

SELF TEST (10)

The angle between the vectors \vec{A} and \vec{B} is 30° given that $|\vec{A}| = 2$, and $|\vec{B}| = 3$,

Calculate (a) $|\vec{A} + \vec{B}|$ (b) $|\vec{A} - \vec{B}|$

Ans. 4.83, 1.615

Q.14. A car weighing 10,000N on a hill which makes an angle of 20° with the horizontal. Find the components of car's weight parallel and perpendicular to the road?

Given Data:

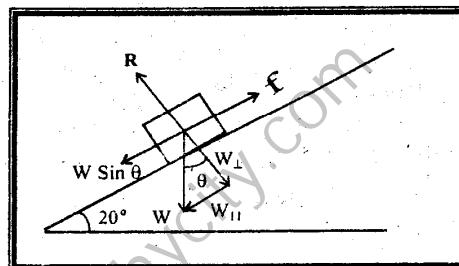
$$W = 10,000 \text{ N}$$

$$\theta = 20^\circ$$

To Find:

$$(a) W_{\parallel} = ?$$

$$(b) W_{\perp} = ?$$



Solution:

(a) The component of the weight of car parallel to the road is

$$W_{\parallel} = W \sin \theta$$

$$W_{\parallel} = 10,000 \sin 20^\circ$$

$$W_{\parallel} = 10,000 \times 0.342$$

$$\boxed{W_{\parallel} = 3420 \text{ N}} \quad \text{Ans.}$$

(b) The component of the weight of car perpendicular to the road is

$$W_{\perp} = W \cos \theta$$

$$W_{\perp} = 10,000 \cos 20^\circ$$

$$W_{\perp} = 10,000 \times 0.939$$

$$\boxed{W_{\perp} = 9390 \text{ N}} \quad \text{Ans.}$$

Q.15. Find the angle between $\vec{A} = 2\hat{i} + 2\hat{j} - \hat{k}$ and $\vec{B} = 6\hat{i} - 3\hat{j} + 2\hat{k}$. (1992)

Given Data:

$$\vec{A} = 2\hat{i} + 2\hat{j} - \hat{k}$$

$$\vec{B} = 6\hat{i} - 3\hat{j} + 2\hat{k}$$

To Find:

$$\theta = ?$$

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XI-Physics Chapter# 2, Page# 29

Solution:

We know that the dot product

$$\vec{A} \cdot \vec{B} = AB \cos \theta$$

Where ' θ ' is the required angle between \vec{A} and \vec{B}

Therefore

$$\cos \theta = \frac{\vec{A} \cdot \vec{B}}{AB} \quad (1)$$

$$\vec{A} \cdot \vec{B} = (2\hat{i} + 2\hat{j} - \hat{k}) \cdot (6\hat{i} - 3\hat{j} + 2\hat{k})$$

$$\vec{A} \cdot \vec{B} = 12(\hat{i} \cdot \hat{i}) - 6(\hat{j} \cdot \hat{j}) - 2(\hat{k} \cdot \hat{k})$$

$$\vec{A} \cdot \vec{B} = 12 - 6 - 2$$

$$\vec{A} \cdot \vec{B} = 4$$

$$\therefore \hat{i} \cdot \hat{i} = \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1$$

$$\therefore \hat{i} \cdot \hat{j} = \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0$$

And

$$|\vec{A}| = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

$$|\vec{A}| = \sqrt{(2)^2 + (2)^2 + (-1)^2}$$

$$|\vec{A}| = \sqrt{4+4+1}$$

$$|\vec{A}| = 3$$

$$|\vec{B}| = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

$$|\vec{B}| = \sqrt{(6)^2 + (-3)^2 + (2)^2}$$

$$|\vec{B}| = \sqrt{36+9+4}$$

$$|\vec{B}| = \sqrt{49}$$

$$|\vec{B}| = 7$$

Putting the value in Equation (1)

$$\cos \theta = \frac{4}{(3)(7)}$$

$$\cos \theta = \frac{4}{(3)(7)}$$

$$\cos \theta = 0.190$$

$$\theta = \cos^{-1}(0.190)$$

$$\boxed{\theta = 79^\circ} \quad \text{Ans.}$$

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XI-Physics Chapter# 2, Page# 30

Q.16. Find the projection of the vector $\vec{A} = \hat{i} - 2\hat{j} + \hat{k}$ onto the direction of vector $\vec{B} = 4\hat{i} - 4\hat{j} + 7\hat{k}$. (2013)

Given Data:

$$\vec{A} = \hat{i} - 2\hat{j} + \hat{k}$$

$$\vec{B} = 4\hat{i} - 4\hat{j} + 7\hat{k}$$

To Find:

Projection of \vec{A} onto $\vec{B} = ?$

Solution:

Projection of \vec{A} onto $\vec{B} = \vec{A} \cdot \hat{b}$

$$|\vec{B}| = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

$$|\vec{B}| = \sqrt{(4)^2 + (-4)^2 + (7)^2}$$

$$|\vec{B}| = \sqrt{16 + 16 + 49}$$

$$|\vec{B}| = \sqrt{81}$$

$$|\vec{B}| = 9$$

To find unit vector of \vec{B} ,

$$\hat{b} = \frac{\vec{B}}{|\vec{B}|}$$

$$\hat{b} = \frac{4\hat{i} - 4\hat{j} + 7\hat{k}}{9}$$

$$\hat{b} = \frac{4\hat{i}}{9} - \frac{4\hat{j}}{9} + \frac{7\hat{k}}{9}$$

$$\hat{b} = \frac{4}{9}\hat{i} - \frac{4}{9}\hat{j} + \frac{7}{9}\hat{k}$$

$$\text{Projection of } \vec{A} \text{ onto } \vec{B} = (\hat{i} - 2\hat{j} - \hat{k}) \cdot \left(\frac{4}{9}\hat{i} - \frac{4}{9}\hat{j} + \frac{7}{9}\hat{k} \right)$$

$$\therefore \hat{i} \cdot \hat{i} = \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1$$

$$\text{and } \hat{i} \cdot \hat{j} = \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0$$

$$= \frac{4}{9}(\hat{i} \cdot \hat{i}) + \frac{8}{9}(\hat{j} \cdot \hat{j}) + \frac{7}{9}(\hat{k} \cdot \hat{k})$$

$$= \frac{4}{9} + \frac{8}{9} + \frac{7}{9} = \frac{4+8+7}{9}$$

Projection of \vec{A} onto \vec{B} = $\frac{19}{9}$	Ans.
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XI-Physics Chapter# 2, Page# 31

