 - v_1$

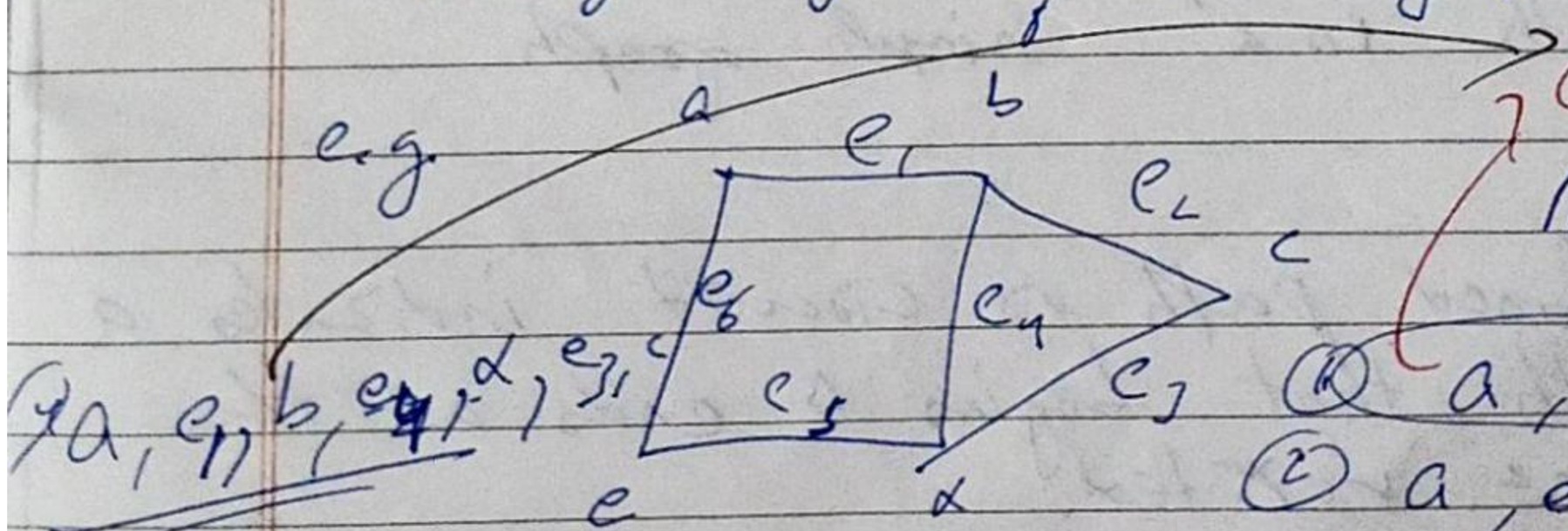
(d) $u_5 - v_2$, $u_1 - v_4$, $u_2 - v_1$, $u_3 - v_3$, $u_4 - v_5$

Ans: — — way

Path: A Connectivity in a graph

A path is a sequence of edges that begins at a vertex of a graph & travels from vertex to vertex along edges of the graph.

e.g.



(a, e_1, b, e_4, d, e_3, c)

edge not repeated

path from A to C

(1) a, e_1, b, e_4, c

(2) a, e_6, e, e_5, d, e_4, b, e_2, c

(3) a, e_6, e, e_5, d, e_4, b, e_1, a, e_4, e_6, e, e_5, d, e_3, c

edge repeated

Path → • vertex repeating with the edges
• " " not " " " "

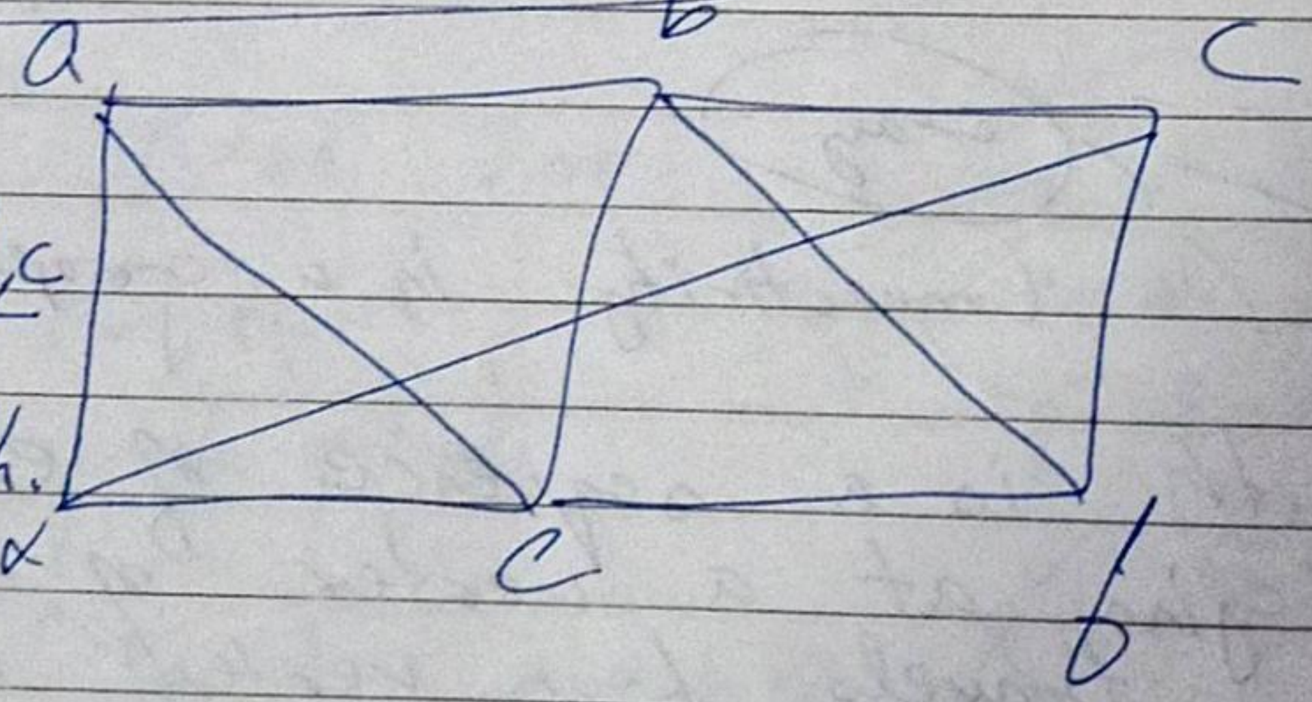
• when edges are repeated, we can create as many paths as ∞.

Simple Path: edges not repeated, vertex can be repeated

In an undirected graph, a path of length n from u to v, is the sequence of n edges $e_1, e_2, \ldots e_n$.

NOTE: A path is simple if it does not contain the same edge more than once

vertex repeated but not edge



a, d, e, b, a, e, f, c

simple path.

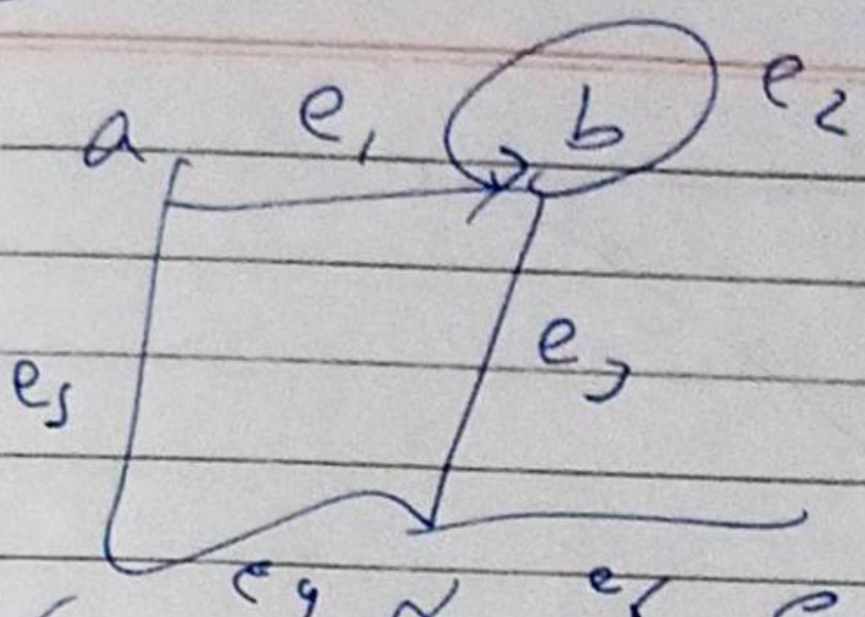
from a to c

Note: A simple path does not mean a path is a simple graph

• A closed path or circuit indicates a path that begins & ends at the same vertex.

Path/walk

Date:
Page:



a to α

a, ~~b~~ e_1, b, e_2, b, e_3, α

vertex b is repeated but not edge.

Path/way

→ a, e_1, b, e_2, b, e_3, α, e_7, e_5, a

closed simple path

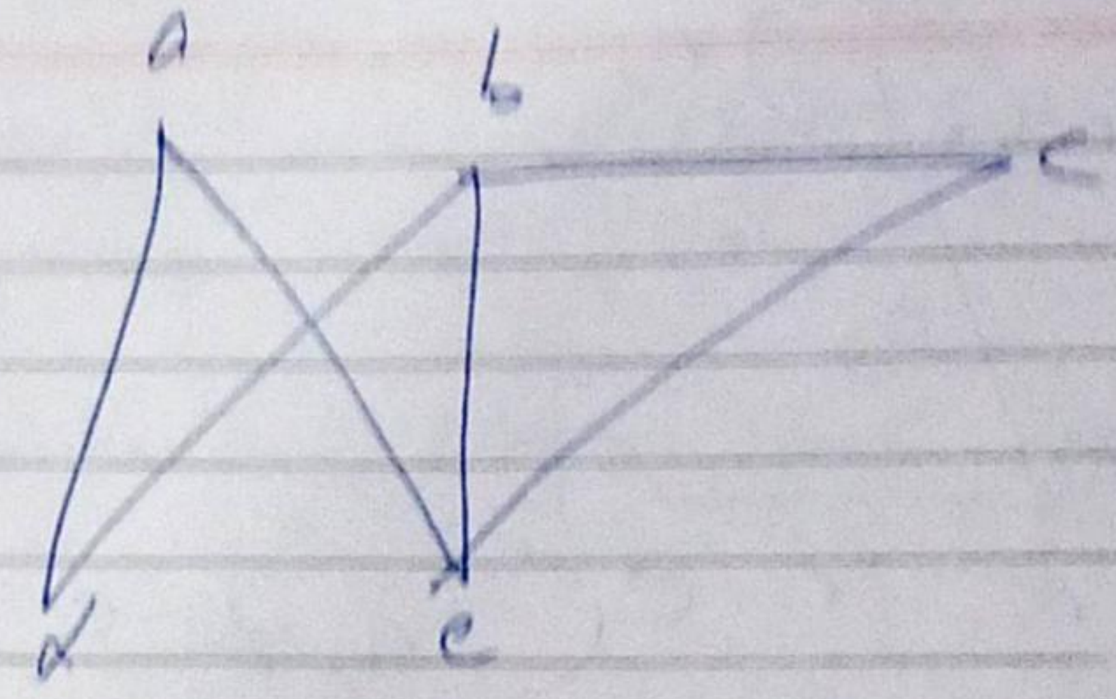
→ a, e_1, b, e_2, b, e_3, α, e_8, c, e_6, α, e_4, c, e_5, a

