

Chapter 9 Vector Differential Calculus. Grad, Div, Curl

P360 - Problem set 9.1

Problem 1-5

PS 9.1

1-5 COMPONENTS AND LENGTH

Find the components of the vector \mathbf{v} with initial point P and terminal point Q . Find $|\mathbf{v}|$. Sketch $|\mathbf{v}|$. Find the unit vector \mathbf{u} in the direction of \mathbf{v} .

1. $P: (1, 1, 0)$, $Q: (6, 2, 0)$
2. $P: (1, 1, 1)$, $Q: (2, 2, 0)$
3. $P: (-3.0, 4.0, -0.5)$, $Q: (5.5, 0, 1.2)$
4. $P: (1, 4, 2)$, $Q: (-1, -4, -2)$
5. $P: (0, 0, 0)$, $Q: (2, 1, -2)$

$$1. \vec{V} = [5, 1, 0]$$

$$|\mathbf{v}| = \sqrt{26}$$

$$\vec{U} = \left[\frac{5\sqrt{26}}{26}, \frac{\sqrt{26}}{26}, 0 \right]$$

$$2. \vec{V} = [1, 1, -1]$$

$$|\mathbf{v}| = \sqrt{3}$$

$$\vec{U} = \left[\frac{\sqrt{3}}{3}, \frac{\sqrt{3}}{3}, -\frac{\sqrt{3}}{3} \right]$$

$$3. \vec{V} = [8.5, -4, 1.7]$$

$$|\mathbf{v}| = \sqrt{72.25 + 16 + 2.89}$$

$$= \sqrt{91.14}$$

$$\vec{U} = \left[\frac{8.5}{\sqrt{91.14}}, \frac{-4}{\sqrt{91.14}}, \frac{1.7}{\sqrt{91.14}} \right]$$

$$4) \vec{V} = [-2, -8, -4]$$

$$|\mathbf{v}| = \sqrt{4 + 64 + 16}$$

$$= \sqrt{84}$$

$$\vec{U} = \left[-\frac{1}{\sqrt{84}}, -\frac{4}{\sqrt{84}}, -\frac{2}{\sqrt{84}} \right]$$

$$5) \vec{V} = [2, 1, -2]$$

$$|\mathbf{v}| = \sqrt{4 + 1 + 4} = 3$$

$$\vec{U} = \left[\frac{2}{3}, \frac{1}{3}, -\frac{2}{3} \right]$$

$$6. Q = [4, 2, 13], |\mathbf{v}| = 4$$

$$7. Q = [4, 0, 1/2], |\mathbf{v}| = \sqrt{149}/4$$

$$8. Q = [13.1, 0.8, -2.0], |\mathbf{v}| = \sqrt{171.61 + 0.64 + 4} = \sqrt{176.25}$$

$$9. Q=[0, 0, 0], |v|=\sqrt{53}$$

$$10. Q=[0, 0, 0], |v|=3\sqrt{2}$$

$$11. 2a=[6, 4, 0], 1/2a=[3/2, 1, 0], -a = [-3, -2, 0]$$

$$12. (a+b)+c=a+(b+c)=[4, 7, 8] \text{ } b \text{ is not consistant.}$$

$$13. b+c=c+b = [1, 5, 8]$$

$$14. 3c-6d=3(c-2d)=[15, -3, 0]$$

$$15. 7(c-b)=7c-7b=7*[9, -7, 8]=[63, -49, 56]$$

$$16. \frac{9}{2}a - 3c=9(\frac{1}{2}a - \frac{1}{3}c)=[-3/2, 12, -24]$$

$$17. (7-3)a=7a-3a=4a=[12, 8, 0]$$

$$18. 4a+3b = [0, 26, 0], -4a-3b=-(4a+3b)=[0, -26, 0]$$

19. 12-associative, 13-commutative, 14-16 scalar multiplication is distributive.

$$20. a + b = [a_1, a_2, \dots, a_n] + [b_1, b_2, \dots, b_n] = [a_1 + b_1, a_2 + b_2, \dots, a_n + b_n] = [b_1 + a_1, b_2 + a_2, \dots, b_n + a_n] = b + a$$

The rest can be approved in the simliar way.