SELF TEST (11)

Three vectors \vec{A} , \vec{B} and \vec{C} are such that.

$$\vec{A} = 3\hat{i} + \hat{j} - 2\hat{k}$$

$$\vec{B} = -\hat{i} + 3\hat{j} + 4\hat{k}$$

$$\vec{C} = 4\hat{i} - 2\hat{j} - 6\hat{k}$$

Find

(a) $\vec{A} \cdot \vec{B}$ (b) $\vec{B} \cdot \vec{C}$ (c) $\vec{A} \cdot \vec{C}$

(d) Angle between \vec{A} and \vec{B} (e) Angle between \vec{B} and \vec{C}

(f) Angle between \vec{A} and \vec{C} (g) projection of \vec{A} on to \vec{B}

(h) projection of \vec{B} on to \vec{C} (i) projection of \vec{A} on to \vec{C}

Q.17 Find the angles α , β , γ which the vector $\vec{A} = 3\hat{i} - 6\hat{j} + 2\hat{k}$ makes with the positive x, y, z axis respectively.

Given Data:

$$\vec{A} = 3\hat{i} - 6\hat{j} + 2\hat{k}$$

To Find:

$$\alpha = ?$$

$$\beta = ?$$

$$\gamma = ?$$

Solution:

$$|\vec{A}| = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

$$|\vec{A}| = \sqrt{(3)^2 + (-6)^2 + (2)^2}$$

$$|\vec{A}| = \sqrt{9 + 36 + 4}$$

$$|\vec{A}| = \sqrt{49}$$

$$|\vec{A}| = 7$$

According to direction cosines of vector \vec{A}

$$\cos \alpha = \frac{A_x}{|\vec{A}|} = \frac{3}{7}$$

$$\alpha = \cos^{-1}(0.428)$$

$$\boxed{\alpha = 64.62^\circ} \text{ Ans.}$$

$$\cos \beta = \frac{A_y}{|\vec{A}|} = \frac{-6}{7}$$

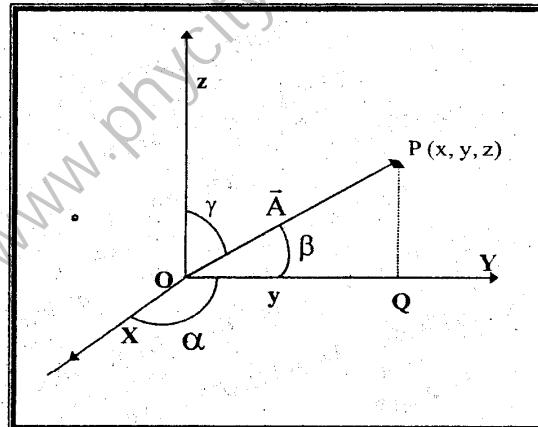
$$\beta = \cos^{-1}(-0.857)$$

$$\boxed{\beta = 149^\circ} \text{ Ans.}$$

$$\cos \gamma = \frac{A_z}{|\vec{A}|} = \frac{2}{7}$$

$$\gamma = \cos^{-1}(0.285)$$

$$\boxed{\gamma = 73.39^\circ} \text{ Ans.}$$



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XI-Physics Chapter# 2, Page# 32

Q.18 Find the work done in moving an object along a vector $\vec{r} = 3\hat{i} + 2\hat{j} - 5\hat{k}$ if the applied force is $\vec{F} = 2\hat{i} - \hat{j} - \hat{k}$.

Given Data:

$$\vec{r} = 3\hat{i} + 2\hat{j} - 5\hat{k}$$

$$\vec{F} = 2\hat{i} - \hat{j} - \hat{k}$$

To Find:

$$W = ?$$

Solution:

According to the definition of dot product.

$$W = \vec{F} \cdot \vec{r}$$

$$W = (2\hat{i} - \hat{j} - \hat{k}) \cdot (3\hat{i} + 2\hat{j} - 5\hat{k})$$

$$W = 6(\hat{i} \cdot \hat{i}) - 2(\hat{j} \cdot \hat{j}) + 5(\hat{k} \cdot \hat{k})$$

$$\therefore \hat{i} \cdot \hat{i} = \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1$$

$$\text{and } \hat{i} \cdot \hat{j} = \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0$$

$$W = 6 - 2 + 5$$

$$\therefore W = 9 \text{ units} \quad \text{Ans.}$$

Q.19. Find the work done by a force 30,000N in moving an object through a distance of 45m when: (a) the force is in the direction of motion; and (b) the force makes an angle of 40° to the direction of motion. Find the rate at which the force is working at a time when the velocity is 2m/sec.

Given Data:

$$F = 30,000 \text{ N}$$

$$d = 45 \text{ m}$$

$$V = 2 \text{ m/Sec.}$$

$$(a) \theta = 0^\circ$$

$$(b) \theta = 40^\circ$$

To Find:

$$(a) P = ? \quad (b) P = ?$$

$$W = ? \quad W = ?$$

Solution:

$$(a) W = \vec{F} \cdot \vec{d}$$

$$W = Fd \cos \theta$$

$$W = (30,000)(45) \cos 0^\circ \quad \because \cos 0^\circ = 1$$

$$W = 1,35,0000 \text{ joules} \quad \text{Ans.}$$

$$P = \vec{F} \cdot \vec{V}$$

$$P = FV \cos \theta$$

$$P = (30,000)(2) \cos 0^\circ$$

$$P = 60,000 \times 1$$

$$P = 60000 \text{ watts} \quad \text{Ans.}$$

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XI-Physics Chapter# 2, Page# 33

(b) $W = \vec{F} \cdot \vec{d}$
 $W = Fd \cos \theta$
 $W = (30,000)(45) \cos 40^\circ$
 $W = 1350000 \times 0.766$
 $W = 1034100 \text{ joules.} \boxed{\text{Ans.}}$

$P = \vec{F} \cdot \vec{V}$
 $P = FV \cos \theta$
 $P = (30,000)(2) \cos 40^\circ$
 $P = 60,000 \times 0.766$
 $P = 60,000 \times 0.766$
 $P = 45960 \text{ watts.} \boxed{\text{Ans.}}$

Q.20. Two vectors \vec{A} and \vec{B} are such that $|\vec{A}|=3$, $|\vec{B}|=4$, and $\vec{A} \cdot \vec{B}=-5$, find;

