

(b) What do you mean by an inner product on a vector space V ? Consider the inner product in

\mathbb{R}^2 defined by $\langle u, v \rangle = 4u_1v_1 + 5u_2v_2$ where $u = (u_1, u_2)$, $v = (v_1, v_2) \in \mathbb{R}^2$.

If $x = (1, 1)$ and $y = (5, -1)$, then find $\|x\|, \|y\|$ and $\langle x, y \rangle$. Also, show that in an inner product space V over \mathbb{R} ,

$$\langle u, v \rangle = \frac{1}{4} \|u+v\|^2 - \frac{1}{4} \|u-v\|^2, \forall u, v \in V.$$

$$2+3+5=10$$

7. (a) State Cayley-Hamilton theorem for matrices. Verify the theorem for the matrix.

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

and hence find M^{-1} .

(b) If possible, diagonalize the symmetric matrix

$$A = \begin{bmatrix} 6 & -2 & -1 \\ -2 & 6 & -1 \\ -1 & -1 & 5 \end{bmatrix}$$

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2024

MATHEMATICS

(Honours Core)

Paper : MAT-HC-5026

(Linear Algebra)

Full Marks : 80

Time : Three hours

The figures in the margin indicate full marks for the questions.

1. Answer the following questions as directed : $1 \times 10 = 10$

(a) Give reason why a line in \mathbb{R}^2 not passing through the origin is not a subspace of \mathbb{R}^2 .

(b) Express $W = \left\{ \begin{bmatrix} 6a-b \\ a+b \\ -7a \end{bmatrix} : a, b \in \mathbb{R} \right\}$

as span of two vectors.

Contd.

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(c) State whether the following statement is true or false :

"A finite dimensional vector space has exactly one basis."

(d) Find the dimension of the subspace of all vectors in \mathbb{R}^3 whose first and third entries are equal.

(e) 0 is an eigenvalue of a matrix A if and only if A is _____. (Fill in the blank)

(f) When is a square matrix said to be diagonalizable?

(g) Write the kernel of the linear transformation $T : \mathbb{R}^3 \rightarrow \mathbb{R}^3$ such that $T(x, y, z) = (x, 0, z)$.

(h) If $u = \begin{bmatrix} 2 \\ -5 \\ -1 \end{bmatrix}$ and $v = \begin{bmatrix} 3 \\ 2 \\ -3 \end{bmatrix}$, then compute $u \cdot v$.

(i) What is the distance between the vectors $\vec{u} = (7, 1)$ and $\vec{v} = (3, 2)$ in the \mathbb{R}^2 plane?

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(i) What do you mean by orthogonal vectors in an inner product space?

2. Answer the following questions: $2 \times 5 = 10$

(a) Let $A = \begin{bmatrix} -6 & 12 \\ -3 & 6 \end{bmatrix}$ and $w = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$.

(b) Determine if w is in null space of A . Let \mathbb{P}_3 be the vector space of all polynomials of degree at most 3. Are the vectors

$p(t) = 1+t^2$ and $q(t) = 1-t^2$ linearly independent in \mathbb{P}_3 ? Justify your answer.

(c) Find the eigenvalues of the matrix

$$A = \begin{bmatrix} 4 & 0 & 0 \\ -2 & 1 & 0 \\ 5 & 4 & -3 \end{bmatrix}$$

(d) Let $\mathcal{B} = \{b_1, b_2, b_3\}$ be a basis for a vector space V and $T : V \rightarrow \mathbb{R}^2$ be a linear transformation such that

$$T(x_1b_1 + x_2b_2 + x_3b_3) = \begin{bmatrix} 2x_1 - 4x_2 + 5x_3 \\ -x_2 + 3x_3 \end{bmatrix}.$$

Find the matrix for T relative to \mathcal{B} .

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(e) Let $v = (1, -2, 0)$ be a vector in \mathbb{R}^3 . Find a unit vector u in the same direction as v .

3. Answer **any four** questions : $5 \times 4 = 20$

(a) If a vector space V has a basis $\mathcal{B} = \{b_1, b_2, \dots, b_n\}$, then prove that any set in V containing more than n vectors must be linearly dependent.

