VECTORS

GUPTA CLASSES

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VECTOR

Introduction

All physical quantities are divided into Scalars and Vectors. Scalars are those quantities which have a magnitudes but no direction whereas vectors are those which posses both magnitude and direction

If a physical quantity in addition to magnitude

(a) has a specified direction,

(b) obeys the law of parallelogram of addition, i.e., $R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$

(c) and its addition is commutative, i.e., $\vec{A} + \vec{B} = \vec{B} + \vec{A}$

then and then only it is said to be a vector. If any of above conditions is not satisfied the physical quantity cannot be a vector.

1. If a physical quantity is a vector it has a direction, but if a physical quantity has a direction, it may or may not be a vector, e.g., time, pressure, surface tension or current, etc., have direction but are not vectors.
2. **Tensors :** are the physical quantities which have no specified direction but different values in different directions. For example Density, Refractive index, Dielectric constant, Electrical conductivity, Stress and strain etc. have different values in different direction in anistropic medium, so become tensor.
3. Angular displacement is vector if very small and is scalar if large.

Polar – Vectors

These are the vectors, which have starting point (eg. displacement) or point of application (eg. force).

Axial – Vectors

These are the vectors, which represent rotational effects and are always along axis of rotation in accordance with right hand screw rule. Angular velocity, torque and angular momentum, etc., are examples of physical quantities of this type.

Equal Vectors

Two vectors are called equal, if the magnitude as well as direction of both is same

Negative Vectors

Any vector is called negative of other, if magnitude of both vectors are same and directions are opposite.

Collinear vectors

The vectors in the same direction or opposite direction with equal or unequal magnitude are called collinear vectors.

Null Vectors

These are the vector with zero magnitude having arbitrary direction.

Unit Vectors

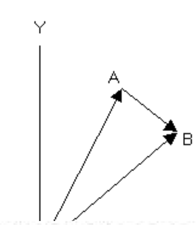
Unit vectors of any vector quantity $\vec{A}$ has the unit magnitude and direction same as of $\vec{A}$. Unit vector of $\vec{A}$ represent the direction of $\vec{A}$ and written as $\hat{A}$ and is given by $\hat{A} = \frac{\vec{A}}{A}$

Orthogonal unit vectors

The unit vector along the x–axis, y–axis and z–axis of the right handed Cartesian coordinate system are written as $\hat{i}$, $\hat{j}$ and $\hat{k}$ respectively. These are called orthogonal unit vectors.

Position and Displacement Vectors

Suppose at any time t_1 an object is at point A in XY plane then a vector $\overrightarrow{OA}$ drawn from O to A is the position vector of object at time t_1. Similarly $\overrightarrow{OB}$ is the position vector of object



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at time t_2. The displacement of object during time interval $(t_2 - t_1)$ is thus from A to B and a vector drawn A to B, $\overrightarrow{AB}$ is the displacement vector of object for time interval $t_2 - t_1$ and is the difference of final position and initial position vector that is $\overrightarrow{AB} = \overrightarrow{OB} - \overrightarrow{OA}$

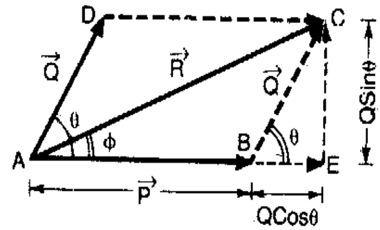
Addition of vectors

As shown in fig., the magnitude of resultant is be given by,

$$R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

And the direction of resultant from $\vec{P}$ will be given by

$$\tan\phi = \frac{CE}{AE} = \frac{Q\sin\theta}{P + Q\cos\theta}$$



Regarding vector addition it is worth noting that :

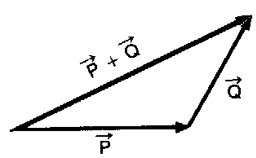
1. To a vector only a vector of same type can be added and the resultant is a vector of the same type. For example, to a force only a force and not velocity can be added and the resultant will be a force and not any other physical quantity.
2. Vector addition is commutative, i.e., $\vec{P} + \vec{Q} = \vec{Q} + \vec{P}$
3. Vector addition is associative, i.e., $\vec{P} + (\vec{Q} + \vec{R}) = (\vec{P} + \vec{Q}) + \vec{R}$
4. The resultant of two vectors can have any value from | P – Q | to | P + Q | depending on the angle between them. The magnitude of resultant decreases as θ increases from 0° to 180°.
5. As, R_{min} = | P - Q | so if $P \neq Q$ then $R_{min} \neq 0$ i.e., resultant of two vectors of unequal magnitude can never be zero. **So minimum number of unequal vectors whose sum can be zero is three.**
6. Let $\vec{P} + \vec{Q} + \vec{R} = 0$ i.e., $\vec{R} = -(\vec{P} + \vec{Q})$. This in turn implies that in case of three vectors the resultant may be zero and it will be only when one vector is equal to the negative of the sum of the remaining two vectors, i.e., vectors are coplanar.
7. From the above it is also clear that **the resultant of 3 non-coplanar vectors can never be zero or minimum number of non-coplanar vectors whose sum can be zero is four.**