- (a) Find the angle between \vec{A} and \vec{B}
- (b) The length $|\vec{A} + \vec{B}|$ and $|\vec{A} - \vec{B}|$ (2011 F)
- (c) The angle between $(\vec{A} + \vec{B})$ and $(\vec{A} - \vec{B})$ (2008)

Given Data:

$$|\vec{A}| = 3$$

$$|\vec{B}| = 4$$

$$\vec{A} \cdot \vec{B} = -5$$

To Find:

- (a) Angle between \vec{A} and $\vec{B} = ?$
- (b) $|\vec{A} + \vec{B}|$ and $|\vec{A} - \vec{B}| = ?$
- (c) Angle between $(\vec{A} + \vec{B})$ and $(\vec{A} - \vec{B}) = ?$

Solution:

We know in dot product

(a) $\vec{A} \cdot \vec{B} = |\vec{A}| |\vec{B}| \cos \theta$

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

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

$$\cos \theta = \frac{-5}{(3)(4)}$$

$$\theta = \cos^{-1}(-0.416)$$

$$\theta = 114.6^\circ \boxed{\text{Ans.}}$$

(b) $|\vec{A}| = \sqrt{\vec{A} \cdot \vec{A}}$ then

$$|\vec{A} + \vec{B}| = \sqrt{(\vec{A} + \vec{B}) \cdot (\vec{A} + \vec{B})}$$

$$= \sqrt{\vec{A} \cdot \vec{A} + \vec{A} \cdot \vec{B} + \vec{B} \cdot \vec{A} + \vec{B} \cdot \vec{B}}$$

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XI-Physics Chapter# 2, Page# 34

$$\vec{B} \cdot \vec{B} = |\vec{B}|^2 \text{ or } \vec{A} \cdot \vec{A} = |\vec{A}|^2$$

$$\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$$

$$|\vec{A} + \vec{B}| = \sqrt{|\vec{A}|^2 + 2\vec{A} \cdot \vec{B} + |\vec{B}|^2}$$

$$|\vec{A} + \vec{B}| = \sqrt{(3)^2 + 2(-5) + (4)^2}$$

$$|\vec{A} + \vec{B}| = \sqrt{9 - 10 + 16}$$

$$|\vec{A} + \vec{B}| = \sqrt{15} \text{ Ans.}$$

And $|\vec{A} - \vec{B}| = \sqrt{(\vec{A} - \vec{B}) \cdot (\vec{A} - \vec{B})}$

$$= \sqrt{\vec{A} \cdot \vec{A} - \vec{A} \cdot \vec{B} - \vec{B} \cdot \vec{A} + \vec{B} \cdot \vec{B}}$$

$$\vec{A} \cdot \vec{A} = |\vec{A}|^2 \quad \vec{B} \cdot \vec{B} = |\vec{B}|^2 \quad \vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$$

$$|\vec{A} - \vec{B}| = \sqrt{|\vec{A}|^2 - 2\vec{A} \cdot \vec{B} + |\vec{B}|^2}$$

$$|\vec{A} - \vec{B}| = \sqrt{|\vec{A}|^2 + 2\vec{A} \cdot \vec{B} + |\vec{B}|^2}$$

$$|\vec{A} - \vec{B}| = \sqrt{(3)^2 - 2(-5) + (4)^2}$$

$$|\vec{A} - \vec{B}| = \sqrt{9 + 10 + 16}$$

$$|\vec{A} - \vec{B}| = \sqrt{35} \text{ Ans.}$$

(c) Let $\vec{A} + \vec{B} = \vec{C}$

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

Then $\vec{C} \cdot \vec{D} = |\vec{C}| |\vec{D}| \cos \theta$

$$\cos \theta = \frac{\vec{C} \cdot \vec{D}}{|\vec{C}| |\vec{D}|}$$

$$\cos \theta = \frac{(\vec{A} + \vec{B}) \cdot (\vec{A} - \vec{B})}{|\vec{A} + \vec{B}| |\vec{A} - \vec{B}|}$$

$$\cos \theta = \frac{\vec{A} \cdot \vec{A} - \vec{A} \cdot \vec{B} + \vec{B} \cdot \vec{A} - \vec{B} \cdot \vec{B}}{|\vec{A} + \vec{B}| |\vec{A} - \vec{B}|}$$

$$\therefore \vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A} \quad \vec{A} \cdot \vec{A} = |\vec{A}|^2 = \vec{B} \cdot \vec{B} = |\vec{B}|^2$$

$$\cos \theta = \frac{|\vec{A}|^2 - \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{B} - |\vec{B}|^2}{|\vec{A} + \vec{B}| |\vec{A} - \vec{B}|}$$

$$\cos \theta = \frac{|\vec{A}|^2 - |\vec{B}|^2}{|\vec{A} + \vec{B}| |\vec{A} - \vec{B}|}$$

$$\cos \theta = \frac{(3)^2 - (4)^2}{(\sqrt{15})(\sqrt{35})}$$

SELF TEST (12)

Example 2.10

Two vectors \vec{A} and \vec{B} are such that

$$|\vec{A}| = 4 \text{ and } |\vec{B}| = 6 \quad \vec{A} \cdot \vec{B} = 13.5$$

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XI-Physics Chapter# 2, Page# 35

$$\cos \theta = \frac{9 - 16}{(3.87)(5.91)}$$

$$\cos \theta = \frac{-7}{22.8717}$$

$$\theta = \cos^{-1}(-0.306)$$

$$\boxed{\theta = 107.8^\circ \text{ Ans.}}$$

Find the magnitude of $|\vec{A} - \vec{B}|$ and $|\vec{A} + \vec{B}|$

$$\boxed{\sqrt{25}, \sqrt{79} \text{ Ans.}}$$

Q.21. If $\vec{A} = 2\hat{i} - 3\hat{j} - \hat{k}$
 $\vec{B} = \hat{i} + 4\hat{j} - 2\hat{k}$

Find (a) $\vec{A} \times \vec{B}$ (b) $\vec{B} \times \vec{A}$ (c) $(\vec{A} + \vec{B}) \times (\vec{A} - \vec{B})$

Solution:

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

$$\begin{aligned} \vec{A} \times \vec{B} &= \hat{i} \begin{vmatrix} -3 & -1 \\ 4 & -2 \end{vmatrix} - \hat{j} \begin{vmatrix} 2 & -1 \\ 1 & -2 \end{vmatrix} + \hat{k} \begin{vmatrix} 2 & -3 \\ 1 & 4 \end{vmatrix} \\ &= \hat{i} \{(-3)(-2) - (-1)(4)\} - \hat{j} \{(2)(-2) - (-1)(1)\} + \hat{k} \{(2)(4) - (-3)(1)\} \\ &= \hat{i}(+6+4) - \hat{j}(-4+1) + \hat{k}(8+3) \end{aligned}$$

$$\boxed{\vec{A} \times \vec{B} = 10\hat{i} + 3\hat{j} + 11\hat{k} \text{ Ans.}}$$

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

$$\begin{aligned} \vec{B} \times \vec{A} &= \hat{i} \begin{vmatrix} 4 & -2 \\ -3 & -1 \end{vmatrix} - \hat{j} \begin{vmatrix} 1 & -2 \\ 2 & -1 \end{vmatrix} + \hat{k} \begin{vmatrix} 1 & 4 \\ 2 & -3 \end{vmatrix} \\ &= \hat{i}(-4-6) - \hat{j}(-1+4) + \hat{k}(-3-8) \end{aligned}$$

$$\boxed{\vec{B} \times \vec{A} = -10\hat{i} - 3\hat{j} - 11\hat{k} \text{ Ans.}}$$

$$(c) (\vec{A} + \vec{B}) \times (\vec{A} - \vec{B})$$

$$\vec{A} = 2\hat{i} - 3\hat{j} - \hat{k}$$

$$\vec{B} = \hat{i} + 4\hat{j} - 2\hat{k}$$

$$\vec{A} + \vec{B} = 3\hat{i} + \hat{j} - 3\hat{k}$$

$$\text{And } \vec{A} = 2\hat{i} - 3\hat{j} - \hat{k}$$

$$\vec{B} = \pm \hat{i} \pm 4\hat{j} \mp 2\hat{k}$$

$$\vec{A} - \vec{B} = \hat{i} - 7\hat{j} + \hat{k}$$

$$(a) (\vec{A} + \vec{B}) \times (\vec{A} - \vec{B}) = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3 & 1 & -3 \\ 1 & -7 & 1 \end{vmatrix}$$

$$= \hat{i} \begin{vmatrix} 1 & -3 \\ -7 & 1 \end{vmatrix} - \hat{j} \begin{vmatrix} 3 & -3 \\ 1 & 1 \end{vmatrix} + \hat{k} \begin{vmatrix} 3 & 1 \\ 1 & -7 \end{vmatrix}$$

$$= \hat{i}(1-21) - \hat{j}(3+3) + \hat{k}(-21-1)$$

$$(\vec{A} + \vec{B}) \times (\vec{A} - \vec{B}) = -20\hat{i} - 6\hat{j} - 22\hat{k} \quad \text{Ans.}$$

Q.22. Determine the unit vector perpendicular to the plane of $\vec{A} = 2\hat{i} - 6\hat{j} - 3\hat{k}$ and $\vec{B} = 4\hat{i} + 3\hat{j} - \hat{k}$.

(2011)

Given Data:

$$\vec{A} = 2\hat{i} - 6\hat{j} - 3\hat{k}$$

$$\vec{B} = 4\hat{i} + 3\hat{j} - \hat{k}.$$

To Find:

Unit vector perpendicular to the plane of \vec{A} and \vec{B} = ?

Solution:

Let \vec{C} be a vector which is perpendicular to the plane of \vec{A} and \vec{B} then.

$$\vec{C} = \vec{A} \times \vec{B}$$

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 2 & -6 & -3 \\ 4 & 3 & -1 \end{vmatrix}$$

$$\vec{A} \times \vec{B} = \hat{i} \begin{vmatrix} -6 & -3 \\ 3 & -1 \end{vmatrix} - \hat{j} \begin{vmatrix} 2 & -3 \\ 4 & -1 \end{vmatrix} + \hat{k} \begin{vmatrix} 2 & -6 \\ 4 & 3 \end{vmatrix}$$

$$\vec{A} \times \vec{B} = \hat{i}(6+9) - \hat{j}(-2+12) + \hat{k}(6+24)$$

$$\vec{C} = 15\hat{i} - 10\hat{j} + 30\hat{k}.$$

Now,

$$|\vec{C}| = \sqrt{C_x^2 + C_y^2 + C_z^2}$$

$$|\vec{C}| = \sqrt{(15)^2 + (-10)^2 + (30)^2}$$

$$|\vec{C}| = \sqrt{225 + 100 + 900}$$

$$|\vec{C}| = \sqrt{1225}$$

$$|\vec{C}| = 35$$

Unit vector perpendicular to the plane of \vec{A} and \vec{B} = $\hat{C} = \frac{\vec{C}}{|\vec{C}|}$

$$\hat{C} = \frac{15\hat{i} - 10\hat{j} + 30\hat{k}}{35}$$

$$\hat{C} = \frac{15\hat{i}}{35} - \frac{10\hat{j}}{35} + \frac{30\hat{k}}{35}$$

$$\hat{C} = \frac{3\hat{i}}{7} - \frac{2\hat{j}}{7} + \frac{6\hat{k}}{7} \quad \text{Ans.}$$

SELF TEST (13)

(i) Determine the vector perpendicular to the plane of $\vec{A} = 4\hat{i} - \hat{j} + \hat{k}$ and

$$\vec{B} = 4\hat{i} + 3\hat{j} + \hat{k}$$

$$\text{Ans. } \frac{-4}{\sqrt{272}}\hat{i} + \frac{16}{\sqrt{272}}\hat{j} + \hat{k}$$

(ii) Determine the unit vector perpendicular to the plane of $\vec{A} = 5\hat{i} - \hat{j} + 2\hat{k}$

$$\text{and } \vec{B} = 4\hat{i} + \hat{j} + 2\hat{k}$$

$$\text{Ans. } \frac{-4}{\sqrt{101}}\hat{i} - \frac{2}{\sqrt{101}}\hat{j} + \frac{9}{\sqrt{101}}\hat{k}$$

Q.23. Using the definition of vector product, prove the law of sine for a plane triangle of sides a, b and c . i.e.

