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" Part - 1 "

1) a) $A = \begin{bmatrix} 2 & 4 \\ 0 & -1 \end{bmatrix}$ $B = \begin{bmatrix} 8 & 3 \\ 5 & 1 \end{bmatrix}$ $C = \begin{bmatrix} -6 & 0 \\ 3 & 2 \end{bmatrix}$

$A \times B = \begin{bmatrix} 2 & 4 \\ 0 & -1 \end{bmatrix}\begin{bmatrix} 8 & 3 \\ 5 & 1 \end{bmatrix} = \begin{bmatrix} 36 & 10 \\ -5 & -1 \end{bmatrix}$

$A \times B \times C = \begin{bmatrix} 36 & 10 \\ -5 & -1 \end{bmatrix}\begin{bmatrix} -6 & 0 \\ 3 & 2 \end{bmatrix} = \begin{bmatrix} -186 & 20 \\ 27 & -2 \end{bmatrix}$

b) $C \times A \times B$

$= \begin{bmatrix} -6 & 0 \\ 3 & 2 \end{bmatrix}\begin{bmatrix} 36 & 10 \\ -5 & -1 \end{bmatrix} = \begin{bmatrix} -216 & -60 \\ 98 & 28 \end{bmatrix}$

2) a) $E = \begin{bmatrix} -1 & 0 & 2 & 1 & 4 \\ -1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 2 \end{bmatrix}$ $X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix}$

$E.X = 0$

$E : R_2 \rightarrow R_2 - R_1$ $E = \begin{bmatrix} -1 & 0 & 2 & 1 & 4 \\ 0 & 1 & -2 & 0 & -4 \\ 0 & 1 & 1 & 0 & 2 \end{bmatrix}$

$E : R_3 \rightarrow R_3 - R_2$

$E = \begin{bmatrix} -1 & 0 & 2 & 1 & 4 \\ 0 & 1 & -2 & 0 & -4 \\ 0 & 0 & 3 & 0 & 6 \end{bmatrix}$

$R_3 \rightarrow R_3/3$ $E = \begin{bmatrix} -1 & 0 & 2 & 1 & 4 \\ 0 & 1 & -2 & 0 & -4 \\ 0 & 0 & 1 & 0 & 2 \end{bmatrix}$

$R_1 \rightarrow R_1 - 2R_3$

$$E = \begin{bmatrix} -1 & 0 & 0 & 1 & 0 \\ 0 & 1 & -2 & 0 & -4 \\ 0 & 0 & 1 & 0 & 2 \end{bmatrix}$$

$R_2 \rightarrow R_2 + 2R_3$

$$E = \begin{bmatrix} -1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 2 \end{bmatrix}$$

Eqn $\quad -x_1 + x_4 = 0$

$x_2 = 0$

$x_1 = x_4$

$x_3 = -2x_5$

$2x_5 + x_3 = 0$

Null space $\Rightarrow \vec{x} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} x_4 + \begin{bmatrix} 0 \\ 0 \\ -2 \\ 0 \\ 1 \end{bmatrix} x_5 \Rightarrow \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & -2 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$

3)
$$\begin{bmatrix} 2 & 0 & 3 \\ 1 & 4 & -1 \\ -5 & 1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 6 \\ -1 \\ -16 \end{bmatrix}$$

$A \cdot x = B$

$x = A^{-1} \cdot B$

$|A| = 2(4(1) - (-1)(1)) - 0(1\times1 - (-1)(-5))$
$+ 3(1\times1 - 4(-5))$

$= 2(4+1) + 3(1+20)$

$= 10 + 63$

$= 73$

cofactor matrix :

$$\begin{bmatrix} 4-(-1) & -(1-5) & (1-(-20)) \\ -(0-3) & 2-(-15) & -(2-0) \\ (0-12) & -(-2-3) & (8-0) \end{bmatrix}$$

$$= \begin{bmatrix} 5 & 4 & 21 \\ 3 & 17 & -2 \\ -12 & 5 & 8 \end{bmatrix}$$

$A^{-1} = \text{Adj } A \times \frac{1}{\det(A)}$

transpose of cofactor matrix $\Rightarrow \begin{bmatrix} 5 & 3 & -12 \\ 4 & 17 & 5 \\ 21 & -2 & 8 \end{bmatrix} = \text{Adj}(A)$

$$A^{-1} \times B = \frac{1}{73} \begin{bmatrix} 5 & 3 & -12 \\ 4 & 17 & 5 \\ 21 & -2 & 8 \end{bmatrix} \begin{bmatrix} 6 \\ -1 \\ -16 \end{bmatrix}$$

$$= \frac{1}{73} \begin{bmatrix} 30 - 3 + (12 \times 16) \\ 24 - 17 - 80 \\ 126 + 2 - (8 \times 16) \end{bmatrix}$$

$$= \frac{1}{73} \begin{bmatrix} 219 \\ -73 \\ 0 \end{bmatrix}$$

$$\therefore \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 3 \\ -1 \\ 0 \end{bmatrix}$$

