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MSc. Murtadha Al-Masoudy
Mathematics
2nd Year

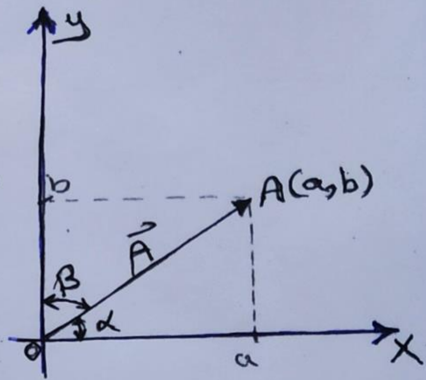
Vectors

vectors in plane

* $\vec{A} = \vec{OA} = ai + bj$

where

i, j :- are the fundamental unit vectors



* Length of $\vec{A} = |A| = \sqrt{a^2 + b^2}$

* Unit vector $= \vec{U_A} = \dfrac{\vec{A}}{|A|} = \dfrac{ai + bj}{|A|}$

$$\vec{U_A} = \frac{a}{|A|} i + \frac{b}{|A|} j \quad \text{——} \; (1)$$

but, $\cos\alpha = \sin\beta = \dfrac{a}{|A|}$ —— (2)

$\cos\beta = \sin\alpha = \dfrac{b}{|A|}$ —— (3)

Sub. eq (2) & eq (3) in eq (1) give:-

* $\vec{U_A} = \cos\alpha\, i + \cos\beta\, j$

or $\vec{U_A} = \cos\alpha\, i + \sin\alpha\, j$

* $\vec{A} = \vec{U_A} \cdot |A| = (\cos\alpha\, i + \sin\alpha\, j) \cdot |A|$

where

a, b :- Direction numbers

α, β :- Direction angles

$\cos\alpha, \cos\beta$:- Direction cosines

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EX.(1):- Find a vector in plane (R^2) of length (7 units) which makes angle (35°) with X-axis?

Answer:-

Since $|A| = 7$ & $\alpha = 35^\circ$

$$\vec{A} = |A|(\cos\alpha\, i + \sin\alpha\, j)$$

$$\therefore \vec{A} = 7 * (\cos 35^\circ i + \sin 35^\circ j)$$

$$= \boxed{5.7 i + 4 j}$$

EX(2):- Find the angle between the vector $\vec{A} = 2i + 3j$ and the X-axis?

Answer:-

$$|A| = \sqrt{(2)^2 + (3)^2} = \sqrt{13}$$

$$\cos\alpha = \frac{a}{|A|} = \frac{2}{\sqrt{13}} \Rightarrow \alpha = \cos^{-1}\left(\frac{2}{\sqrt{13}}\right)$$

$$\boxed{\alpha = 56.3^\circ}$$

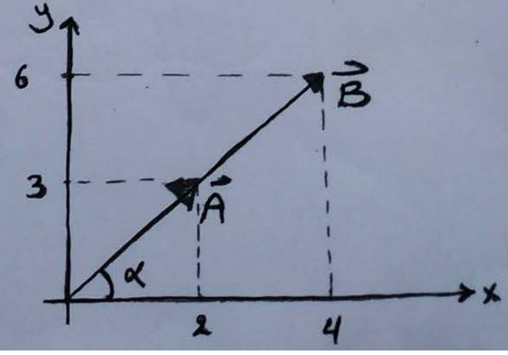
Note:- Two vectors are parallel if either is proportional to an other

i.e $\vec{A} \parallel \vec{B} \Leftrightarrow \vec{B} = t\vec{A}$ $(\vec{U}_A = \vec{U}_B)$

where t is a scalar quantity

EX(3):- The two vectors $\vec{A} = 2i + 3j$ and $\vec{B} = 4i + 6j$ are parallel, for the reason that