closed path

edge can be repeated

but not simple as e_6 is repeated

Q: Tom



(a) a, e, b, c, b ✓

(b) a, e, a, d, b, c, a ✗

(c) a, b, a, d, b, e ✗

(d) c, b, d, a, e, c ✓

(e) a, d, b, e, c, b ✓

(f) a, e, c, b, e, a ✓

(g) d, b, c, e, a, d ✓

Q-1 - which of the following list is a path

(a) All, (b) b, g, f

(c) a, c, d, e, f

(d) a, d, f, e, g

(e) None

S-Oct / Path is a way

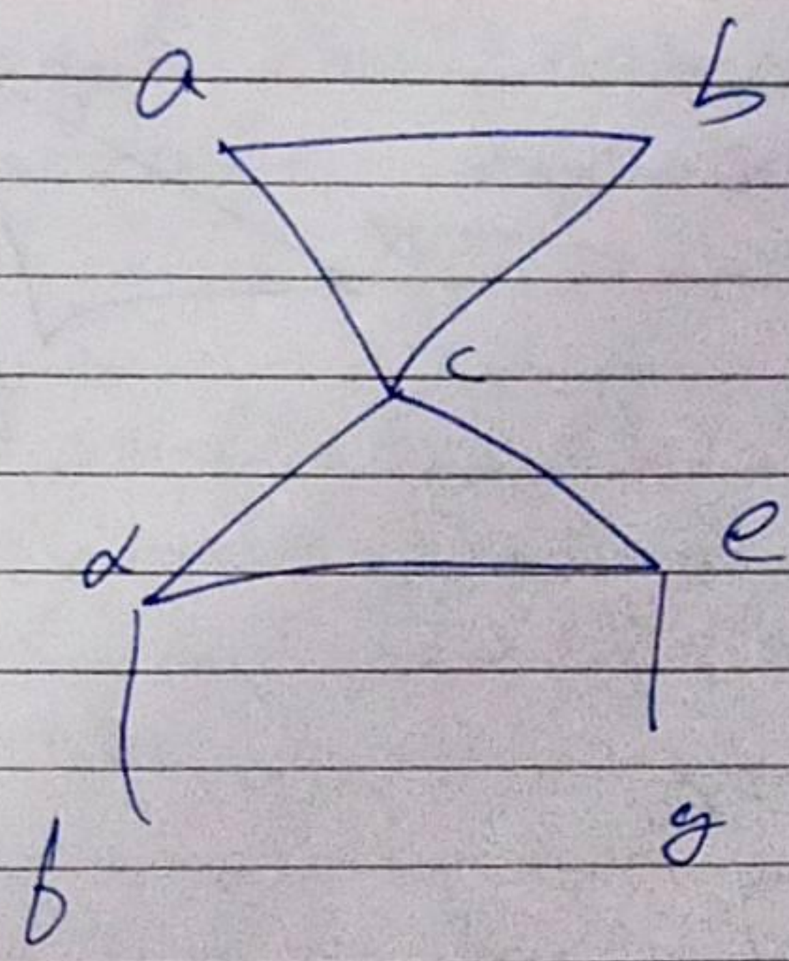
[Path / Way]

Connectedness In Undirected graph

An undirected graph is called connected if there is a path b/w every pair of distinct vertices of the graph.

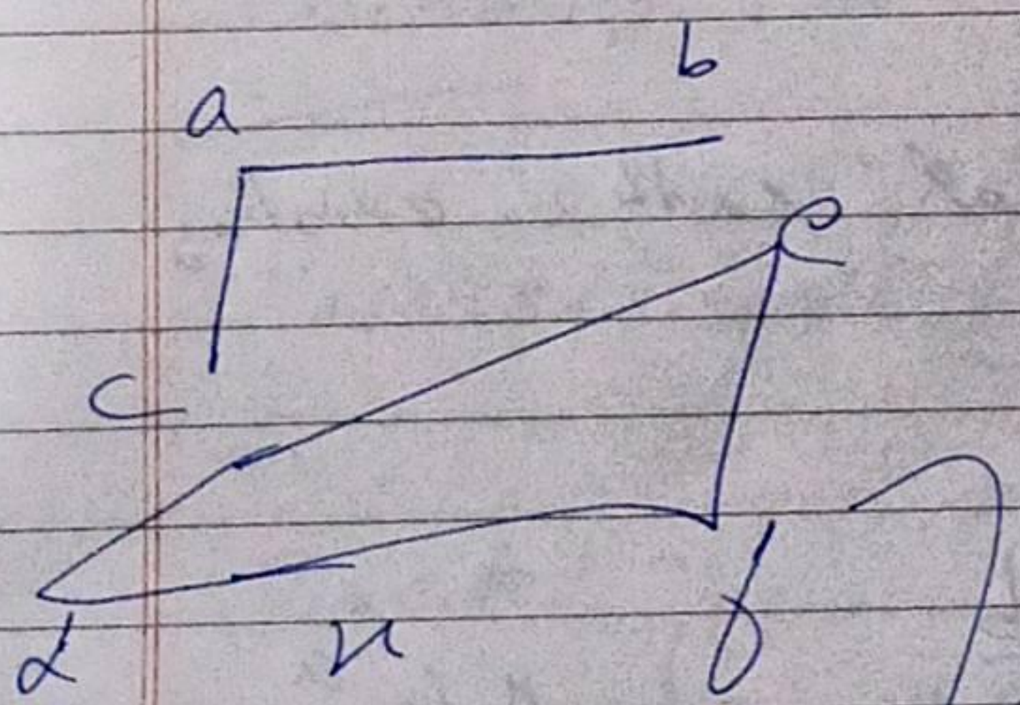
Date:
Page:

e.g.



every vertices is connected to other vertices

Result: There is a simple path b/w every pair of distinct vertices of a connected undirected graph