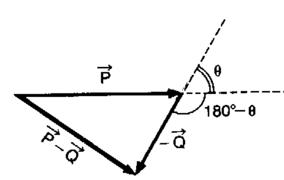
Subtraction of vector

Subtraction of a vector from a vector is the addition of its negative vector, i.e., $\vec{P} - \vec{Q} = \vec{P} + (-\vec{Q})$

In case of subtraction of a vector from a vector

1. $R = \left|\vec{P} - \vec{Q}\right| = \sqrt{P^2 + Q^2 - 2PQ\cos\theta}$
2. Subtraction is not commutative, i.e., $\vec{P} - \vec{Q} \neq \vec{Q} - \vec{P}$ [but $-(\vec{Q} - \vec{P})$]





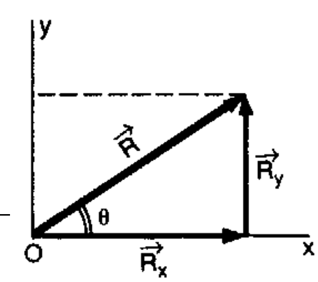
Resolution of Vector into Components

Any vector can be resolved in *two or more (upto infinite) vectors* whose combined effect is same as that of given vector, The resolved vectors are called components of given vector. If a vector is resolved in two mutually perpendicular component (as shown in figure) then there components are called rectangular component.

By law of vector addition, $\vec{R} = \overrightarrow{R_x} + \overrightarrow{R_y}$ or $\vec{R} = R_x\hat{i} + R_y\hat{j}$

where $R_x = R\cos\theta$ ……………………...(1)

and $R_y = R\sin\theta$ ……………………..(2)



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so $R = \sqrt{R_x^2 + R_y^2}$ and $\tan\theta = (R_y / R_x)$

Scalar Product of Two Vectors

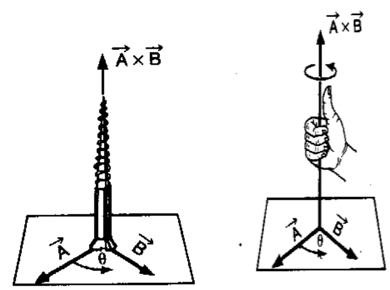
The scalar product (or dot product) of two vectors is written as $\vec{A}\cdot\vec{B}$ and is given by $\vec{A}\cdot\vec{B}$ = AB cos θ

1. It is always a scalar which is positive if angle between the vectors is acute (i.e, < 90°) and negative if angle between them is obtuse (i.e., 90° < θ < 180°).
2. It is commutative, i.e., $\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}$
3. It is distributive, i.e., $\vec{A}\cdot(\vec{B}+\vec{C}) = \vec{A}\cdot\vec{B}+\vec{A}\cdot\vec{C}$
4. As by definition $\vec{A}\cdot\vec{B}$ = AB cos θ, The angle between the vectors $\theta = \cos^{-1}\left[\frac{\vec{A}\cdot\vec{B}}{AB}\right]$
5. Scalar product of two vectors will be maximum when cos θ = max = 1, i.e., θ = 0°, $(\vec{A}\cdot\vec{B})_{max} = AB$
6. Scalar product of two vectors will be minimum when cos θ = min = - 1, i.e., θ = 180° $(\vec{A}\cdot\vec{B})_{min} = -AB$
7. The scalar product of a vector by itself is termed as self dot product and is given by

   $$(\vec{A})^2 = \vec{A}\cdot\vec{A} = AA\cos\theta = A^2 \quad \text{i.e., } A = \sqrt{\vec{A}\cdot\vec{A}}$$

8. In case of orthogonal unit vector $\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$ and $\hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 1\times1\cos 90 = 0$
9. In terms of components
   $\vec{A}\cdot\vec{B} = [A_xB_x + A_yB_y + A_zB_z]$

Vector Product of Two Vectors



The vector product or cross product of two vectors $\vec{A}$ and $\vec{B}$ are two vectors, then their vector product written as $\vec{A}\times\vec{B}$ is a vector $\vec{C}$ given by

$$\vec{C} = \vec{A}\times\vec{B} = AB\sin\theta\,\hat{n}$$

The direction of $\vec{A}\times\vec{B}$, i.e., $\vec{C}$ is perpendicular to the plane containing vectors $\vec{A}$ and $\vec{B}$ and in the sense of advance of a right handed screw rotated from $\vec{A}$ (first vector) to $\vec{B}$ (second vector) through the smaller angle between them.