$$\vec{B} = 2(2i + 3j) = 2\vec{A}$$



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Vectors in aspace :-

$\vec{A} = \vec{OA} = a\vec{i} + b\vec{j} + c\vec{k}$

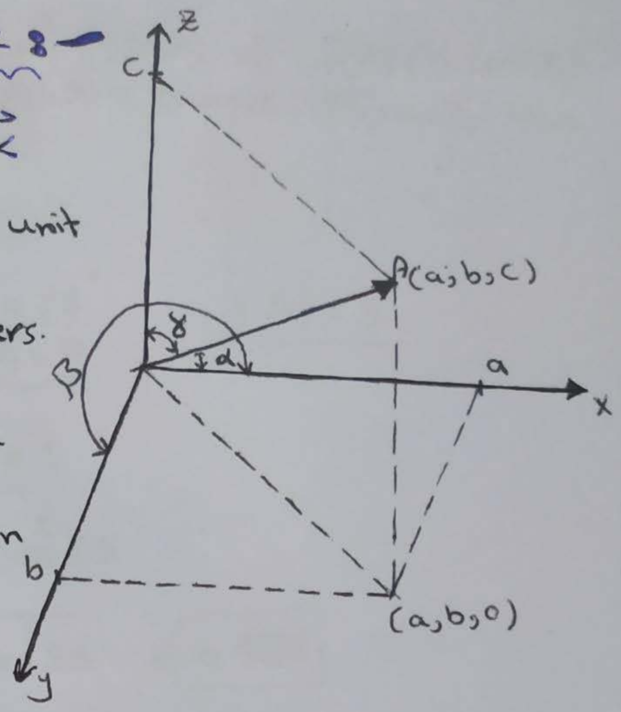
where :-

i, j, k :- are the fundamental unit vectors.

a, b, c :- Direction numbers.

α, β, γ :- Direction angle

$\cos\alpha, \cos\beta, \cos\gamma$:- Direction cosines.



$$* \ \vec{U_A} = \frac{\vec{A}}{|A|}$$

$$* \ \text{Length of } \vec{A} = |A| = \sqrt{a^2 + b^2 + c^2}$$

$$\vec{U_A} = \frac{ai + bj + ck}{|A|}$$

$$\vec{U_A} = \frac{a}{|A|} i + \frac{b}{|A|} j + \frac{c}{|A|} k$$

$$\cos\alpha = \frac{a}{|A|} \ ; \ \cos\beta = \frac{b}{|A|} \ ; \ \cos\gamma = \frac{c}{|A|}$$

$$\therefore \ \vec{U_A} = \cos\alpha \, i + \cos\beta \, j + \cos\gamma \, k$$

where

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$$

and $\vec{A} = |A| \cdot \vec{U_A}$

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EX(1):- Find a vector in R^3 (space) of length (5 units) that makes angles ($70°$) with the x-axis, ($85°$) with the y-axis

Answer:-

$\alpha = 70°$ $\quad B = 85°$ $\quad |A| = 5$

$\gamma = ?$ $\quad$ Vector $\vec{A} = ?$

$$\cos^2\alpha + \cos^2 B + \cos^2\gamma = 1$$

$$\cos^2\gamma = 1 - \cos^2 70 - \cos^2 85$$

$$\cos\gamma = \sqrt{1 - \cos^2 70 - \cos^2 85} = \boxed{0.935}$$

$$\vec{A} = |A| \cdot (\cos\alpha\, i + \cos B\, j + \cos\gamma\, K)$$

$$= 5 * (\cos 70°\, i + \cos 85°\, j + 0.935\, k)$$

$$= \boxed{5 * (1.7\, i + 0.435\, j + 0.935\, k)}$$

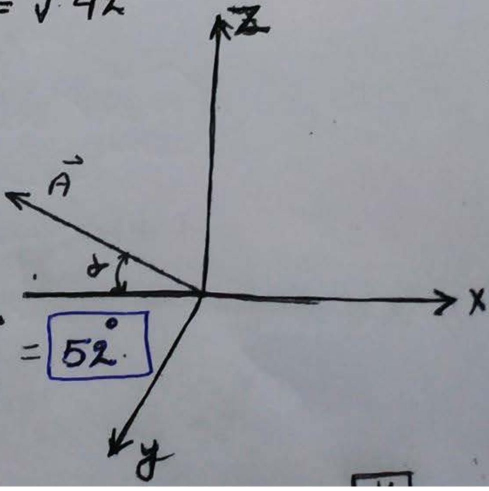
EX(2):- Find the acute angle between the x-axis and the vector $\vec{A} = -4i + 5j + K$?