Prove That:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

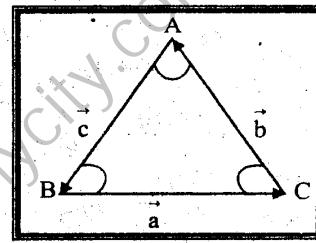
Solution:

Consider a triangle ABC

$$\text{Magnitude of area of } \Delta = \frac{1}{2} \left| \vec{a} \times \vec{b} \right| = \frac{1}{2} ab \sin C$$

$$\text{OR } \frac{1}{2} \left| \vec{c} \times \vec{a} \right| = \frac{1}{2} ca \sin B$$

$$\text{OR } \frac{1}{2} \left| \vec{b} \times \vec{c} \right| = \frac{1}{2} bc \sin A$$



So from eq (i), (ii) and (iii)

$$\frac{1}{2} ab \sin C = \frac{1}{2} bc \sin A = \frac{1}{2} ca \sin B$$

$$ab \sin C = bc \sin A = ca \sin B$$

Divide all the terms by abc

$$\frac{ab \sin C}{abc} = \frac{bc \sin A}{abc} = \frac{ca \sin B}{abc}$$

$$\frac{\sin C}{c} = \frac{\sin A}{a} = \frac{\sin B}{b}$$

OR	$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$	Proved.
----	--	---------

$$\text{OR } \frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

Q.24. If \vec{r}_1 and \vec{r}_2 are the position vectors (both lie on xy plane) making angle θ_1 and θ_2 with the positive x – axis measured counter clockwise, fine their vector product.

(i) when $|\vec{r}_1| = 4 \text{ cm}$, $\theta_1 = 30^\circ$ and $|\vec{r}_2| = 3 \text{ cm}$, $\theta_2 = 90^\circ$

Given Data:

$$|\vec{r}_1| = 4 \text{ cm}, \theta_1 = 30^\circ$$

$$|\vec{r}_2| = 3 \text{ cm}, \theta_2 = 90^\circ$$

To Find:

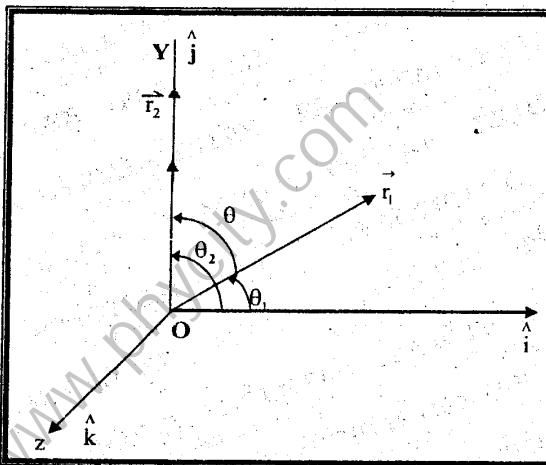
$$|\vec{r}_1 \times \vec{r}_2| = ?$$

Solution:

$$\theta = \theta_2 - \theta_1$$

$$\theta = 90^\circ - 30^\circ$$

$$\theta = 60^\circ$$



Now,

$$|\vec{r}_1 \times \vec{r}_2| = \vec{r}_1 \cdot \vec{r}_2 \sin \theta$$

$$|\vec{r}_1 \times \vec{r}_2| = 12 \left(\frac{\sqrt{3}}{2} \right)$$

$$|\vec{r}_1 \times \vec{r}_2| = 6\sqrt{3} \text{ cm}^2 \quad \text{Ans.}$$

SELF TEST (14)

If \vec{r}_1 and \vec{r}_2 are the position vectors (both lie on xy plane) making angle θ_1 and θ_2 with the positive x – axis measured counter clockwise, fine their vector product.

(ii) $|\vec{r}_1| = 6 \text{ cm}$ $|\vec{r}_2| = 3 \text{ cm}$ $\theta_1 = 220^\circ$ $\theta_2 = 40^\circ$ Ans. (Zero)

(iii) $|\vec{r}_1| = 10 \text{ cm}$ $|\vec{r}_2| = 9 \text{ cm}$ $\theta_1 = 20^\circ$ $\theta_2 = 110^\circ$ Ans. (90 cm^2)

EXTRA PROBLEMS

Q#1. Two forces of equal magnitude are acting at a point. Find the angle between the forces when the magnitude of resultant is also equal to the magnitude of either of these forces. (2003 P.M)

Given Data:

$$|\vec{F}_1| = |\vec{F}_2| = |\vec{F}|$$

To Find:

$$\theta = ?$$

Solution:

$$F = \sqrt{F_1^2 + F_2^2 + 2FF_2 \cos \theta}$$

$$F = F_1 = F_2$$

$$F = \sqrt{F^2 + F^2 + 2FF \cos \theta}$$

$$F = \sqrt{2F^2 + 2F^2 \cos \theta}$$

$$F = \sqrt{2F^2 (1 + \cos \theta)}$$

$$F = (\sqrt{2F^2 (1 + \cos \theta)})^2$$

$$F^2 = 2F^2 (1 + \cos \theta)$$

$$1 = 2(1 + \cos \theta)$$

$$\frac{1}{2} = 1 + \cos \theta$$

$$\frac{1}{2} - 1 = \cos \theta$$

$$\frac{1 - 2}{2} = \cos \theta$$

$$-\frac{1}{2} = \cos \theta$$

$$0 = \cos^{-1} (-0.5)$$

$$\theta = 120^\circ \quad \text{Ans.}$$

SELF TEST (15)

Two vectors of magnitude 10 units and 15 units are acting at a point. The magnitude of their resultant is 20 units. Find the angle between them. (1993)

Ans: 75.52°

Q#2. Find the work done in moving an object along a straight line from (3, 2, -1) to (2, -1, 4) in a force field which is given by $\vec{F} = 4\hat{i} - 3\hat{j} + 2\hat{k}$.

Given Data:

$$(x_1, y_1, z_1) = (3, 2, -1)$$

$$(x_2, y_2, z_2) = (2, -1, 4)$$

$$\vec{F} = 4\hat{i} - 3\hat{j} + 2\hat{k}$$

To Find:

$$W = ?$$

According to the definition of work done.

$$W = \vec{F} \cdot \vec{d}$$

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XI-Physics Chapter# 2, Page# 40