1. Vector product of two vectors is not commutative, i.e., $\vec{A}\times\vec{B} \neq \vec{B}\times\vec{A}$ [but $= -\vec{B}\times\vec{A}$]
2. The vector product is distributive when the order of the vectors is strictly maintained, i.e.,

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

3. As by definition of vector product of two vectors $\vec{A}\times\vec{B} = AB\sin\theta\,\hat{n}$ or $|\vec{A}\times\vec{B}| = AB\sin\theta$

   i.e. angle between two vector can be given by $\theta = \sin^{-1}\frac{|\vec{A}\times\vec{B}|}{|\vec{A}||\vec{B}|}$

4. The vector product of two vectors will be max. when sin θ = 1, i.e., θ =90° i.e. $[\vec{A}\times\vec{B}]_{max} = AB\,\hat{n}$
5. The vector product of two non-zero vectors will be min. when |sin θ| = 0, i.e., θ = 0° or 180° and $[\vec{A}\times\vec{B}]_{min} = 0$

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6. The self cross product, i.e., product of a vector by itself vanishes, i.e., is a null vector i.e., $\vec{A}\times\vec{A}=\vec{0}$

7. In case of orthogonal unit vector $\hat{i}\times\hat{i}=\hat{j}\times\hat{j}=\hat{k}\times\hat{k}=0$

8. In case of orthogonal unit vectors $\hat{i},\hat{j}$ and $\hat{k}$ in accordance with right hand screw rule:

$\hat{i}\times\hat{j}=\hat{k}$ $\hat{j}\times\hat{k}=\hat{i}$ $\hat{k}\times\hat{i}=\hat{j}$

9. And as cross product is not commutative,

$\hat{j}\times\hat{i}=-\hat{k}$ $\hat{k}\times\hat{j}=-\hat{i}$ $\hat{i}\times\hat{k}=-\hat{j}$

10. In terms of components $\vec{A}\times\vec{B}=\begin{vmatrix}\hat{i} & \hat{j} & \hat{k}\\ A_x & A_y & A_z\\ B_x & B_y & B_z\end{vmatrix}$

Swimmer and River Problem

A swimmer who can swim in still water at speed V wants to cross a river flowing at speed v. In what direction should he swim to cross the river (a) in least time (b) along shortest distance?

Solution; (a) Let the swimmer starts swimming in a direction making an angle θ with OB as shown in Fig. If L is the width of the river, time taken by the swimmer to cross the river will be

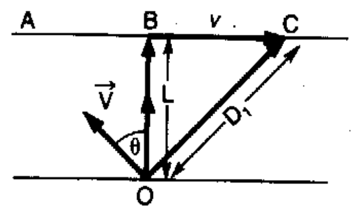
$t=\dfrac{L}{V\cos\theta}$ [as component of V along OB will be Vcosθ]

This time will be minimum when cos θ = max =1, i.e., θ = 0°

i.e., to cross river in shortest time the swimmer should swim perpendicular to the flow.

In this situation

(i) time taken to cross the river will be t_1 = (L/V)



(Shortest time)

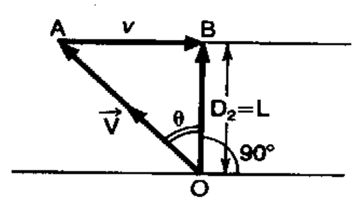
(ii) In this time the flow of water will take the swimmer from B to C such that BC = v x t_1= (vL/V)

(iii) The resultant displacement of the swimmer from initial point

$$OC = D_1 = \sqrt{L^2+(vL/V)^2} = L\sqrt{1+(v/V)^2}$$

(b) As the shortest distance between two banks is the perpendicular distance between them, i.e., L, so in order to cross the river along shortest path OB (= L) the swimmer should swim at an angle θ to OB such that the horizontal component of his velocity balances the speed of flow. i.e.,

$V\sin\theta = v$ or $\sin\theta = (v/V)$ or $\theta = \sin^{-1}(v/V)$



(Shortest distance)

i.e., to cross the river along shortest path swimmer should swim at an angle (90 + θ) to the direction of flow, with θ = $\sin^{-1}$ (v/V).