Answer:-

$$|A| = \sqrt{(-4)^2 + (5)^2 + (1)^2} = \sqrt{42}$$

$$\cos\alpha = \frac{a}{|A|} = \frac{-4}{\sqrt{42}} = 0.617$$

$$\alpha = \cos^{-1}(0.617) \cong 128°$$



∴ The required angle is $180° - 128° = \boxed{52°}$

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Definition

(1) Algebrac addition :-

If $\vec{A} = a_1 i + b_1 j$ and $\vec{B} = a_2 i + b_2 j$

Then $\vec{A} + \vec{B} = (a_1 + a_2) i + (b_1 + b_2) j$

(2) Subtraction :-

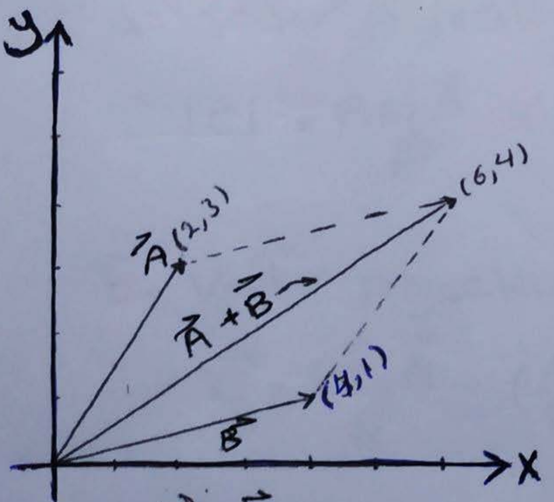
$\vec{A} - \vec{B} = (a_1 - a_2) i + (b_1 - b_2) j$

EX(1) :- If $\vec{A} = 2i + 3j$ and $\vec{B} = 4i + j$, then find $\vec{A} + \vec{B}$ and $\vec{B} - \vec{A}$ and sketch ?

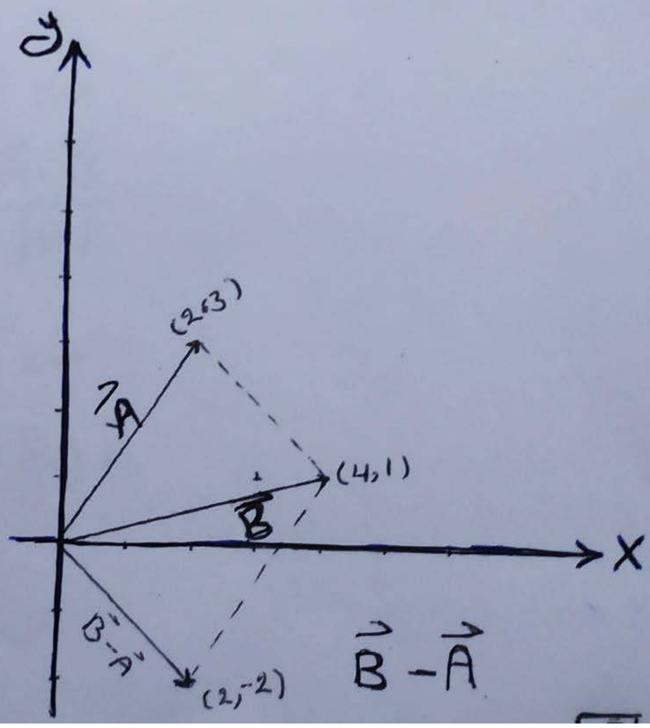
Answer :-

$$\vec{A} + \vec{B} = (2i + 3j) + (4i + j)$$
$$= (2+4) i + (3+1) j$$
$$= \boxed{6i + 4j}$$

$$\vec{B} - \vec{A} = (4i + j) - (2i + 3j)$$
$$= (4-2) i + (1-3) j$$
$$= \boxed{2i - 2j}$$



$\vec{A} + \vec{B}$



$\vec{B} - \vec{A}$

* Scalar product (Dot-product) :-

Let $\vec{A} = a_1 i + a_2 j + a_3 k$ and $\vec{B} = b_1 i + b_2 j + b_3 k$

* $\boxed{\vec{A} \cdot \vec{B} = |A| \cdot |B| \cdot \cos\theta}$

where θ is the angle between $\vec{A}$ and $\vec{B}$

Properties :-

1- $\vec{A} \cdot \vec{A} = |A|^2$

2- $\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A} = a_1 b_1 + a_2 b_2 + a_3 b_3$