21-25 FORCES, RESULTANT

Find the resultant in terms of components and its magnitude.

21. $\mathbf{p} = [2, 3, 0]$, $\mathbf{q} = [0, 6, 1]$, $\mathbf{u} = [2, 0, -4]$
22. $\mathbf{p} = [-1, -2, 3]$, $\mathbf{q} = [3, 21, -16]$,
 $\mathbf{u} = [-4, -19, 13]$
23. $\mathbf{u} = [8, -1, 0]$, $\mathbf{v} = [\frac{1}{2}, 0, \frac{4}{3}]$, $\mathbf{w} = [-\frac{17}{2}, 1, \frac{11}{3}]$
24. $\mathbf{p} = [-1, 2, -3]$, $\mathbf{q} = [1, 1, 1]$, $\mathbf{u} = [1, -2, 2]$
25. $\mathbf{u} = [3, 1, -6]$, $\mathbf{v} = [0, 2, 5]$, $\mathbf{w} = [3, -1, -13]$

$$21) \vec{r} = \vec{p} + \vec{q} + \vec{u} \\ = [4, 9, -3]$$

$$|\vec{r}| = \sqrt{16+81+9} = \sqrt{106}$$

$$22) \vec{r} = \vec{p} + \vec{q} + \vec{u} \\ = [0, 0, 0]$$

$$|\vec{r}| = 0$$

$$23) \vec{r} = \vec{u} + \vec{v} + \vec{w} \\ = [0, 0, 5]$$

$$|\vec{r}| = 5$$

$$24) \vec{r} = \vec{p} + \vec{q} + \vec{u} \\ = [1, 1, 0]$$

$$|\vec{r}| = \sqrt{2}$$

$$25) \vec{r} = \vec{u} + \vec{v} + \vec{w}$$

$$= [6, 2, -14]$$

$$|\vec{r}| = \sqrt{36+4+196} = \sqrt{236}$$

26-37 FORCES, VELOCITIES

26. **Equilibrium.** Find \mathbf{v} such that $\mathbf{p}, \mathbf{q}, \mathbf{u}$ in Prob. 21 and \mathbf{v} are in equilibrium.
27. Find \mathbf{p} such that $\mathbf{u}, \mathbf{v}, \mathbf{w}$ in Prob. 23 and \mathbf{p} are in equilibrium.
28. **Unit vector.** Find the unit vector in the direction of the resultant in Prob. 24.

$$26) \vec{v} = 0 - \vec{r} = [-4, -9, 3]$$

$$27) \vec{p} = 0 - \vec{r} = [0, 0, -5]$$

$$28) \vec{u} = \frac{\vec{r}}{|\vec{r}|} = \left[\frac{\sqrt{2}}{2}, \frac{\sqrt{2}}{2}, 0 \right]$$

29. **Restricted resultant.** Find all \mathbf{v} such that the resultant of \mathbf{v} , \mathbf{p} , \mathbf{q} , \mathbf{u} with \mathbf{p} , \mathbf{q} , \mathbf{u} as in Prob. 21 is parallel to the xy -plane.
30. Find \mathbf{v} such that the resultant of \mathbf{p} , \mathbf{q} , \mathbf{u} , \mathbf{v} with \mathbf{p} , \mathbf{q} , \mathbf{u} as in Prob. 24 has no components in x - and y -directions.
31. For what k is the resultant of $[2, 0, -7]$, $[1, 2, -3]$, and $[0, 3, k]$ parallel to the xy -plane?
32. If $|\mathbf{p}| = 6$ and $|\mathbf{q}| = 4$, what can you say about the magnitude and direction of the resultant? Can you think of an application to robotics?
33. Same question as in Prob. 32 if $|\mathbf{p}| = 9$, $|\mathbf{q}| = 6$, $|\mathbf{u}| = 3$.