Note; In this situation;

(i) Time taken to cross the river $t_2=L/V\cos\theta$ (= $t_1/\cos\theta > t_1$)

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(ii) Resultant displacement of the swimmer $D_2 = L < D_1$, i.e., when path is shortest time is not least and when time is least path is not shortest.

Relative Velocity

When we consider the motion of a particle, we assume a fixed point relative to which the given particle is in motion. For example, if we say that water is flowing or wind is blowing or a person is running with a speed v, we mean that these all are relative to the earth (which we have assumed to be fixed).

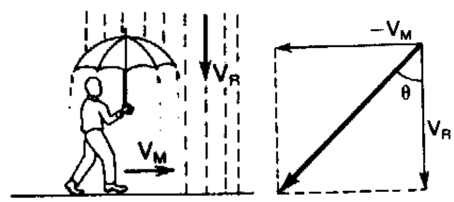
If $\overrightarrow{v_A}$ and $\overrightarrow{v_B}$ are velocities of two bodies relative to earth, the velocity of B relative to A will be given by $\overrightarrow{v_{BA}} = \overrightarrow{v_B} - \overrightarrow{v_A}$

Examples:

(a) If two bodies are moving along the same line in the same direction with velocities v_A and v_B relative to earth, the velocity of B relative to A will be given by $v_{BA} = v_B - v_A$

If it is positive the direction of v_{BA} is that of B and if negative the direction of v_{BA} is opposite to that of However, if the bodies are moving towards or away from each other, as directions of v_A and v_B are opposite, velocity of B relative to A will have magnitude $v_{BA} = v_B - (- v_A) = v_B + v_A$ and directed towards A or away from A respectively.

(b) If rain is falling vertically with a velocity $\vec{V}_R$ and an observer is moving horizontally with speed $\vec{V}_M$ the velocity of rain relative to observer will be $\overrightarrow{V_{RM}} = \overrightarrow{V_R} - \overrightarrow{V_M}$



which by law of vector addition has magnitude $V_{RM} = \sqrt{V_R^2 + V_M^2}$

and direction $\theta = \tan^{-1}(V_M / V_R)$ with the vertical as shown in fig.

VECTORS Assignment

1. Two forces, one of 10 N and another of 6 N acts upon a body. The directions of the forces are unknown. The resultant force on the body is
   1. Between 6 and 10 N
   2. Between 4 and 16 N
   3. More than 6 N
   4. more than 10 N
2. Two forces, equal in magnitude, have a resultant with its magnitude equal to either. The angle between them is
   1. 45° 2. 60° 3. 90° 4. 120°
3. Two non zero vectors $\vec{A}$ and $\vec{B}$ are such that $|\vec{A} + \vec{B}| = |\vec{A} - \vec{B}|$. The angle between them is
   1. 0° 2. 60° 3. 90° 4. 180°
4. If $\vec{A} = 4\hat{i} + 3\hat{j} - 2\hat{k}$ and $\vec{B} = 8\hat{i} + 6\hat{j} - 4\hat{k}$, the angle between $\vec{A}$ and $\vec{B}$ is
   1. 45° 2. 60° 3. 0° 4. 90°
5. A river is flowing from west to east at a speed of 5 metres per minute. A man on the south bank of the river, capable of swimming at 10 metres per minute in still water, wants to swim across the river to a point directly opposite in shortest time. He should swim in a direction
   1. 60° west of north 2. 30° east of north
   3. 30° west of north 4. 60° east of north

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6. A particle is moving eastwards with a velocity of 5 m/s. In 10 seconds the velocity changes to 5 m/s northwards. The average acceleration in this time is
   1. 1/√2 m/s² towards north west
   2. ½ m/s² towards north west
   3. 1/ √ 2 m/s² towards north east
   4. ½ m/s² towards north east

7. A monkey is climbing a vertical tree with a velocity of 5 m/s and a dog is running towards the tree with a velocity of 5√3 m/s. The velocity of the dog relative to the monkey is
   1. 10 m/s at 30° with the horizontal
   2. 10 m/s at 60° with the horizontal
   3. 8 √3 m/s at 30° with the horizontal
   4. 8 √3 m/s at60° with the horizontal