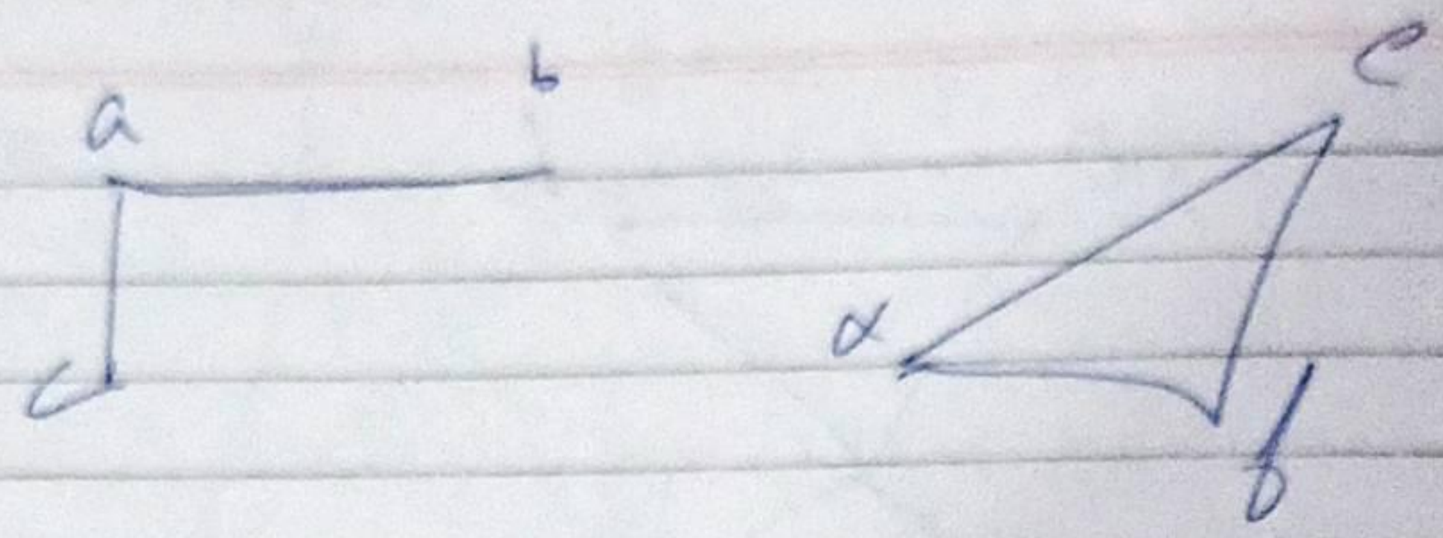
from a to e ∄ path

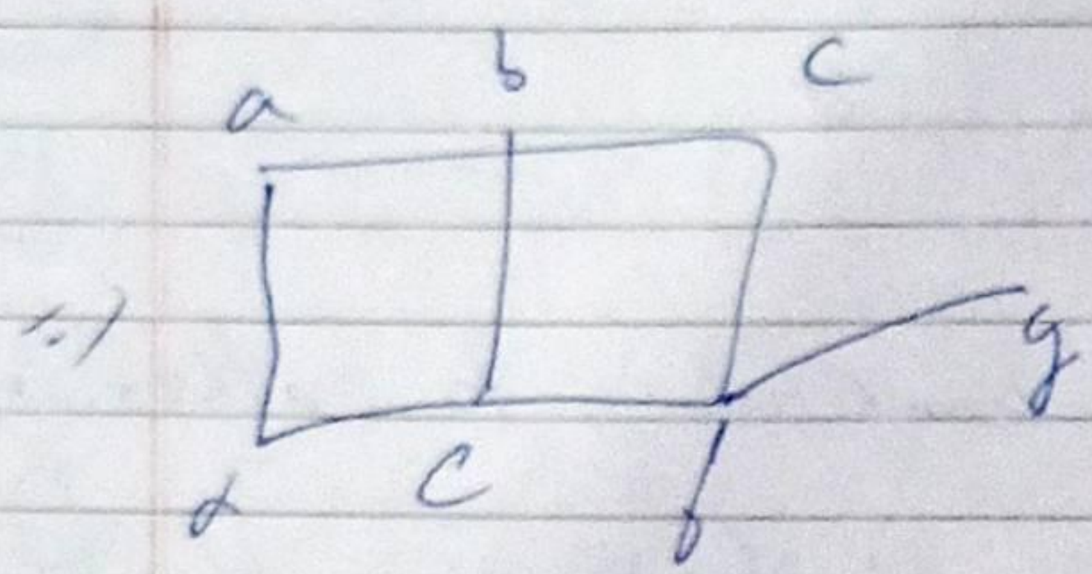
11:00 - - -

when → Disconnected graph (H) we have

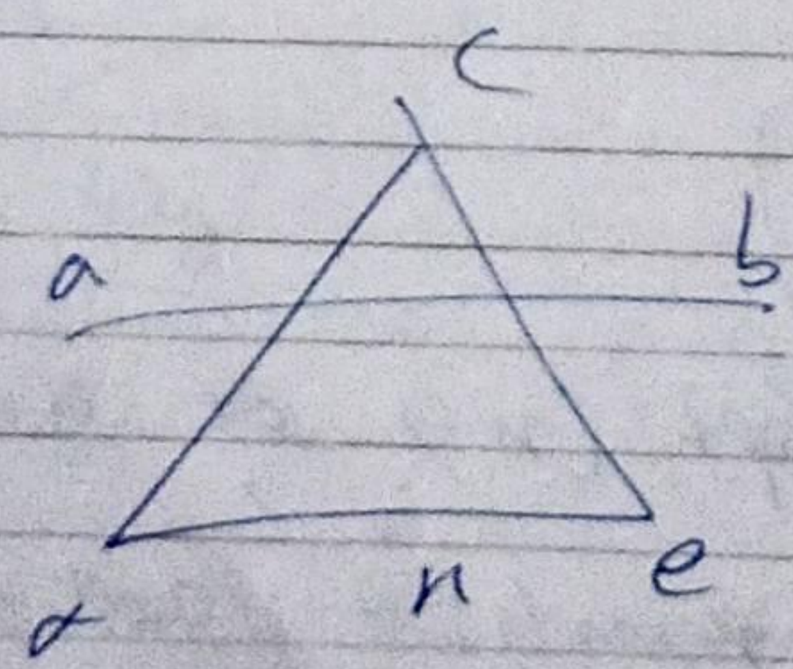
connected components :- exist in a disconnected graph

Disjoint set of vertices ~~and~~ ~~and~~ of the graph which are not connected among themselves but within themselves they r connected.





a → g ⇒ a – b – c – f – g
a → f → ✓
a → e = ✓
d → c → ✓
d – g = ✓, for all path existing



⇒ n is a Disconnected graph

No path b/w a & c.

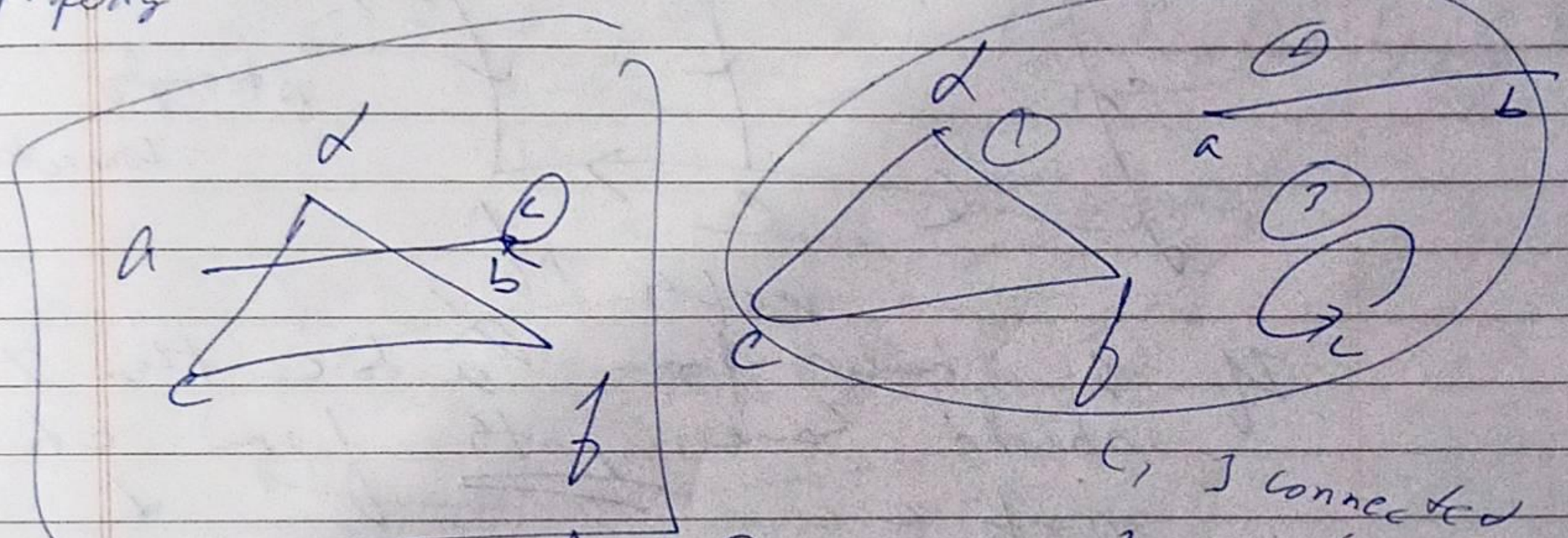
16- 17:3.

Date: there will be
Page: min 2 disconnected components

When graph is disconnected there will be connected components.

Result: A result G that is not connected has 2 or more connected components that are disjoint and have the graph as their union.

Property



Connectivity in Directed graph

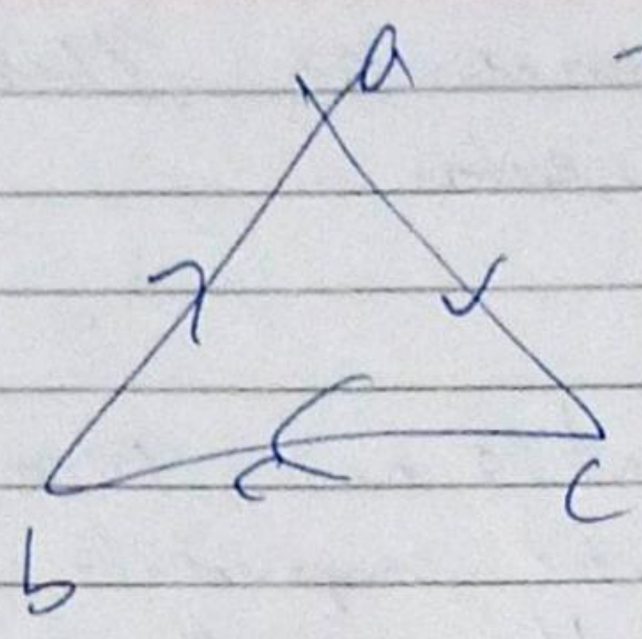
Undirected graph - { connected, Disconnected }