3- $\cos\theta = \dfrac{\vec{A} \cdot \vec{B}}{|A| \cdot |B|} = \dfrac{a_1 b_1 + a_2 b_2 + a_3 b_3}{\sqrt{a_1^2 + a_2^2 + a_3^2} \cdot \sqrt{b_1^2 + b_2^2 + b_3^2}}$

4- $\vec{A} \perp \vec{B} \iff \vec{A} \cdot \vec{B} = 0$ [Orthogonal vectors]

5- $ai + bj \perp bi - aj$

6- Projection :-

a- Scalar projection :-

$$|C| = Proj_{\vec{B}} \vec{A} = \frac{\vec{A} \cdot \vec{B}}{|B|}$$

b- Vector projection :-

$$\vec{C} = \vec{Proj}_{\vec{B}} \vec{A} = \left(\frac{A \cdot B}{B \cdot B}\right) \vec{B}$$

EX(1):- Find the angle θ between $\vec{A} = i - 2j - 2K$ and $\vec{B} = 6i + 3j + 2K$?

Answer:-

$A \cdot B = (1)(6) + (-2)(3) + (-2)(2) = 6 - 6 - 4 = \boxed{-4}$

$|A| = \sqrt{(1)^2 + (-2)^2 + (-2)^2} = \sqrt{9} = \boxed{3}$

$|B| = \sqrt{(6)^2 + (3)^2 + (2)^2} = \sqrt{49} = \boxed{7}$

$|A| \cdot |B| = 3 * 7 = \boxed{21}$

$\therefore \cos\theta = \frac{A \cdot B}{|A| \cdot |B|} = \frac{-4}{21} \Rightarrow \theta = \cos^{-1}\left(\frac{-4}{21}\right)$

$\therefore \boxed{\theta \approx 101^\circ}$

EX(2):- Show that the two vectors $\vec{A} = 3i - 2j + K$ and $\vec{B} = 2j + 4K$ are orthogonal ?

Answer:-

$A \cdot B = (3)(0) + (-2)(2) + (1)(4)$
$= 0 - 4 + 4 = 0$

$\because A \cdot B = 0$

$\therefore$ The two vectors $\vec{A}$ and $\vec{B}$ are orthogonal

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EX(3):- Find the vector projection of ($\vec{B} = 6i + 3j + 2k$) onto ($\vec{A} = i - 2j - 2k$) and the Scalar Component of $\vec{B}$ in the direction of $\vec{A}$?

Answer:- The vector projection is

$$\text{Proj}_{\vec{A}} \vec{B} = \left(\frac{A \cdot B}{A \cdot A}\right) \vec{A}$$

$$= \left(\frac{(1)(6) + (-2)(3) + (-2)(2)}{(1)^2 + (-2)^2 + (-2)^2}\right)(i - 2j - 2k)$$

$$= \frac{6 - 6 - 4}{1 + 4 + 4}(i - 2j - 2k)$$

$$= \frac{-4}{9}(i - 2j - 2k)$$

$$= \boxed{\frac{-4}{9} i + \frac{8}{9} j + \frac{8}{9} k}$$

and the scalar component is

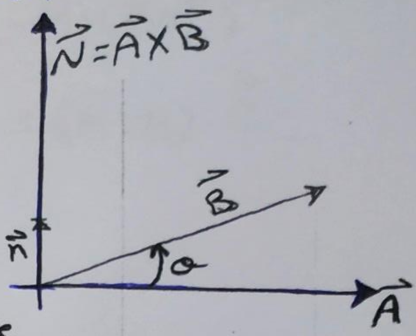
$$\text{Proj}_{\vec{A}} \vec{B} = \frac{\vec{A} \cdot \vec{B}}{|A|}$$

$$= \frac{(1)(6) + (-2)(3) + (-2)(2)}{\sqrt{(1)^2 + (-2)^2 + (-2)^2}}$$

$$= \frac{-4}{\sqrt{9}} = \boxed{\frac{-4}{3}}$$

Vector Product (Cross Product):-

$$* \boxed{\vec{N} = \vec{A} \times \vec{B} = \vec{n}\,|A||B| \sin\theta}$$



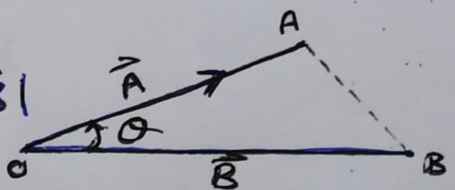
where $\vec{n}$ is the normal unit vector normal to $\vec{A}$ and $\vec{B}$