8. A car is moving towards east with a speed of 25 km/h. To the driver of the car, a bus appears to move towards north with a speed of 25√3 km/h. What is the actual velocity of the bus?
   1. 50 km/h, 30°east of north
   2. 50√3 km/h, 30° east of north
   3. 50 km/h, 30° west of north
   4. 50√3 km/h, 30° west of north

9. Two balls are rolling on a flat surface. Once has velocity components 1 m/s and √3 m/s and other has velocity components 2 m/s and 2 m/s along the rectangular axis x and y, respectively. If both the balls start moving from the same point, the angle between their direction of motion is
   1. 15° 2. 30° 3. 45° 4. 60°

10. If $\left|\vec{F_1}\times\vec{F_2}\right| = \vec{F_1}\cdot\vec{F_2}$, then $\left|\vec{F_1}+\vec{F_2}\right|$ is
   1. $F_1 + F_2$ 2. $\sqrt{F_1^2+F_2^2}$
   3. $\sqrt{F_1^2+F_2^2+\frac{F_1\times F_2}{\sqrt{2}}}$ 4. $\sqrt{F_1^2+F_2^2+\sqrt{2}F_1F_2}$

11. A boat which has a speed of 5km/h in still water crosses a river of width 1 km along the shortest possible path in 15 minutes. The velocity of the river water in km/h is
   1. 1 2. 3 3. 4 4. √41

12. Two forces have magnitudes in the ratio 3 : 5 and the angle between their directions is 60°. If their resultant is 35 N, their magnitudes are
   1. 12 N, 20 N 2. 15 N, 25 N
   3. 18 N, 30 N 4. 21 N, 28 N

13. Five equal forces of 10 N each are applied at one point and all are lying in one plane. If the angles between them are equal, the resultant of these forces will be
   1. 0 N 2. 10 N 3. 20 N 4. 10 √2 N

14. Three vectors $\vec{A}$, $\vec{B}$ and $\vec{C}$ satisfy the relation $\vec{A}\cdot\vec{B}=0$ and $\vec{A}\cdot\vec{C}=0$ The vector $\vec{A}$ is parallel to
   1. $\vec{B}$ 2. $\vec{C}$ 3. $\vec{B}\cdot\vec{C}$ 4. $\vec{B}\times\vec{C}$

15. Which of the following vectors is perpendicular to the vector $4\hat{i}-3\hat{j}$?
   1. $4\hat{i}+3\hat{j}$ 2. $6\hat{i}$ 3. $7\hat{k}$ 4. $3\hat{i}-4\hat{j}$

16. A boat is moving with a velocity $3\hat{i}+4\hat{j}$ with respect to the ground. The water in the river is flowing with a velocity $-3\hat{i}-4\hat{j}$ with respect to the ground. The velocity of the boat relative to the water is
   1. $8\hat{j}$ 2. $6\hat{i}+8\hat{j}$ 3. $-6\hat{i}-8\hat{j}$ 4. $5\sqrt{2}\hat{i}$

17. Two vectors $\vec{A}$ and $\vec{B}$ lie in a plane, another vector $\vec{C}$ lies outside this plane, then the resultant of these three vectors i.e., $\vec{A}+\vec{B}+\vec{C}$
   1. Can be zero
   2. Cannot be zero
   3. Lies in the plane containing $\vec{A}+\vec{B}$
   4. Lies in the plane containing $\vec{A}-\vec{B}$

18. The forces acting on a body of mass 5 kg is ($3\hat{i}+4\hat{j}$) N. The magnitude of acceleration of body is
   1. 0.2 m/s^2 2. 1 m/s^2 3. 1.4 m/s^2 4. 5.0 m/s^2

19. What is the angle between the force (x + y) and (x – y) if their resultant is $\sqrt{2(x^2+y^2)}$
   1. 0° 2. 30° 3. 60° 4. 90°

20. What is the numerical value of the vector $3\hat{i}+4\hat{j}+5\hat{k}$
   1. 3√2 2. 5√2 3. 7√2 4. 9√2

21. 1 $\vec{A}$ is directed vertically downward and $\vec{B}$ is directed along north. What is the direction of $\vec{A}\times\vec{B}$
   1. east 2. west 3. north east 4. north west

22. Resultant of two forces each P, acting at an angle θ is
   1. 2P sin(θ/2) 2. 2P cos(θ/2) 3. 2P cosθ 4. P√2

23. The magnitude of vector product of the two vectors is √3 times their scalar product. The angle between the vectors is
   1. π/2 2. π/6 3. π/3 4. π/4