Directed - { strongly connected, weakly " }

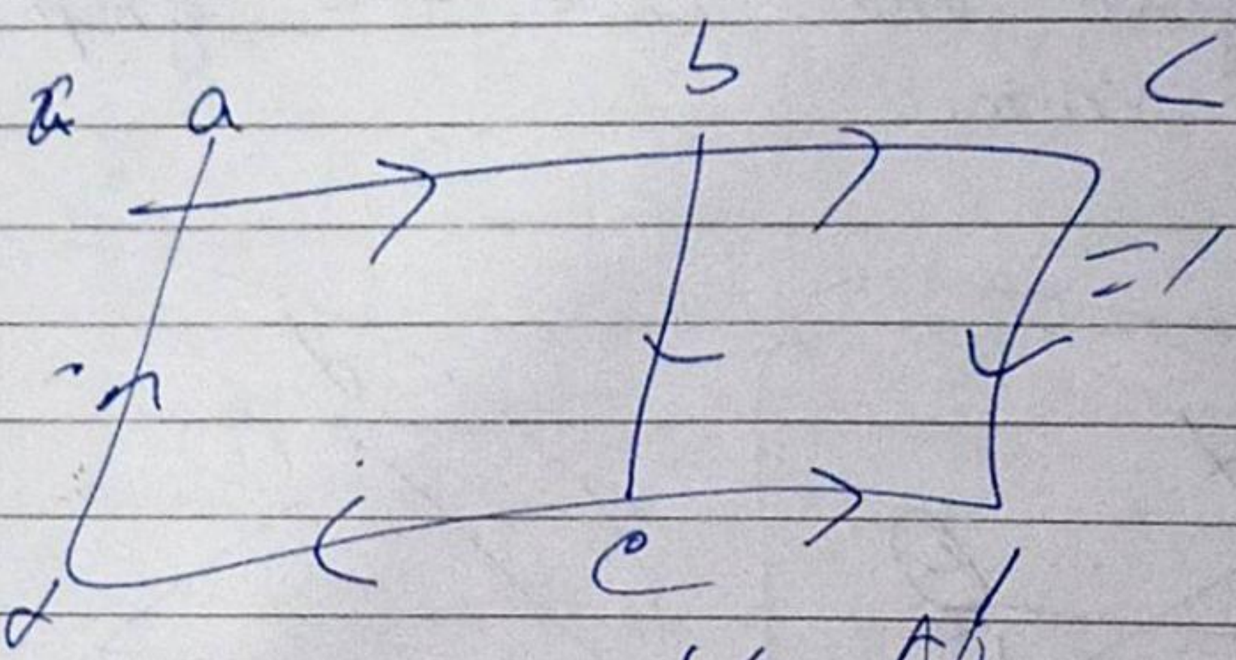
strongly connected

a - c

c to a



If we remove arrow then it is connected



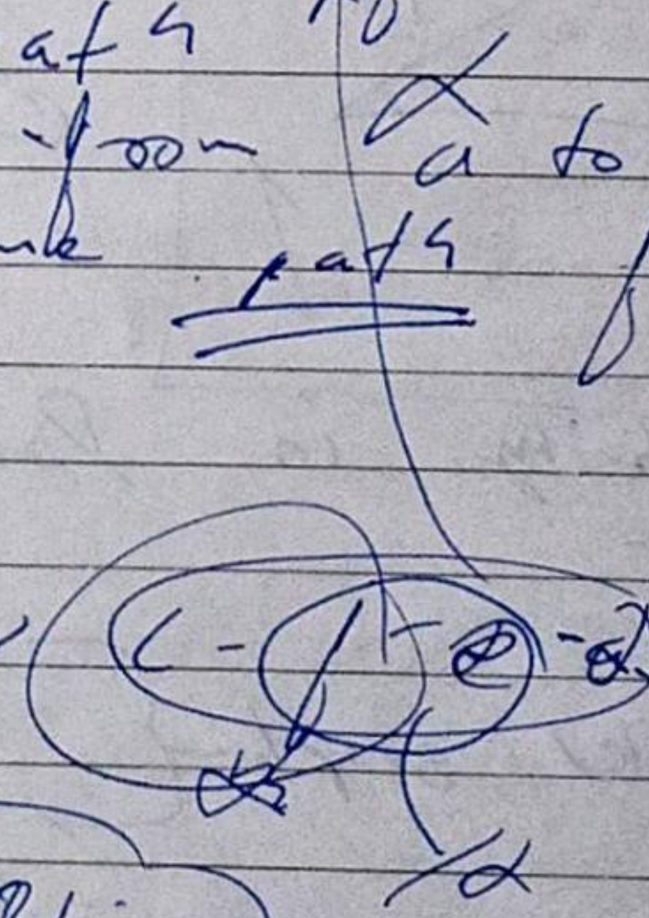
not strongly connected

If I have a path a to c then I should have path from c to a

a - b - c

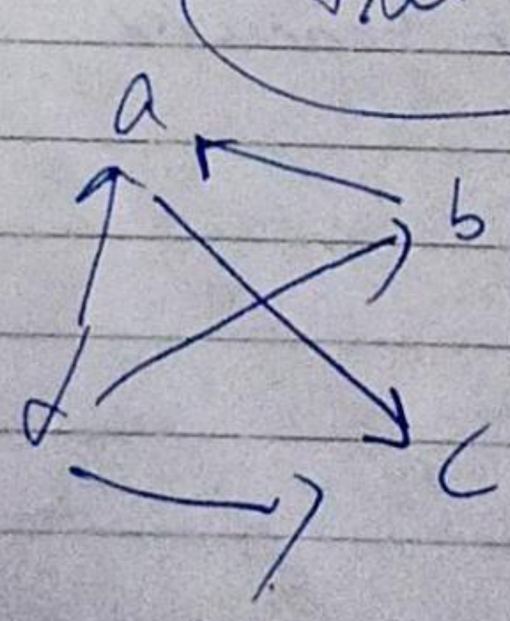
a to c

c to a



strongly connected

till 31:00



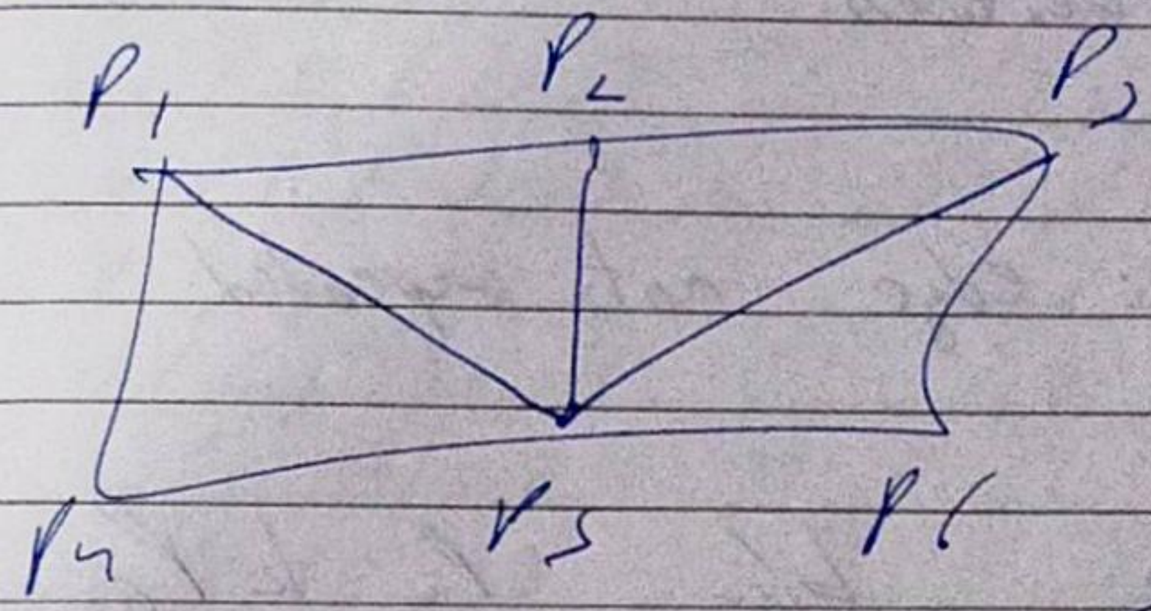
strongly or weakly connected

weakly connected

Date:
Page:

Consider the graph

P_4 to P_6



edge ~~again~~ separated

$\alpha = \{P_4, P_1, P_2, P_5, P_1, P_2, P_3, P_6\}$

not a simple path

7 edges

length $(\alpha) = 7$

$\beta = \{P_4, P_1, P_5, P_2, P_6\} =$ not a path

not a Path

$\gamma = \{P_4, P_1, P_5, P_3, P_6\}$ — $L(\gamma) = 4$

simple Path

$\delta = \{P_4, P_5, P_6\}$ — $L(\delta) = 2$

$G = \{P_4, P_5, P_3, P_6\}$

$L(G) = 3$

Distance (u, v) = length of shortest path b/w u, v

Distance → Shortest path b/w any pair of vertices.

min

simple path: edge not repeated

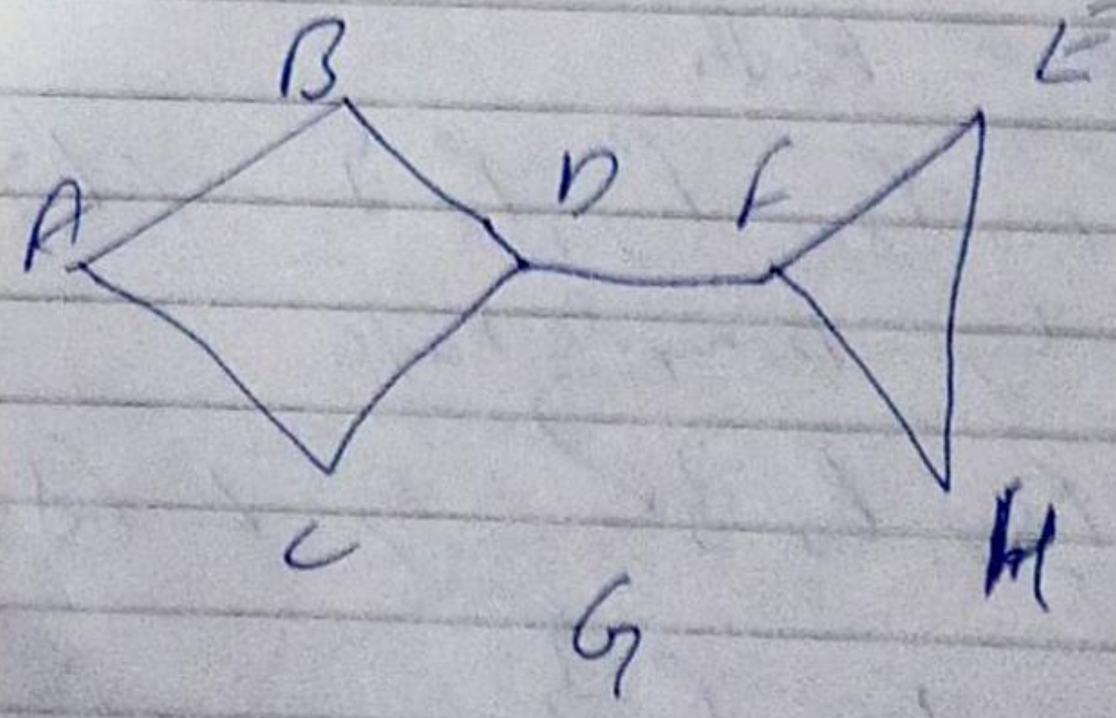
min distance b/w P_4 to P_6

2 Units

Length

Diameter: Diameter of a graph G denoted as diam(G) is the max distance b/w any vertices in the graph G.

Mat of the min distance



distance

$d(A, D) = 1$
$d(A, D) = 2$
$d(A, E) = 1$
$d(A, F) = 3$
$d(A, E) = 4$
$d(A, H) = 4$

Date:
Page:

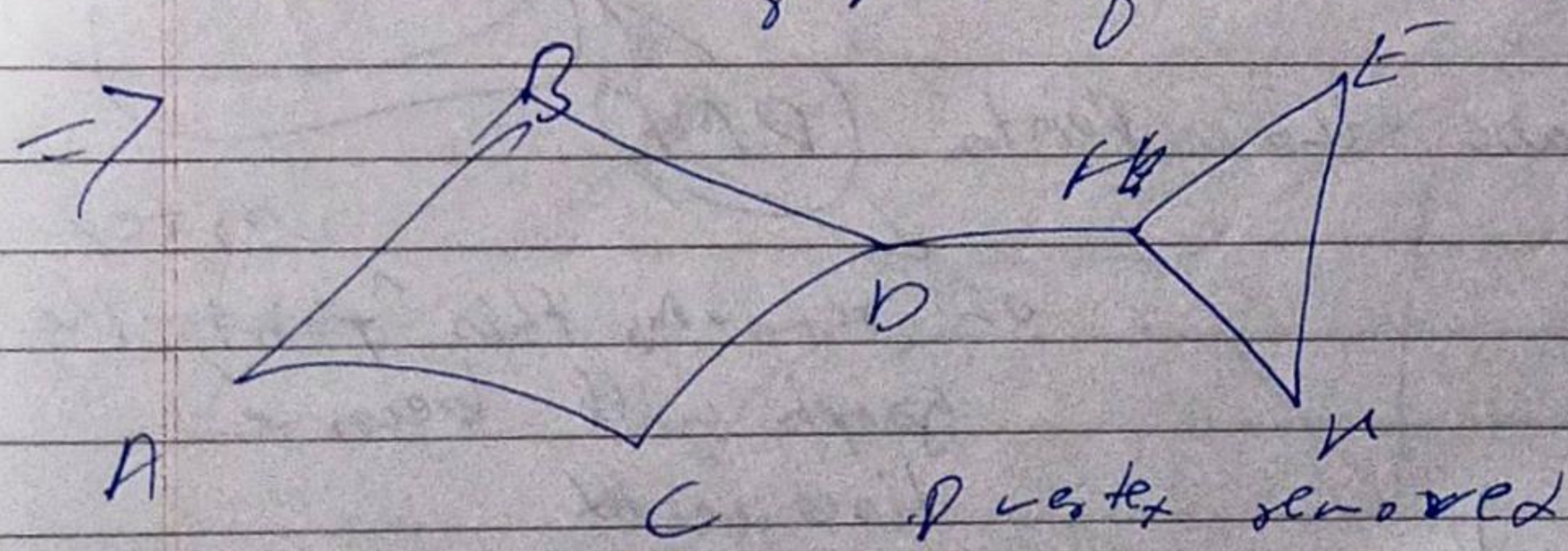
$d(B, C) = 2$
$d(B, D) = 1$
$d(B, F) = 2$
$d(B, E) = 3$
$d(B, H) = 3$
$d(C, D) = 1$
$d(C, F) = 2$
$d(C, E) = 3$
$d(C, H) = 3$