(b) Let $b_1 = \begin{bmatrix} 1 \\ -3 \end{bmatrix}, b_2 = \begin{bmatrix} 2 \\ -5 \end{bmatrix}$ and $x = \begin{bmatrix} -2 \\ 1 \end{bmatrix}$.
 $3+2=5$

(i) Show that the set $\mathcal{B} = \{b_1, b_2\}$ is a basis of \mathbb{R}^2

(ii) Find the coordinate vector $[x]$ of x relative to \mathcal{B} .

(c) Given that 2 is an eigenvalue of the

$$\text{matrix } A = \begin{bmatrix} 4 & -1 & 6 \\ 2 & 1 & 6 \\ 2 & -1 & 8 \end{bmatrix}$$

Find a basis for the corresponding eigenspace.

(d) Prove that an $n \times n$ matrix A is diagonalizable if and only if A has n linearly independent eigenvectors.

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(e) Compute the orthogonal projection of $\begin{bmatrix} 1 \\ 7 \end{bmatrix}$ onto the line through $\begin{bmatrix} -4 \\ 2 \end{bmatrix}$ and the origin.

(f) If $\{u, v\}$ is an orthonormal set in an inner product space V , then show that $\|u - v\| = \sqrt{2}$.

Answer either (a) **or** (b) from each of the following questions :

4. (a) Find the rank and the nullity of the matrix

$$A = \begin{bmatrix} -2 & -5 & 8 & 0 & -17 \\ 1 & 3 & -5 & 1 & 5 \\ 3 & 11 & -19 & 7 & 1 \\ 1 & 7 & -13 & 5 & -3 \end{bmatrix}$$

(b) Let $b_1 = \begin{bmatrix} -9 \\ 1 \end{bmatrix}, b_2 = \begin{bmatrix} -5 \\ -1 \end{bmatrix}, c_1 = \begin{bmatrix} 1 \\ -4 \end{bmatrix}$ and

consider the bases for \mathbb{R}^2 given by $\mathcal{B} = \{b_1, b_2\}$ and $C = \{c_1, c_2\}$ $5+5=10$

(i) Find the change-of-coordinates matrix from C to \mathcal{B}

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(e) Let $v = (1, -2, 0)$ be a vector in \mathbb{R}^3 . Find a unit vector u in the same direction as v .

3. Answer **any four** questions : $5 \times 4 = 20$

(a) If a vector space V has a basis $\mathcal{B} = \{b_1, b_2, \dots, b_n\}$, then prove that any set in V containing more than n vectors must be linearly dependent.

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(i) Show that the set $\mathcal{B} = \{b_1, b_2\}$ is a basis of \mathbb{R}^2

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Find a basis for the corresponding eigenspace.

(d) Prove that an $n \times n$ matrix A is diagonalizable if and only if A has n linearly independent eigenvectors.

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(ii) Find the change-of-coordinates matrix from C to \mathcal{B}

5. (a) (i) If $n \times n$ matrices A and B are similar, then show that they have the same characteristic polynomial. 3

(ii) If $A = \begin{bmatrix} 4 & 0 & -2 \\ 2 & 5 & 4 \\ 0 & 0 & 5 \end{bmatrix}$ then find an

invertible matrix P and a diagonal matrix D such that $A = PDP^{-1}$ 7

(b) (i) Let $\mathcal{B} = \{b_1, b_2, b_3\}$ and $\mathcal{D} = \{d_1, d_2\}$ be bases for vector spaces V and W respectively. Let $T : V \rightarrow W$ be a linear transformation with the property that

$$T(b_1) = 3d_1 - 5d_2, T(b_2) = -d_1 + 6d_2, T(b_3) = 4d_2.$$

Find the matrix for T relative to \mathcal{B} and \mathcal{D} . 5

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(ii) Let A be a real 2×2 matrix with a complex eigenvalue

$\lambda = a - bi$ ($b \neq 0$) and an associated eigenvector v in \mathbb{C}^2 . Show that

$$A(Re v) = a Re v + b Im v \text{ and}$$

$$A(Im v) = b Re v + a Im v \quad 5$$

6. (a) Let $\mathcal{B} = \left\{ \begin{bmatrix} 2 \\ -5 \\ 1 \end{bmatrix}, \begin{bmatrix} 4 \\ -1 \\ 2 \end{bmatrix} \right\}$ be a basis for a

subspace W of \mathbb{R}^3 . Using the Gram-Schmidt process construct an orthogonal basis for W . Hence, find an orthonormal basis.

$$8+2=10$$

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