4) a) $D = \begin{bmatrix} 3 & 4 \\ 5 & 6 \end{bmatrix}$

$\det(D) = 3(6) - 5(4)$

$= -2$

b) D is nonsingular as $\det(D) \neq 0$ and its inverse can be calculated

5) $F = \begin{bmatrix} -3 & -2 & 1 & 3 \\ 2 & 4 & 1 & -2 \\ -1 & 2 & 2 & 1 \\ -1 & 4 & -3 & 1 \end{bmatrix}$

$rref(F) = \begin{bmatrix} 1 & 0 & 0 & -1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$

Basis for column space $= \left\{ \begin{bmatrix} -3 \\ 2 \\ -1 \\ -1 \end{bmatrix}, \begin{bmatrix} -2 \\ 4 \\ 2 \\ 4 \end{bmatrix}, \begin{bmatrix} 1 \\ 1 \\ 2 \\ -3 \end{bmatrix} \right\}$

pivot columns, column 1, 2, 3

6) Row space

$rref(F) = \begin{bmatrix} 1 & 0 & 0 & -1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$

Basis for row space

$= \{ [-3\ -2\ 1\ 3], [2\ 4\ 1\ -2], [-1\ 2\ 2\ 1] \}$

7) Subspaces

a) Rank of matrix = dim (col (matrix)).

Rank of matrix represents linearly independent columns, which is directly the basis of column space

Rank (F) = 3

b) column space of F = col (F)

row space of F = row (F)

$\boxed{\dim(\text{col}(F)) = \dim(\text{row}(F))}$

This is also called rank theorem, which states that rank of a matrix is same for row & column space.

8) Eigenvalues and ~~Eigen~~ Eigenvectors

a) Eigenvector is a non-zero ~~matrix~~ vector x that, when multiplied by a matrix, results in a scaled version of the eigenvector x. The scaling factor is λ (eigen value)

b) $$G = \begin{bmatrix} 3 & 6 \\ 2 & 2 \end{bmatrix}$$

$$\det(G - \lambda I) = 0$$

$$G - \lambda I = \begin{bmatrix} 3 & 6 \\ 2 & 2 \end{bmatrix} - \lambda \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$\begin{vmatrix} 3-\lambda & 6 \\ 2 & 2-\lambda \end{vmatrix} = 0$$

$$(3-\lambda)(2-\lambda) = 12$$

$$\lambda^2 - 5\lambda - 6 = 0$$

$$(\lambda - 6)(\lambda + 1) = 0$$

$$\boxed{\lambda = 6, -1}$$

$$\text{Eigenvalues } (L) = \begin{bmatrix} 6 & 0 \\ 0 & -1 \end{bmatrix}$$

For $\lambda = 6$

$$(G - 6I)x = 0$$

$$\begin{bmatrix} -3 & 6 \\ 2 & -4 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0$$

$$\boxed{x_1 = 2x_2}$$

$$x = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$$

For $\lambda = -1$

$$(G + I)x = 0$$

$$\begin{bmatrix} 4 & 6 \\ 2 & 3 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0 \Rightarrow x = \begin{bmatrix} -3 \\ 2 \end{bmatrix}$$

Eigenvectors $\rightarrow \begin{bmatrix} 2 & -3 \\ 1 & 2 \end{bmatrix}$

Normalized $\vec{v_1} = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$ $\quad |\vec{v_1}| = \sqrt{5}$

$= \frac{1}{\sqrt{5}} \begin{bmatrix} 2 \\ 1 \end{bmatrix} = \begin{bmatrix} 0.8944 \\ 0.4472 \end{bmatrix}$

$\vec{v_2} = \begin{bmatrix} -3 \\ 2 \end{bmatrix}$ $\quad |\vec{v_2}| = \sqrt{13}$

$= \frac{1}{\sqrt{13}} \begin{bmatrix} -3 \\ 2 \end{bmatrix} = \begin{bmatrix} -0.8321 \\ 0.5547 \end{bmatrix}$

$\vec{v} = \begin{bmatrix} 0.8944 & -0.8321 \\ 0.4472 & 0.5547 \end{bmatrix}$

"Part - II"

1) pyruvate $\xrightarrow{\text{to}}$ Succinyl - CoA;

(a) EC ~~6.4.1~~ 6.4.1.1 pyruvate $\rightarrow$ oxaloacetate

ATP + pyruvate + HCO_3 $\rightarrow$ ADP + phosphate + oxaloacetate.