29 Vector start from origin.
parallel to x - y means no component in z -direction.

Let result

$$\vec{z} = \vec{v} + \vec{p} + \vec{q} + \vec{u} = [x, y, 0]$$

So x and y are arbitrary

$$\vec{v} = \vec{z} - [4, 9, -3]$$

$$= [x-4, y-9, 3]$$

$$\text{Let } V_1 = x-4, V_2 = y-9.$$

$$\text{So } \vec{v} = [V_1, V_2, 3]$$

where V_1 and V_2 are arbitrary

$$30. \vec{v} = [0, 0, c] - [1, 1, 0]$$

$$= [-1, -1, c] \text{ where } c \text{ is a constant.}$$

$$31 -7 - 3 + k = 0$$

$$k = 10$$

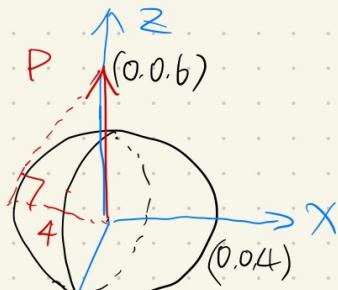
32. magnitude, min=2, max=10
direction:

a cone,

plus half

sphere.

may be call
ice cream.



(Sorry upside down)

Robotic vision, the area where Robot can see/detect or scan?

$$33. \text{magnitude, min=0, max=18}$$

direction

enhanced ice cream

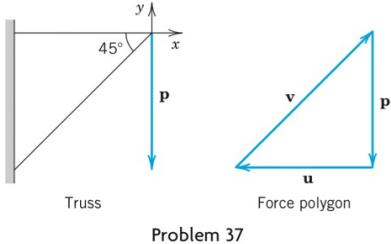
without blind spot?

34. **Relative velocity.** If airplanes A and B are moving southwest with speed $|v_A| = 550$ mph, and northwest with speed $|v_B| = 450$ mph, respectively, what is the relative velocity $\mathbf{v} = \mathbf{v}_B - \mathbf{v}_A$ of B with respect to A ?

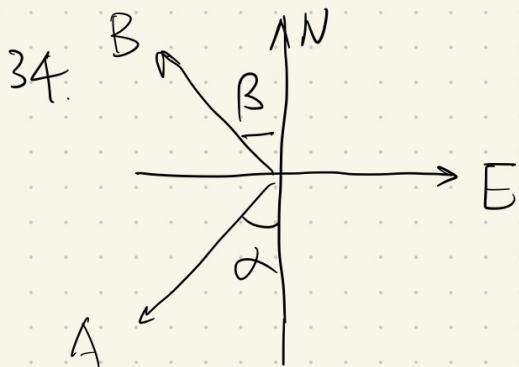
35. Same question as in Prob. 34 for two ships moving northeast with speed $|\mathbf{v}_A| = 22$ knots and west with speed $|\mathbf{v}_B| = 19$ knots.

36. **Reflection.** If a ray of light is reflected once in each of two mutually perpendicular mirrors, what can you say about the reflected ray?

37. **Force polygon.** Truss. Find the forces in the system of two rods (truss) in the figure, where $|\mathbf{p}| = 1000$ nt. Hint. Forces in equilibrium form a polygon, the *force polygon*.

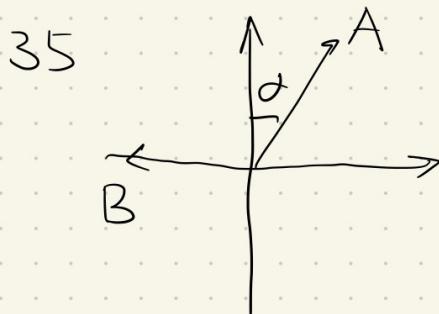


Problem 37



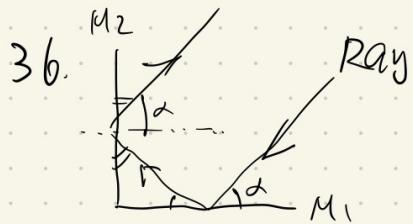
$$V = V_B - V_A \text{ on northeast.}$$

$$\begin{aligned} & [550 \sin \alpha - 450 \sin \beta, \\ & 550 \cos \alpha - 450 \cos \beta] \end{aligned}$$



$$V = V_B - V_A \text{ on northeast}$$

$$[22 \sin \alpha - 19, 22 \cos \alpha]$$



Reverse the direction.