$d(D, F) = 1$
$d(D, E) = 2$
$d(D, H) = 2$
$d(F, E) = 1$
$d(E, H) = 1$
$d(C, H) = 1$

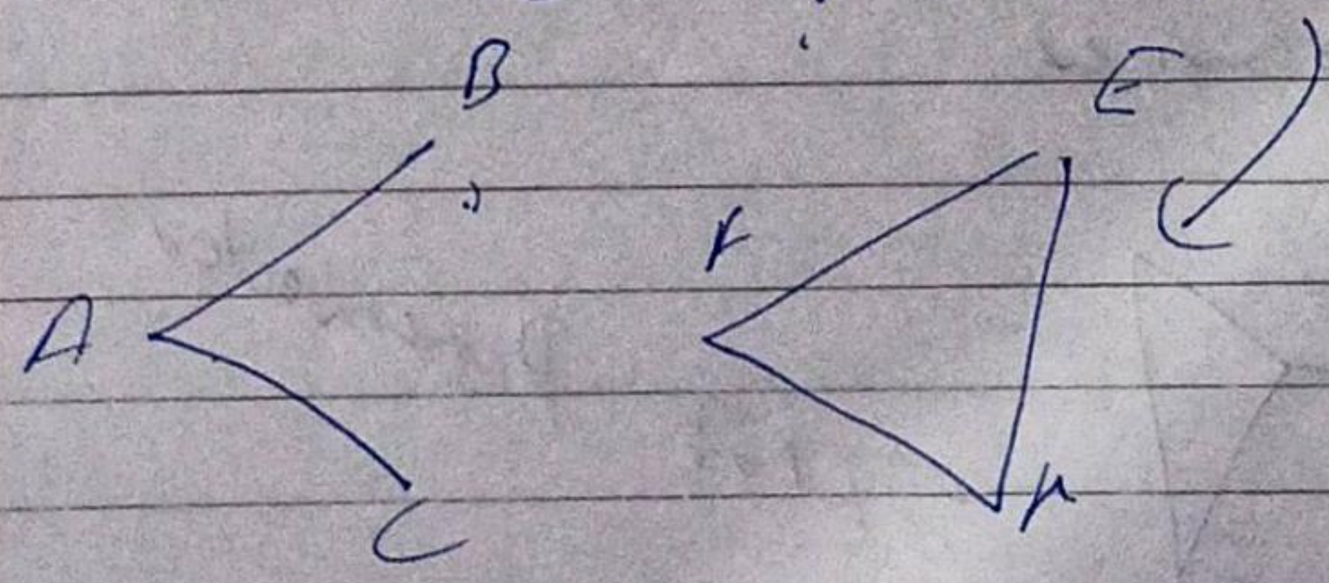
Now from distances b/w every pair of vertices, we have to look for the max value. i.e diameter

Diameter $(G) = 4$

Diameter is of graph.
Distance is of pair of vertices.

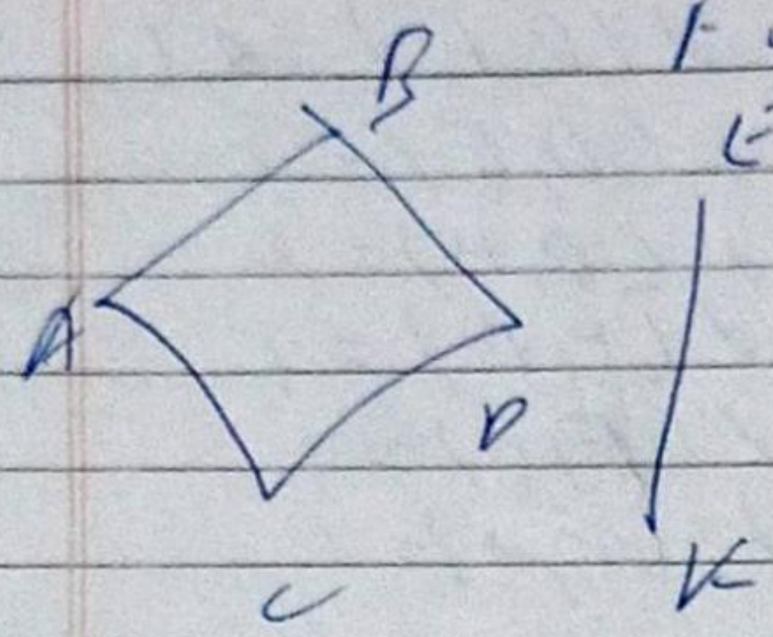


Vertex removed



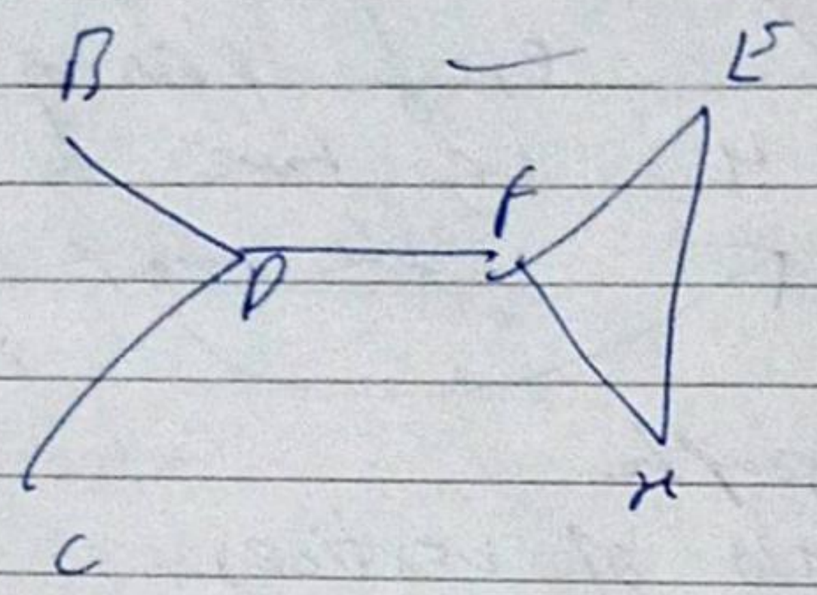
Date:
Page:

F vertex removed



2 2 components

A vertex removes



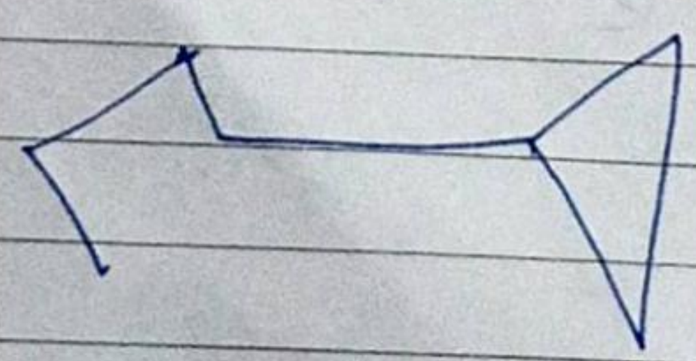
cut vertices

There are two points $D \cap F$

vertex

on removing this ~~point~~, the graph will become disconnected

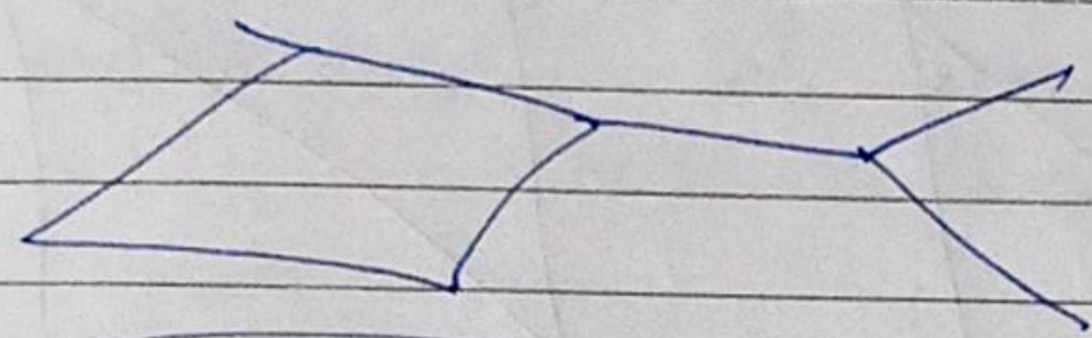
$\Rightarrow \{C, D\}$ removed



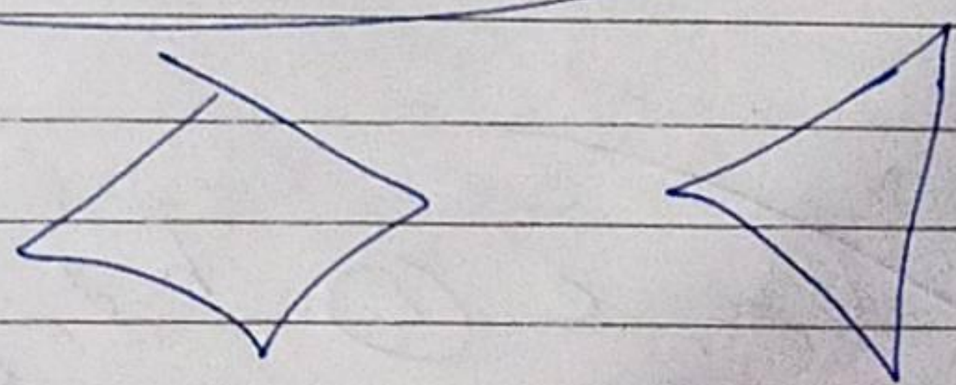
$\Rightarrow$ Not Disconnected

Date:
Page:

{E, n} removed



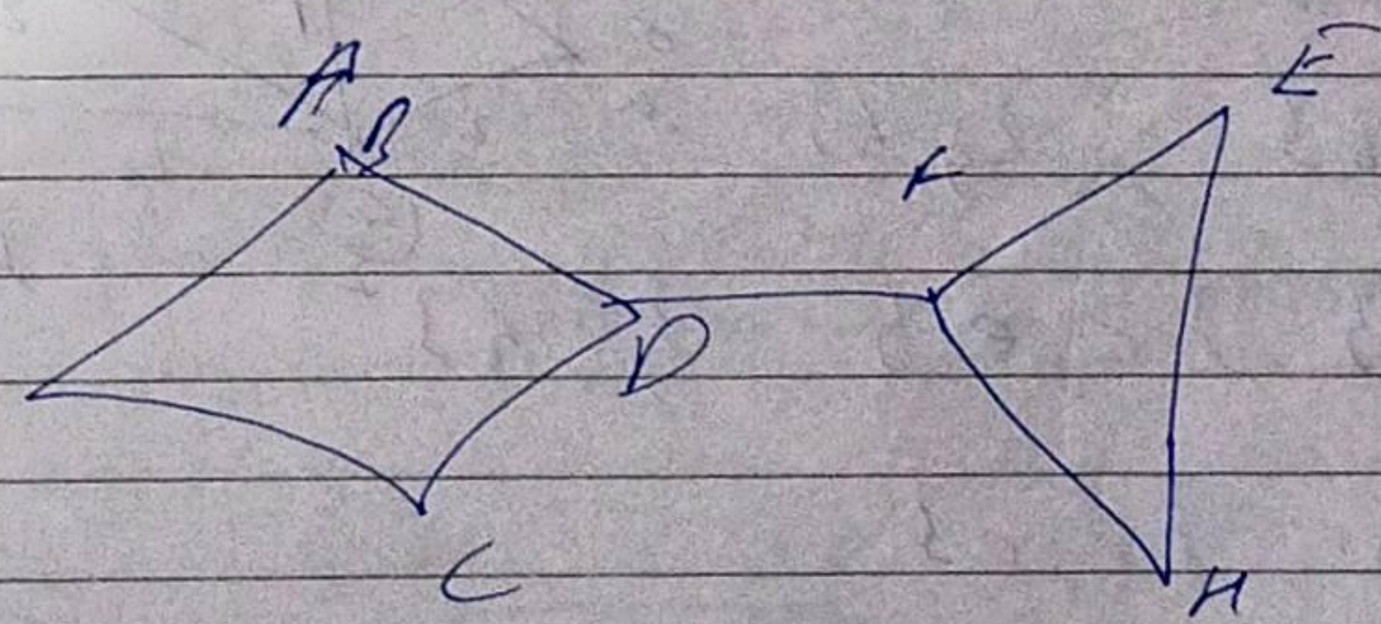
{D, F} removed → Bridge or Cut Edge



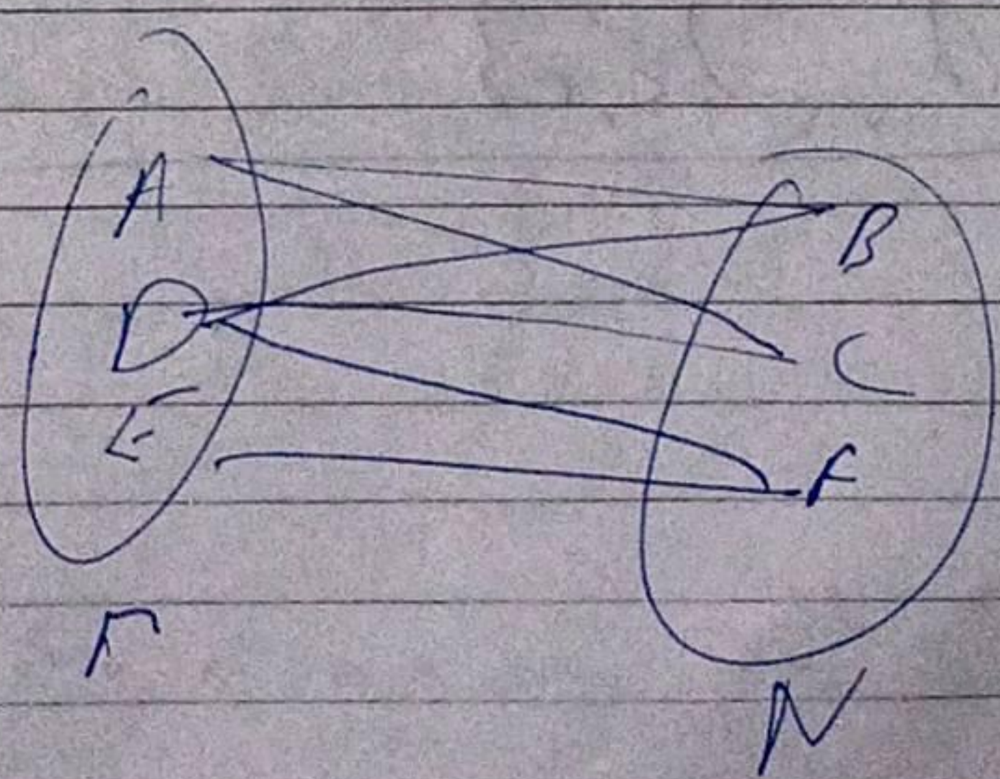
⇒ Disconnected

Edge removed Disconnect the graph

⇒



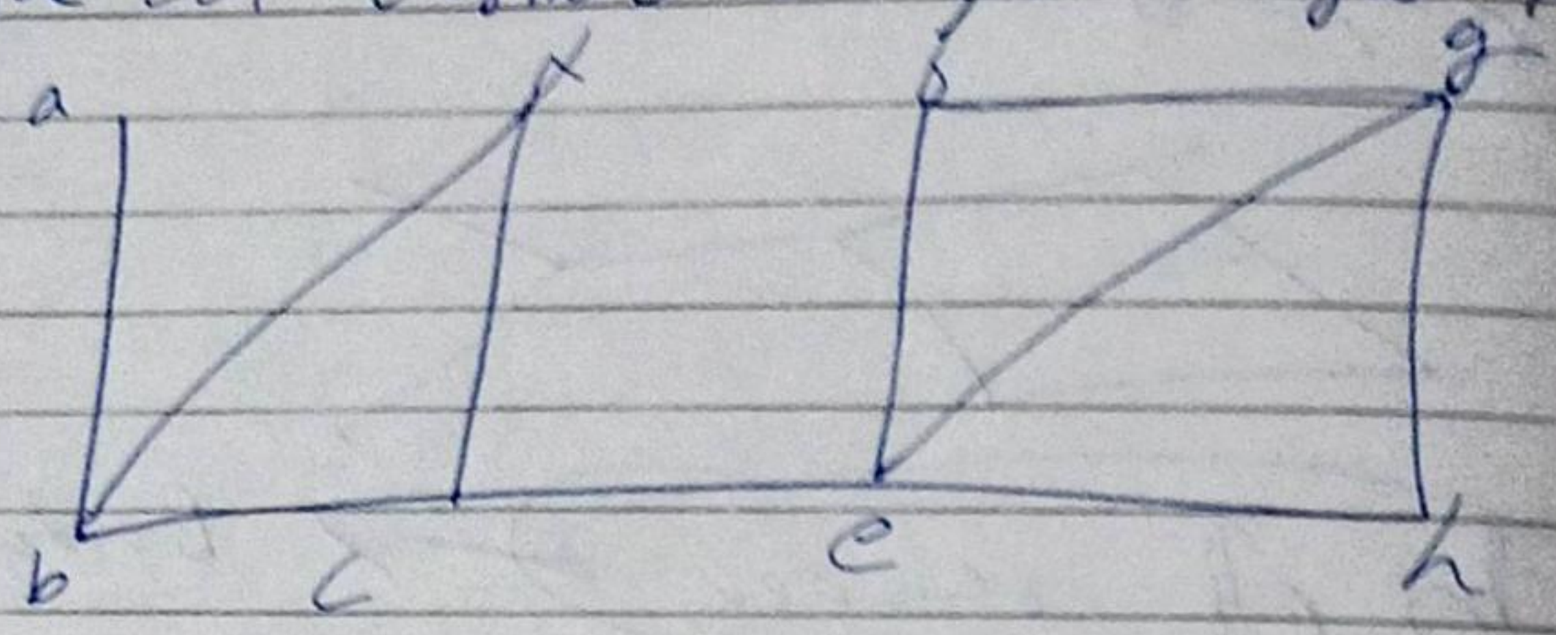
Not a Bipartite graph



n2

Date:
Page:

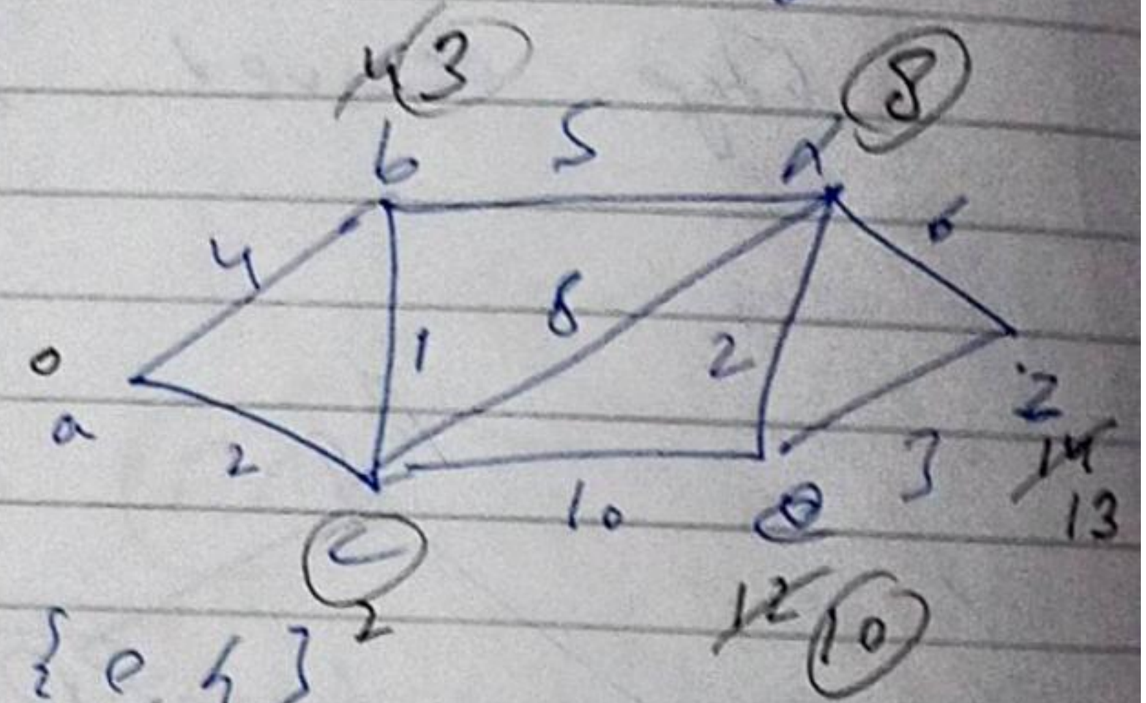
Q1 find the cut vertices & cut edges in G:



cut vertices

(a) a, b, c (b) b, c, e (c) b, d, f, c

(d) c, e.