(b) EC 1.1.1.37

oxaloacetate $\longleftrightarrow$ (S) - Malate

oxaloacetate + NADPH + $H^{\oplus}$ $\rightarrow$ (S)-Malate + $NAD^{\oplus}$

(c) EC 4.2.1.2

Fumarate $\longleftrightarrow$ (S) - Malate

(S) - Malate $\rightarrow$ Fumarate + H_2O

(d) EC 1.3.5.1

Succinate $\longleftrightarrow$ Fumarate

Fumarate + Quinol $\rightarrow$ succinate + Quinone

(e) EC 6.2.1.5

Succinyl-CoA $\leftarrow$ Succinate

ATP + Succinate + CoA $\rightarrow$ ADP + phosphate + Succinyl-CoA

2) Map:

pyruvate $\xrightarrow{6.4.1.1}$ oxaloacetate $\xleftrightarrow{1.1.3.7}$ (S)-Malate

(S)-Malate $\updownarrow$ 4.2.1.2

Succinyl-CoA $\xleftrightarrow{6.2.1.5}$ Succinate $\xleftrightarrow{1.3.5.1}$ Fumarate

3) S - Matrix

Metabolite	R(a)	R(b)	R(c)	R(d)	R(e)
ATP	-1	0	0	0	-1
ADP	+1	0	0	0	+1
phosphate	+1	0	0	0	+1
HCO_3^-	-1	0	0	0	0
pyruvate	-1	0	0	0	0
oxaloacetate	+1	-1	0	0	0
(S) - Malate	0	+1	-1	0	0
NAD^+	0	+1	0	0	0
NADH	0	-1	0	0	0
H^+	0	-1	0	0	0
Fumarate	0	0	+1	-1	0
H_2O	0	0	+1	0	0
Succinate	0	0	0	+1	-1
Quinone	0	0	0	+1	0
quinol	0	0	0	-1	0
CoA	0	0	0	0	-1
Succinyl-CoA	0	0	0	0	+1

4) E - Matrix

Metabolite	C	H	O	N	P	S
ATP	10	16	13	5	3	0
ADP	10	15	10	5	2	0
phosphate	0	3	4	0	1	0
HCO_3^-	1	1	3	0	0	0
pyruvate	3	4	3	0	0	0
oxaloacetate	4	4	5	0	0	0
(S)-Malate	4	6	5	0	0	0
NAD^+	21	27	14	7	2	0
NADH	21	28	14	7	2	0
H^+	0	1	0	0	0	0
fumarate	4	4	4	0	0	0
H_2O	0	2	1	0	0	0
Succinate	4	6	4	0	0	0
Quinone	6	4	2	0	0	0
Quinol	6	6	2	0	0	0
CoA	21	36	16	7	3	1
Succinyl-CoA	25	40	19	7	3	1

5) on doing $E \times S$

as $E_{17 \times 6}$ & $S_{17 \times 5}$ to make $E \times S$ feasible

lets take $E^T \times S$

$[6 \times 17 * 17 \times 5 = 6 \times 5]$

on doing $E^T \times S$ we have

6 rows

5 columns

6) $E^T \times S = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$

element (2, 1)
that means E^T second row of S first column
is <u>imbalance</u>

$E^T \times S$ signifies in Rxn 1 H is imbalanced on product side (one more H^+ extra)

ATP + pyruvate + HCO_3^- $\longrightarrow$ ADP + phosphate + oxaloacetate
adding one H^+ in reactant will make it <u>balanced</u>.

Balanced Rxn (a)

EC : 6.4.1.1

ATP + pyruvate + HCO_3^- + H^+ → ADP + phosphate + oxaloacetate

7) EC # 6.2.1.5

6. ligases
6.2 forming carbon sulfur bonds
6.2.1 Acid - thiol ligases (GDP - forming)
6.2.1.5 succinate - CoA ligase (ADP forming)

8) other pathway (in S. cerevisiae) which the reaction represented by EC - 6.2.1.5 participate in are,

- TCA cycle (citrate cycle)
- propanoate metabolism
- Exosome pathways

Gene encoding EC 6.2.1.5 → YGR244C

NCBI gene Id → 853159

NCBI protein Id → NP_011760

uniprot : P53312