Where \vec{F} is applied force, \vec{d} is displacement which is given by $\vec{d} = \overline{AB}$

$$\begin{aligned}
 \vec{d} &= (x_2 - x_1) \hat{i} + (y_2 - y_1) \hat{j} + (z_2 - z_1) \hat{k} \\
 \vec{d} &= [2 - 3] \hat{i} + [(-1) - 2] \hat{j} + [4 - (-1)] \hat{k} \\
 \vec{d} &= [-1] \hat{i} + [-3] \hat{j} + [5] \hat{k} \\
 \vec{d} &= -\hat{i} - 3\hat{j} + 5\hat{k} \\
 W &= \vec{F} \cdot \vec{d} = (4\hat{i} - 3\hat{j} + 2\hat{k}) \cdot (-\hat{i} - 3\hat{j} + 5\hat{k}) \\
 &= (4)(-1)(\hat{i} \cdot \hat{i}) + (4)(-3)(\hat{i} \cdot \hat{j}) + (4)(5)(\hat{i} \cdot \hat{k}) \\
 &\quad + (-3)(-1)(\hat{j} \cdot \hat{i}) + (-3)(-3)(\hat{j} \cdot \hat{j}) + (-3)(5)(\hat{j} \cdot \hat{k}) \\
 &\quad + (2)(-1)(\hat{k} \cdot \hat{i}) + (2)(-3)(\hat{k} \cdot \hat{j}) + (2)(5)(\hat{k} \cdot \hat{k}) \\
 \hat{i} \cdot \hat{i} &= \hat{j} \cdot \hat{j} = \hat{k} \cdot \hat{k} = 1 \\
 \hat{i} \cdot \hat{j} &= \hat{j} \cdot \hat{k} = \hat{k} \cdot \hat{i} = 0 \\
 W &= (4)(1)(\hat{i} \cdot \hat{i}) + (-3)(\hat{j} \cdot \hat{j}) + (2)(5)\hat{k} \cdot \hat{k} \\
 W &= -4 + 9 + 10
 \end{aligned}$$

W = 15 units Ans.

To find out angle θ we need to know the magnitude of the vectors \vec{F} and \vec{r}

$$\begin{aligned}
 |\vec{F}| &= \sqrt{(4)^2 + (-3)^2 + (2)^2} \\
 &= \sqrt{16 + 9 + 25} \\
 |\vec{F}| &= \sqrt{29} \\
 |\vec{d}| &= \sqrt{(-1)^2 + (-3)^2 + (5)^2} \\
 &= \sqrt{1 + 9 + 25} \\
 |\vec{d}| &= \sqrt{35}
 \end{aligned}$$

$$\cos \theta = \frac{\vec{F} \cdot \vec{d}}{|\vec{F}| |\vec{d}|}$$

$$\cos \theta = \frac{15}{\sqrt{29} \sqrt{35}} = 0.47$$

$$\theta = \cos^{-1}(0.47)$$

$\theta = 61.91^\circ$ Ans.

SELF TEST (16)

An object moves along a straight line from (3, 2, -6) to (14, 13, 9) when a uniform force $\vec{F} = 4\hat{i} + \hat{j} + 3\hat{k}$ acts on it. Find the work done and the angle between the force and displacement. (2001)

17.98 Unit
 18.83°

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Xi-Physics Chapter# 2, Page# 41

Q#3. Two sides of triangle are formed by the vector $\vec{A} = 3\hat{i} + 6\hat{j} - 2\hat{k}$ and vector $\vec{B} = 4\hat{i} - \hat{j} + 3\hat{k}$. Determine the area of the triangle.

Given Data:

$$\vec{A} = 3\hat{i} + 6\hat{j} - 2\hat{k}$$

$$\vec{B} = 4\hat{i} - \hat{j} + 3\hat{k}$$

To Find:

Area of triangle = ?

Solution:

$$\text{Area of triangle} = \frac{1}{2} |\vec{A} \times \vec{B}|$$

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3 & 6 & -2 \\ 4 & -1 & 3 \end{vmatrix}$$

$$= \hat{i} \begin{vmatrix} 6 & -2 \\ -1 & 3 \end{vmatrix} - \hat{j} \begin{vmatrix} 3 & -2 \\ 4 & 3 \end{vmatrix} + \hat{k} \begin{vmatrix} 3 & 6 \\ 4 & -1 \end{vmatrix}$$

$$= \hat{i}(18-2) - \hat{j}(9+8) + \hat{k}(-3-24)$$

$$\therefore \vec{A} \times \vec{B} = 16\hat{i} - 17\hat{j} - 27\hat{k}$$

$$\text{and } |\vec{A} \times \vec{B}| = \sqrt{(16)^2 + (-17)^2 + (-27)^2} = \sqrt{1274}$$

$$\text{Now, Area of } \Delta = \frac{1}{2} |\vec{A} \times \vec{B}|$$

$$\boxed{\text{Area of } \Delta = \frac{1}{2} \sqrt{1274} \text{ Ans.}}$$

SELF TEST (17)

(i) Two sides of triangle are formed by the vector $\vec{A} = 4\hat{i} - 3\hat{j} + 2\hat{k}$ and vector $\vec{B} = \hat{i} - \hat{j} + 5\hat{k}$.

Determine the area of the triangle.

$$\text{Ans: } \frac{1}{2} \sqrt{494}$$

(ii) Two sides of parallelogram are formed by vector $\vec{A} = 3\hat{i} - \hat{j} + 4\hat{k}$ and vector $\vec{B} = 2\hat{i} - \hat{j} + 5\hat{k}$. Determine the area of the parallelogram.

$$\text{Ans: } \sqrt{51}$$

(iii) If $\vec{P} = 2\hat{i} - 2\hat{j} + 3\hat{k}$, and $\vec{Q} = \hat{i} + 2\hat{j} - \hat{k}$ find a unit vector perpendicular to the plane containing both \vec{P} and \vec{Q} . If \vec{P} and \vec{Q} form the sides of a parallelogram, find the area of the parallelogram. (2007 Failures)

Q#4.

Prove That:

$$\left| \vec{A} \times \vec{B} \right|^2 + (\vec{A} \cdot \vec{B})^2 = A^2 B^2 \quad (2013)$$

Solution:

$$\begin{aligned} L.H.S &= \left| \vec{A} \times \vec{B} \right|^2 + (\vec{A} \cdot \vec{B})^2 \\ &= (AB \sin \theta)^2 + (AB \cos \theta)^2 \because \left| \vec{A} \times \vec{B} \right| = AB \sin \theta \\ &= A^2 B^2 \sin^2 \theta + A^2 B^2 \cos^2 \theta \because \vec{A} \cdot \vec{B} = AB \cos \theta \\ &= A^2 B^2 (\sin^2 \theta + \cos^2 \theta) \quad \because \sin^2 \theta + \cos^2 \theta = 1 \end{aligned}$$

$$L.H.S = A^2 B^2 \times 1$$

$$\begin{aligned} L.H.S &= A^2 B^2 \\ &= R.H.S \end{aligned}$$

Q#5. Find the value of p for which the following vectors are perpendicular to each other. (1996, 2009)

$$\vec{A} = \hat{i} + p\hat{j} + 3\hat{k} \quad \vec{B} = 3\hat{i} + 3\hat{j} - 4\hat{k}$$