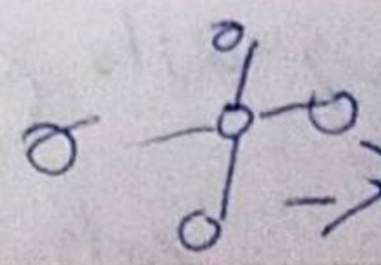
cut edges

(a) {a, b} , {g, h}

(b) {b, c} {c, e} {e, h}

(c) {a, b} , {c, e}

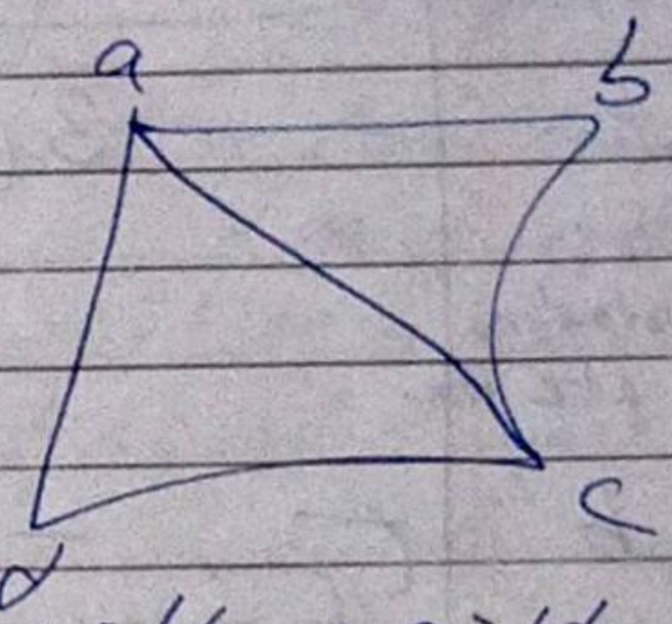
(d) {b, d} , {c, e}



→ not labelled graph

6-Oct

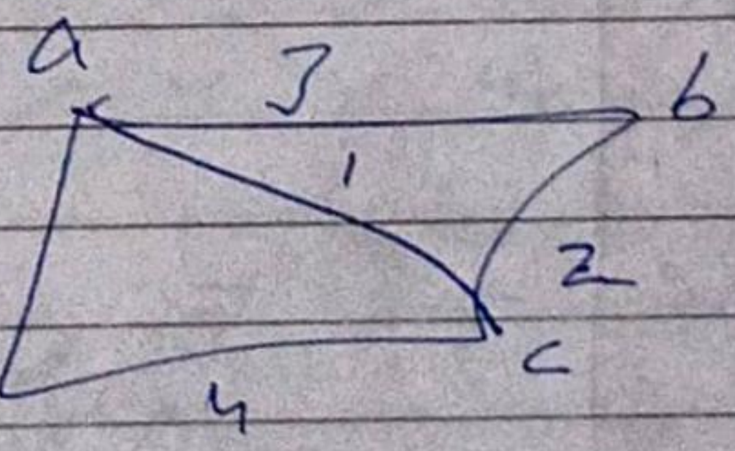
Labelled graph: A graph with labels to the vertices



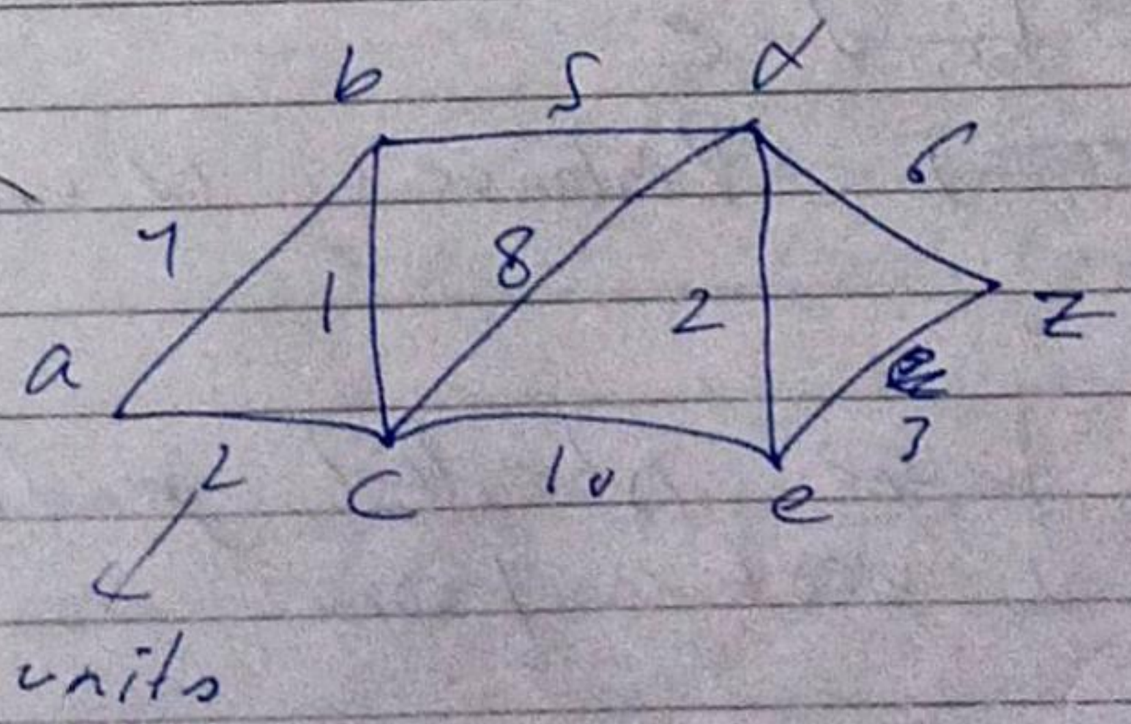
Weighted graph: A graph with weights assign to edges

used to find out some weight assigned to it (edge) units

shortest path



Dijkstra's Algo for length in units shortest path



shortest path b/w a to z

Note: No direct edge → mention ∞

we have to write the min value

4 units (19-20 100)

2 units via 'a' → no direct edge

path

Source	a	b	c	d	e	z
a	0	4 (a)	2 (a)	∞	∞	∞
a, c	—	3 (a, c)	—	10 (a, c)	12 (a, c)	∞
a, c, b	—	—	—	8 (a, c, b)	12 (a, c)	∞
a, c, b, d.	—	—	—	—	10 (a, c, b, d)	14 (a, c, b, d)
a, c, b, d, e	—	—	—	—	—	13 (a, c, b, d, e)

replace

cost

value

path

min in this line

standing ate now

shortest path ⇒ a to z is

a - c - b - d - e

~~shortest~~ Distance = 13 units

We have found shortest path to every vertex from source vertex

min value is still has to be find

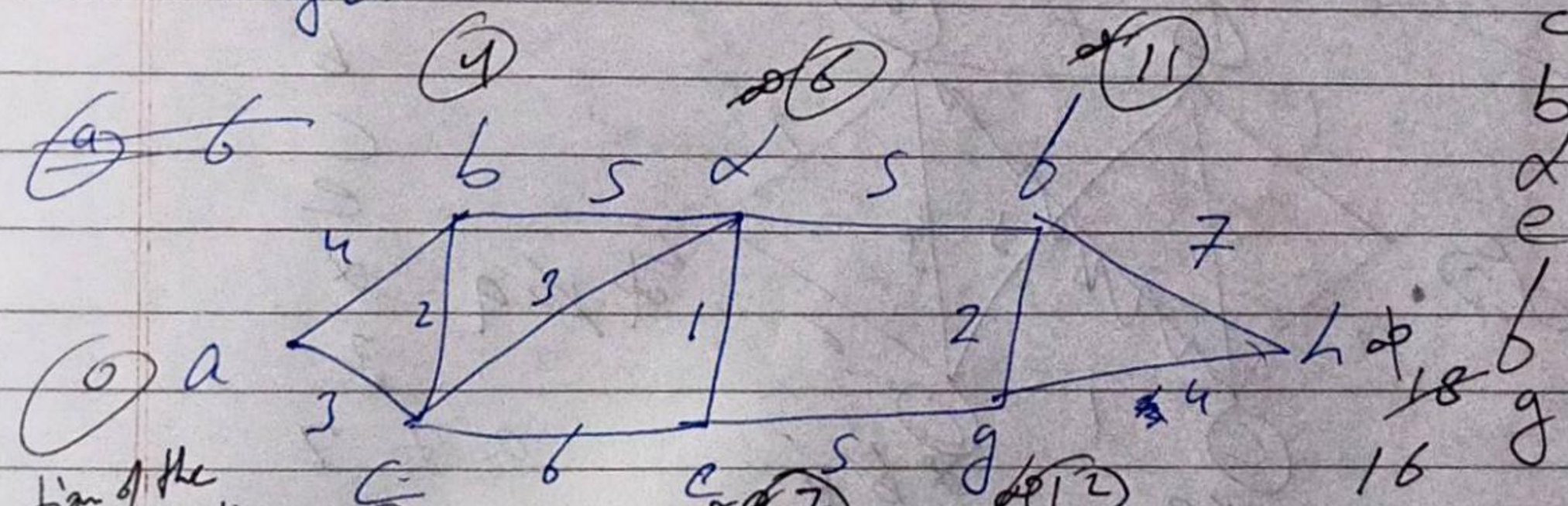
- we replace, if we found a smaller ~~dis~~ path.
- If no direct edge is found => ~~dis~~ don't replace
- If we find a larger distance than previous, don't replace

-1 75:00 - 7:00

Q: What is the ~~at~~ third step value for e

Q: Find the distance ~~f~~ to vertex e and from a in the step 4 of the dijkstra's algo.