24. Given $\vec{A}=\hat{i}+2\hat{j}-3\hat{k}$. When a vector $\vec{B}$ is added to $\vec{A}$, we get a unit vector along X – axis. Then $\vec{B}$ is
   1. $-2\hat{j}+3\hat{k}$ 2. $-\hat{i}-2\hat{j}$
   3. $-\hat{i}+3\hat{k}$ 4. $2\hat{j}-3\hat{k}$

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25. The angle between the z – axis and the vector $i+\hat{j}+\sqrt{2}\hat{k}$

1. 30° 2. 45° 3. 60° 4. 90°

26. A man walks 40 m north, then 30 m east and then 40 m south. What is his displacement from the starting point

1. 30 m east 2. 150 m east
3. 40 m west 4. 150 m east

27. A vector is represented by $i+3\hat{j}+5\hat{k}$. Its length in X – Y plane is

1. 1 2. 3 3. 5 4. √10

28. Three forces $(2i-3\hat{j}+4\hat{k})$, $(8i-7\hat{j}+6\hat{k})$ and $m(i-\hat{j}+\hat{k})$ keep a body in equilibrium. The value of m is

1. 10 2. –10 3. 20 4. – 20

29. An object originally at the point (2, 5, 1) cm is given displacement $(8i-2\hat{j}+\hat{k})$. The coordinate of the new position are

1. (10, 3, 2) 2. (8, -2, 1) 3. (0, 0, 0) 4. none of these

30. What is the angle between $\vec{A}\times\vec{B}$ and $\vec{A}+\vec{B}$

1. 0° 2. 45° 3. 60° 4. 90°

31. A particle is moving on a circular path with constant speed v. What is the change in its velocity after it has described an angle of 60°?

1. v√2 2. v√3 3. v 4. 2v

32. The resultant of two forces makes an angle 30° and 60° with them and has a magnitude of 40 N. The magnitude of two forces are

1. 20 N, 20N 2. 20 N, 28N
3. 20 N, 20√3N 4. 20 N, 60N

33. Given $\vec{A}=2\hat{i}-\hat{j}+2\hat{k}$ and $\vec{B}=-\hat{i}-\hat{j}+\hat{k}$. The unit vector of $\vec{A}-\vec{B}$ is

1. $\frac{3\hat{i}+\hat{k}}{\sqrt{10}}$ 2. $\frac{3\hat{i}}{\sqrt{10}}$

3. $\frac{\hat{k}}{\sqrt{10}}$ 4. $\frac{-3\hat{i}-\hat{k}}{\sqrt{10}}$

34. Ship A is traveling with a velocity of 5 km/h due east. A second ship is heading 30° east of north. What should be the speed of second ship if it is to remain always due north with respect of the first ship?

1. 10 km/h 2. 9 km/h 3. 8 km/h 4. 7 km/h

35. A vector of length m is turned through an angle β about its tail. The change in position vector of its head is

1. 2m sin(β/2) 2. 2m cos(β/2)

3. 2m tan(β/2) 4. 2m cot(β/2)

36. What is the unit vector along $\hat{i}+\hat{j}$

1. $\frac{\hat{i}+\hat{j}}{\sqrt{2}}$ 2. $\sqrt{2}(\hat{i}+\hat{j})$

3. $\hat{i}+\hat{j}$ 4. $\hat{k}$

37. The ratio of maximum and minimum magnitudes of resultant of two vectors $\vec{A}$ and $\vec{B}$ is 3 : 1. Now A =

1. B 2. 2B 3. 3B 4. 4B

38. The area of the triangle formed by the adjacent sides with $\vec{A}=-3\hat{i}+2\hat{j}-4\hat{k}$ and $\vec{B}=-\hat{i}+2\hat{j}+\hat{k}$ is

1. $\frac{\sqrt{165}}{2}$ 2. $\frac{\sqrt{137}}{2}$ 3. $\sqrt{165}$ 4. $\sqrt{137}$

Answers: 1-b, 2-d, 3-c, 4-c, 5-c, 6-a, 7-a, 8-a, 9-a, 10-d, 11-b, 12-b, 13-a, 14-d, 15-c, 16-b, 17-b, 18-b,19-d, 20-b, 21-a, 22-b, 23-c, 24-a, 25-b, -26-a, 27-b, 28-b, 29-a, 30-d, 31-c, 32-c, 33-a, 34-a, 35-a, 36-a, 37-b, 38-a

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