$$\vec{A} \times \vec{B} = \begin{vmatrix} i & j & k \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$$

where, $\vec{A} = a_1 i + a_2 j + a_3 k$
$\vec{B} = b_1 i + b_2 j + b_3 k$

Properties :-

1. $\vec{A} \times \vec{A} = 0$
2. $\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$
3. $\vec{A} \parallel \vec{B} \Leftrightarrow \vec{A} \times \vec{B} = 0$
4. Area of $\triangle OAB = \frac{1}{2} |\vec{A} \times \vec{B}|$



Ex(1):- Find $\vec{A} \times \vec{B}$ and $\vec{B} \times \vec{A}$ if $(\vec{A} = 2i + j + k)$ and $(\vec{B} = -4i + 3j + k)$?

Answer:-

$$\vec{A} \times \vec{B} = \begin{vmatrix} i & j & k \\ 2 & 1 & 1 \\ -4 & 3 & 1 \end{vmatrix}$$

$$\vec{A} \times \vec{B} = \begin{vmatrix} 1 & 1 \\ 3 & 1 \end{vmatrix} i - \begin{vmatrix} 2 & 1 \\ -4 & 1 \end{vmatrix} j + \begin{vmatrix} 2 & 1 \\ -4 & 3 \end{vmatrix} k$$

$$= [(1*1) - (3*1)]\,i - [(2*1) - (-4*1)]\,j + [(2*3) - (-4*1)]\,k$$

$$\boxed{\vec{A} \times \vec{B} = -2i - 6j + 10k} \text{ but } \boxed{\vec{B} \times \vec{A} = -\vec{A} \times \vec{B} = 2i + 6j - 10k}$$

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Triple Product:-

1- Scalar triple product $(\vec{A},\vec{B},\vec{C}) = \vec{A}\cdot(\vec{B}\times\vec{C})$

$$= (\vec{A}\times\vec{B})\cdot\vec{C}$$

Note:- Volume of box is

$$\boxed{V = |\vec{A}\cdot\vec{B}\times\vec{C}|}$$

Note:- Volume of pyramid (Tetrahedron)

$$\boxed{V = \frac{1}{6}|\vec{A}\cdot\vec{B}\times\vec{C}|}$$

2- Vector triple product

$$\vec{A}\times(\vec{B}\times\vec{C}) = (\vec{A}\cdot\vec{C})\vec{B} - (\vec{A}\cdot\vec{B})\vec{C}$$

Note:- $i\cdot i = j\cdot j = k\cdot k = 1$

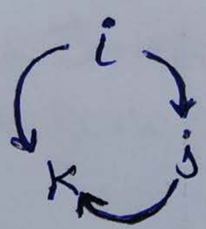
$i\times i = j\times j = k\times k = 0$

$i\cdot j = j\cdot k = k\cdot i = 0$

$i\times j = k$

$j\times k = i$

$k\times i = j$



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H.W No.1

(1)- Find the length and direction of each vector and the angle it makes with the positive X-axis

(a)/ $i + j$ (b)/ $\sqrt{3}\,i + j$ (c)/ $5i + 12j$

(2)- Find a unit vector in the direction of the vector from $P_1(1, 0, 1)$ to $P_2(3, 2, 0)$.

(3)- Find a vector 6 units long in the direction of $\vec{A} = 2i + 2j - K$.

(4)- Find the length and direction of $A \times B$ and $B \times A$

(a) $\vec{A} = 2i - 2j - K$ $\vec{B} = i + j + K$

(b) $\vec{A} = 2i$ $\vec{B} = -3j$

(5)- Find the area of the tringle whose vertices are $A(1,-1,0)$; $B(2,1,-1)$ and $C(-1,1,2)$

(6)- If $\vec{A} = 2i - j$ and $\vec{B} = i + 3j - 2K$, find $A \times B$ then calculate $(A \times B) \cdot A$

(7)- Let $\vec{A} = 5i - j + k$; $B = j - 5K$ and $\vec{C} = -15i + 3j - 3K$ which pairs of vector are (a) Perpendicular (b) Parallel ?