select → a 1st step
c 2nd
b 3rd step
d 4th step
e
b
g

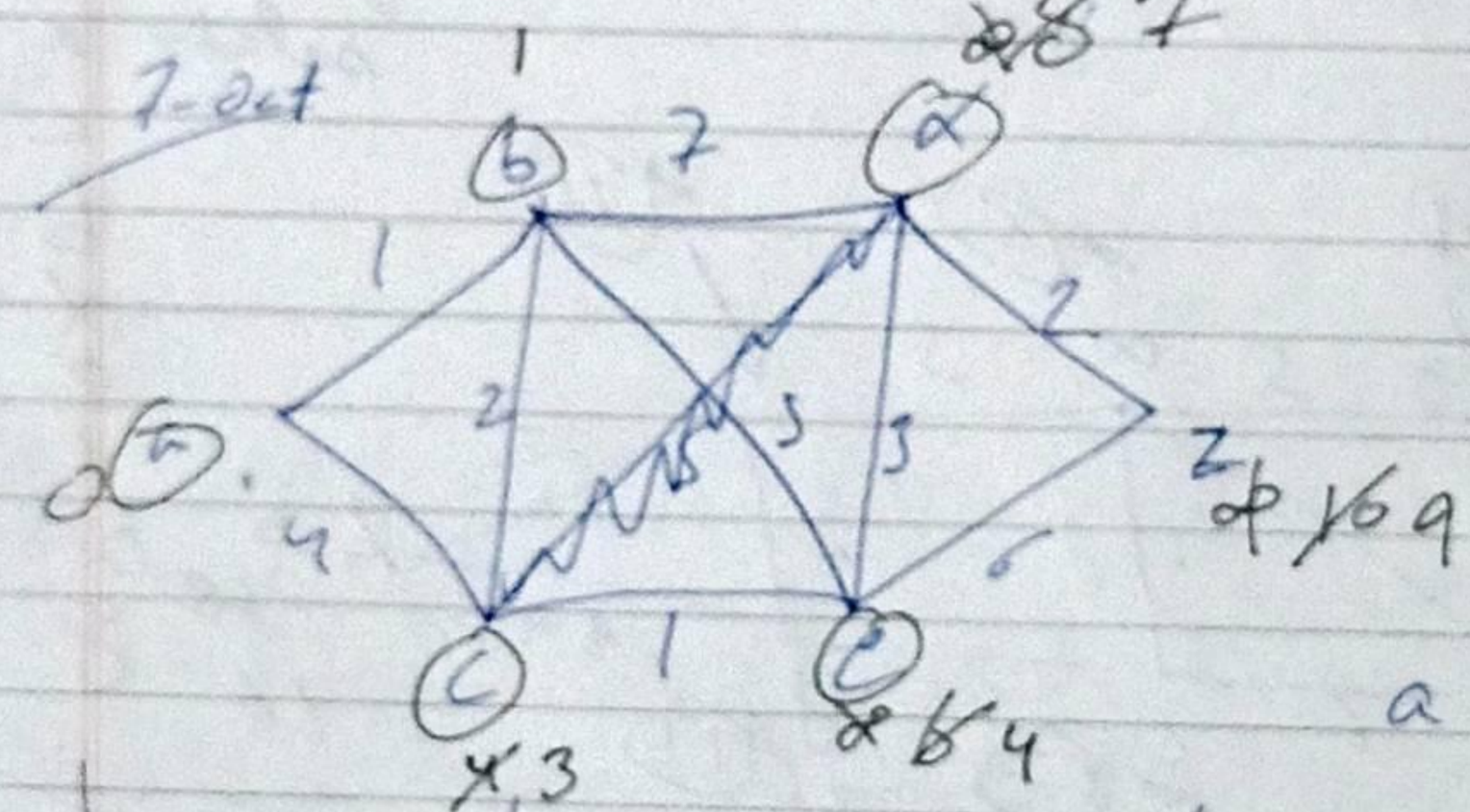


selection of the vertices

(a) b, a (b) a, ∞ (c) b, 14 (d) 7, 11

Source	a	b	c	d	e	f	g	h
(1) a	—	4(a)	3(a)	∞	∞	∞	∞	∞
(2) a, c	—	4(a)	—	6(a,c)	9(a,c)	∞	∞	∞
a, c, b	—	—	—	6(a,c)	9(a,c)	∞	∞	∞
a, c, b, d	—	—	—	—	9(a,c,d)	11(a,c,d)	∞	∞

Date
Page



relection
a
b
c
e
d
z
a to z

source	a	c	d	e	z
a	—	1(a)	2(a)	∞	∞
a, b	—	—	3(a,b)	8(a,b)	6(a,b) ∞
a, b, c	—	—	—	8(a,b)	4 (a,b,c) ∞
a, b, c, e	—	—	—	7 (a,b,c,e)	— 10 (a,b,c,e)

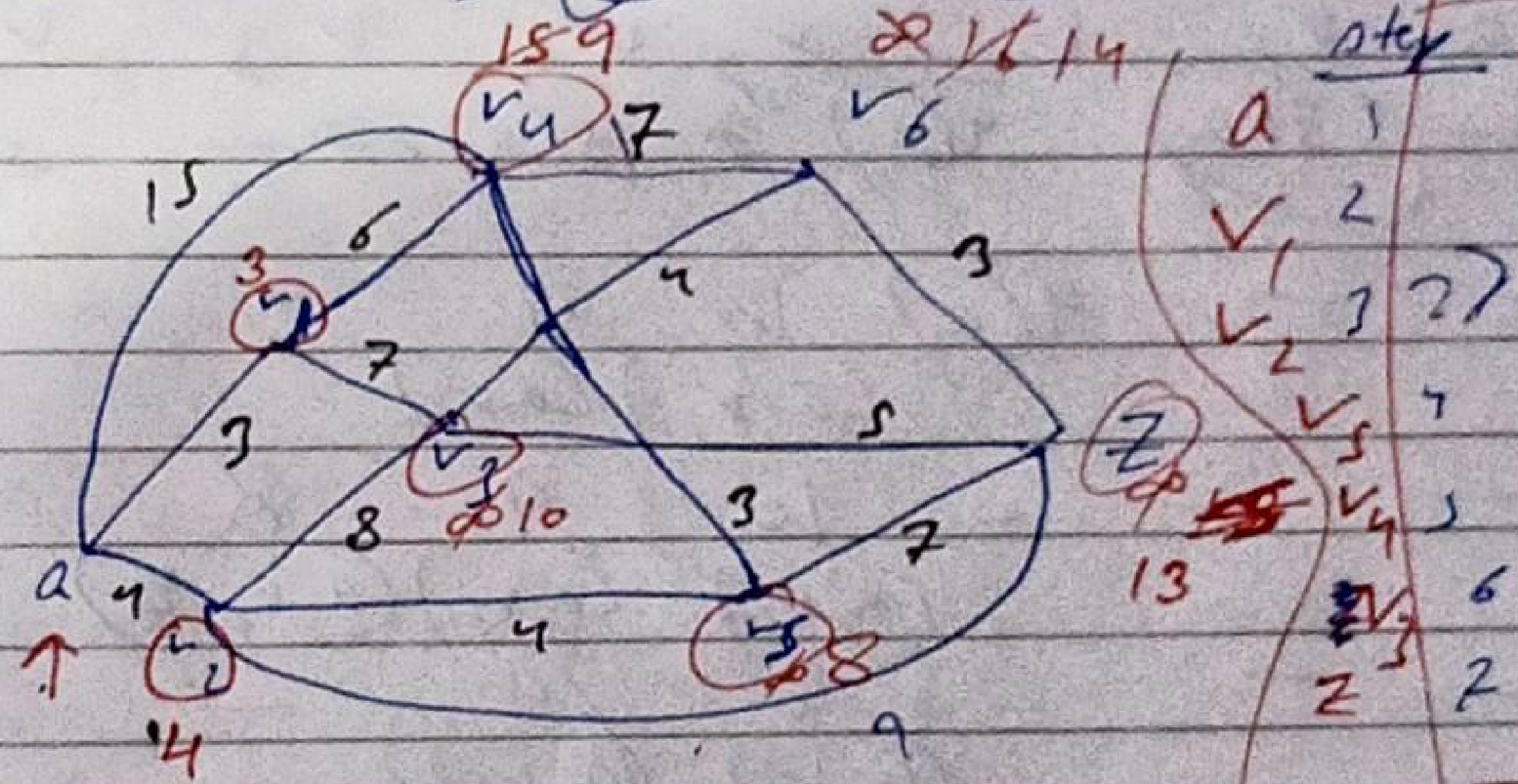
	a	b	c	d	e	z
a, b, c, e, d	—	—	—	—	—	(a, b, c, e, d)

shortest path =>

a-b-c-e-d-z

Q: 1 which vertex is selected in step 4 ?

(a) v_2 (b) v_3 (c) v_5 (d) v_4



step	
a	1
v_1	2
v_2	3
v_3	4
v_5	5
v_4	6
z	7

1 vertex

source	a	v_1	v_2	v_3	v_4	v_5	v_6	z
a	—	3 (a)	7 (a)	∞	∞	∞	∞	∞
a, v_1	—	—	4 (a)	10 (a, v_1)	9 (a, v_1)	∞	∞	∞
a, v_1, v_2	—	—	4 (a)	10 (a, v_1)	—	12 (a, v_1, v_4)	16 (a, v_1, v_4)	∞
a, v_1, v_4, v_5								

Till Unit 4 → DK algo

Date:
Page:

Q.2 The distance to z is replaced from ∞ to a value in step _____ with distance _____

(a) 2, 18 (b) 4, 15 (c) 3, 13 (d) 6, 15

Q.3 - The distance of v_6 & z in 6th step from a is

(a) 16, 13 (b) 14, 15 (c) 13, 13 (d) 14, 13

Source	a	v_1	v_2	v_3	v_4	v_5	v_6	z
a	—	7(a)	4(a)	∞	15(a)	∞	∞	∞
a, v_1	—	—	4(a)	10 (a, v_1)	9 (a, v_1)	∞	∞	∞
a, v_1, v_2	—	—	—	10 (a, v_1)	9 (a, v_1)	8 (a, v_2, [illegible])	∞	13 (a, v_2)
a, v_1, v_2, v_5	—	—	—	10 (a, v_1)	9 (a, v_1)	—	∞	13 (a, v_2)
a, v_1, v_2, v_5, v_4	—	—	—	10 (a, v_1)	—	—	16 (a, v_1, v_4)	13 (a, v_2)
a — — v_3	—	—	—	—	—	—	14 (a, v_1, v_3)	13 (a, v_2)
(— — z)								

a to z = 13

(2 ans)