When the vectors are perpendicular to each other then $\vec{A} \cdot \vec{B} = 0$

$$\vec{A} \cdot \vec{B} = (\hat{i} + p\hat{j} + 3\hat{k}) \cdot (3\hat{i} + 3\hat{j} - 4\hat{k})$$

$$\therefore \vec{A} \cdot \vec{B} = A_x B_x + A_y B_y + A_z B_z$$

$$\vec{A} \cdot \vec{B} = 1 \times 3 + p \times 3 + 3 \times -4$$

$$\vec{A} \cdot \vec{B} = 3 + 3p - 12$$

$$\vec{A} \cdot \vec{B} = 3p - 9$$

$$\vec{A} \cdot \vec{B} = 0$$

$$0 = 3p - 9$$

$$3p = 9$$

$$p = 9/3$$

$$\boxed{p = 3}$$

SELF TEST (19)

Find the value of λ for which the following vectors are perpendicular to each.

$$\vec{A} = 4\hat{i} + 2\lambda\hat{j} + \hat{k} \quad \vec{B} = 3\hat{i} + 2\hat{j} + 5\hat{k}$$

$$\boxed{\text{Ans: } -\frac{17}{4}}$$

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XI-Physics Chapter# 2, Page# 43

Q.6: The pilot of a plane flies 300km in the due east direction, then 100km 60° in the north-east direction and then 200km due north. Determine the resultant displacement and the direction of the resultant w.r.t + Ve X – axis using rectangular component method. (2008 Failures)

Given Data:

$$|\vec{A}_1| = 300\text{km}$$

$$|\vec{A}_2| = 100\text{km}$$

$$|\vec{A}_3| = 200\text{km}$$

$$\theta_1 = 0^\circ$$

$$\theta_2 = 60^\circ$$

$$\theta_3 = 90^\circ$$

To Find:

$$|\vec{A}| = ?$$

$$\theta = ?$$

Solution:

Resolving \vec{A}_1 , \vec{A}_2 and \vec{A}_3 into

Rectangular component.

$$A_{1x} = A_1 \cos \theta_1$$

$$A_{1x} = 300 \cos 0^\circ \because \cos 0^\circ = 1$$

$$A_{1x} = 300 \times 1$$

$$\boxed{A_{1x} = 300\text{km}}$$

$$A_{1y} = A_1 \sin \theta_1$$

$$A_{1y} = 300 \sin 0^\circ \because \sin 0^\circ = 0^\circ$$

$$A_{1y} = 300 \times 0$$

$$\boxed{A_{1y} = 0}$$

$$A_{2x} = A_2 \cos \theta_2$$

$$A_{2x} = 100 \cos 60^\circ \because \cos 60^\circ = 0.5$$

$$A_{2x} = 100 \times 0.5$$

$$\boxed{A_{2x} = 50\text{km}}$$

$$A_{2y} = A_2 \sin \theta_2$$

$$A_{2y} = 100 \sin 60^\circ \because \sin 60^\circ = 0.866$$

$$A_{2y} = 100 \times 0.866$$

$$\boxed{A_{2y} = 86.6\text{ km}}$$

$$A_{3x} = A_3 \cos \theta_3$$

$$A_{3x} = 200 \cos 90^\circ \because \cos 90^\circ = 0$$

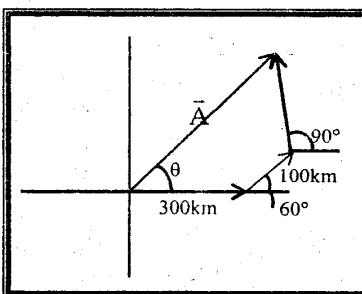
$$A_{3x} = 200 \times 0$$

$$\boxed{A_{3x} = 0}$$

$$A_{3y} = A_3 \sin \theta_3$$

$$A_{3y} = 200 \sin 90^\circ \because \sin 90^\circ = 1$$

$$A_{3y} = 200 \times 1 = 200\text{km}$$



Resultant along x – axis

$$A_x = A_{1x} + A_{2x} + A_{3x}$$

$$A_x = 300 + 50 + 0$$

$$\boxed{A_x = 350\text{ km}}$$

Resultant along y – axis

$$A_y = A_{1y} + A_{2y} + A_{3y}$$

$$A_y = 0 + 86.6 + 200$$

$$\boxed{A_y = 286.6\text{ km}}$$

Magnitude of resultant vector

$$|\vec{A}| = \sqrt{(A_x)^2 + (A_y)^2}$$

$$|\vec{A}| = \sqrt{(350)^2 + (286.6)^2}$$

$$= \sqrt{122500 + 82139.65}$$

$$= \sqrt{204639.65}$$

$$\boxed{|\vec{A}| = 414.89\text{ km}}$$

Direction of resultant vector

$$\theta = \tan^{-1} \left(\frac{A_y}{A_x} \right)$$

$$\theta = \tan^{-1} \left(\frac{286.6}{350} \right)$$

$$\theta = \tan^{-1}(0.955)$$

$$\boxed{\theta = 43.68^\circ}$$

Q.7 The magnitude of two vectors are 4 and 5 units and the angle between them is 30° . Taking first vector along x-axis, find out the magnitude of resultant vector and its direction. (1997)

Given Data:

$$|\vec{A}| = 4 \text{ units}$$

$$|\vec{B}| = 5 \text{ units}$$

$$\theta_1 = 0^\circ$$

$$\theta_2 = 30^\circ$$

To Find:

$$|\vec{R}| = ?$$

$$\theta = ?$$

Resolving \vec{A} in to rectangular components

$$A_x = A \cos \theta_1$$

$$A_x = 4 \cos 0^\circ$$

$$A_x = 4 \times 1 \quad \because \cos 0^\circ = 1$$

$$\boxed{\mathbf{A_x = 4 \text{ units}}} \text{ Ans.}$$

Resolving \vec{B} into rectangular components

$$B_x = B \cos \theta_2$$

$$B_x = 5 \cos 30^\circ$$

$$B_x = 5 \times 0.866 \quad \because \cos 30^\circ = 0.866$$

$$\boxed{\mathbf{B_x = 4.330 \text{ units}}} \text{ Ans.}$$

Resultant along x-axis

$$R_x = A_x + B_x$$

$$R_x = 4 + 4.33$$

$$\boxed{\mathbf{R_x = 8.33 \text{ units}}} \text{ Ans.}$$

Resultant along -y-axis

$$R_y = A_y + B_y$$

$$R_y = 0 + 2.5$$

$$\boxed{\mathbf{R_y = 2.5 \text{ units}}} \text{ Ans.}$$

Magnitude of resultant vector

$$R = \sqrt{(R_x)^2 + (R_y)^2}$$

$$R = \sqrt{(8.33)^2 + (2.5)^2}$$

$$\boxed{\mathbf{R = 75.63 \text{ units}}} \text{ Ans.}$$

Direction of resultant vector

$$\theta = \tan^{-1} \left(\frac{R_y}{R_x} \right)$$

$$\theta = \tan^{-1} \left(\frac{2.5}{8.33} \right)$$

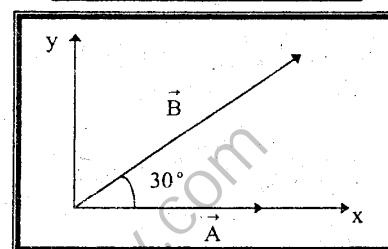
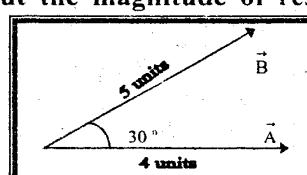
$$\theta = \tan^{-1} (0.3)$$

$$\boxed{\mathbf{\theta = 16.7^\circ}} \text{ Ans.}$$

SELF TEST (20)

The magnitude of two vectors are 10 units and 8 units and the angle between them is 45° . Taking first vector along x-axis, find out the magnitude of resultant vector and its direction.

Ans: 17.98 Unit
18.83°

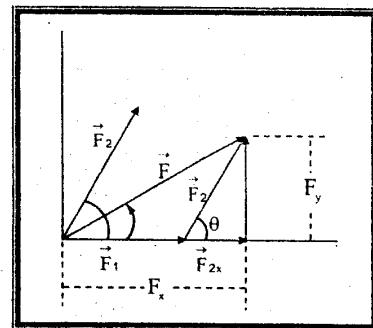


Question: 8

Two forces \vec{F}_1 & \vec{F}_2 are acting on a body. The angle between \vec{F}_1 and \vec{F}_2 is θ . Assuming \vec{F}_1 along x-axis, resolve \vec{F}_2 into two components. Find the resultant force completely.

Answer:

Consider two forces \vec{F}_1 & \vec{F}_2 acting on a body as shown in the figure.



Resolving \vec{F}_1 into two rectangular components \vec{F}_{1x} and \vec{F}_{1y} .

$$F_{1x} = F_1 \cos \theta_1 \quad | \quad F_{1y} = F_1 \sin \theta_1$$

$$F_{1x} = F_1 \cos 0^\circ \quad | \quad F_{1y} = F_1 \sin 0^\circ$$

$$F_{1x} = F_1 \quad | \quad F_{1y} = 0$$

Resolving \vec{F}_2 into two rectangular components \vec{F}_{2x} and \vec{F}_{2y} .

$$F_{2x} = F_2 \cos \theta_2 \quad | \quad F_{2y} = F_2 \sin \theta_2$$

$$\theta_2 = \theta \quad | \quad F_{2y} = F_2 \sin \theta$$

$$F_{2x} = F_2 \cos \theta \quad |$$

The magnitude of total force along x-axis.

$$F_x = F_1 + F_{2x}$$

$$F_x = F_1 + F_2 \cos \theta \longrightarrow (i)$$

The magnitude of the total force along y-axis

$$F_y = F_{2y}$$

$$F_y = F_2 \sin \theta \longrightarrow (ii)$$

If \vec{F} be the resultant force then its magnitude can be found by Pythagoras theorem i.e.

$$F^2 = (F_x)^2 + (F_y)^2 \longrightarrow (iii)$$

putting value of F_x and F_y from eq (i) and (ii) in eq.(iii)

$$F^2 = (F_1 + F_2 \cos \theta)^2 + (F_2 \sin \theta)^2$$

$$F^2 = F_1^2 + 2 F_1 F_2 \cos \theta + F_2^2 \cos^2 \theta + F_2^2 \sin^2 \theta$$

$$F^2 = F_1^2 + 2 F_1 F_2 \cos \theta + F_2^2 (\cos^2 \theta + \sin^2 \theta)$$

$$\text{But } \cos^2 \theta + \sin^2 \theta = 1$$

$$F^2 = F_1^2 + 2 F_1 F_2 \cos \theta + F_2^2$$

$$F^2 = F_1^2 + F_2^2 + 2 F_1 F_2 \cos \theta$$

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XI-Physics Chapter# 2, Page# 46

$$F = \sqrt{F_1^2 + F_2^2 + 2 F_1 F_2 \cos \theta}$$

The direction of \vec{F} can be found by formula

$$\tan \alpha = \frac{F_y}{F_x}$$

$$\alpha = \tan^{-1} \left(\frac{F_y}{F_x} \right)$$

$$\Rightarrow \alpha = \tan^{-1} \left(\frac{F_2 \sin \theta}{F_1 + F_2 \cos \theta} \right)$$

Q.9 One of rectangular component of force 50N is 25N, find value of other.

(2010)

Given Data:

$$F = 50\text{N}$$

$$F_x = 25\text{N}$$

To Find:

$$F_y = ?$$

Solution:

$$F = \sqrt{F_x^2 + F_y^2}$$

$$F^2 = F_x^2 + F_y^2$$

$$50^2 = 25^2 + F_y^2$$

$$2500 = 625 + F_y^2$$

$$2500 - 625 = F_y^2$$

$$F_y^2 = 1075$$

Taking square root on both sides

$$\sqrt{F_y^2} = \sqrt{1075}$$

$$\therefore F_y = 32.79\text{N}$$

SELF TEST (21)

Find the angle between the vectors $\vec{A} = 1\hat{i} + 2\hat{j} + 3\hat{k}$ and $\vec{B} = 8\hat{i} + 2\hat{j} + 6\hat{k}$

(2012 Failure)

SELF TEST (22)

Two vectors \vec{A} and \vec{B} are such that $|\vec{A}| = 4$, $|\vec{B}| = 6$, and $|\vec{A} - \vec{B}| = 5$. Find $|\vec{A} + \vec{B}|$

(2012)