$$37. P: [0, -1000]$$

$$U: [-1000, 0]$$

$$V: [1000, 1000]$$

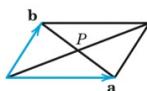
34, 35: it seems assume

α, β are 45°

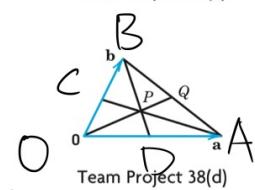
maybe this is by default

38. TEAM PROJECT. Geometric Applications. To increase your skill in dealing with vectors, use vectors to prove the following (see the figures).

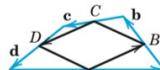
- (a) The diagonals of a parallelogram bisect each other.
- (b) The line through the midpoints of adjacent sides of a parallelogram bisects one of the diagonals in the ratio 1 : 3.
- (c) Obtain (b) from (a).
- (d) The three medians of a triangle (the segments from a vertex to the midpoint of the opposite side) meet at a single point, which divides the medians in the ratio 2 : 1.
- (e) The quadrilateral whose vertices are the midpoints of the sides of an arbitrary quadrilateral is a parallelogram.
- (f) The four space diagonals of a parallelepiped meet and bisect each other.
- (g) The sum of the vectors drawn from the center of a regular polygon to its vertices is the zero vector.



Team Project 38(a)



Team Project 38(d)



Team Project 38(e)

$$\overrightarrow{OC} = \frac{1}{2} \mathbf{b}$$

$$\overrightarrow{OB} = \frac{1}{2} \mathbf{a}$$

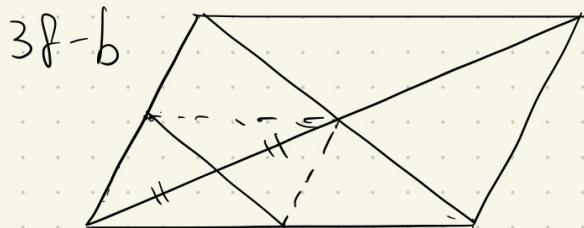
$$\overrightarrow{DC} = \frac{1}{2} \overrightarrow{AB}$$

$$\triangle CDP \sim \triangle ABP$$

$$\overrightarrow{DP} = \frac{1}{2} \overrightarrow{PB}$$

$$38-a \quad \frac{1}{2}\mathbf{a} + \frac{1}{2}\mathbf{b} = \frac{1}{2}(\mathbf{a}+\mathbf{b})$$

$$\frac{1}{2}\mathbf{a} - \frac{1}{2}\mathbf{b} = \frac{1}{2}(\mathbf{a}-\mathbf{b})$$



$$\frac{1}{4}\mathbf{a} - \frac{1}{4}\mathbf{b} = \frac{1}{4}(\mathbf{a}-\mathbf{b})$$

$$\frac{1}{4} : \frac{3}{4} = 1 : 3$$

38-c: obvious

$$38-d \quad \overrightarrow{AB} = \mathbf{a} - \mathbf{b}$$

$$\overrightarrow{AQ} = \frac{1}{2}(\mathbf{a}-\mathbf{b})$$

$$\overrightarrow{QO} = \mathbf{a} + \frac{1}{2}(\mathbf{a}-\mathbf{b})$$

$$38-e \quad \mathbf{a} - \mathbf{d} = \mathbf{c} - \mathbf{b}$$

$$\frac{1}{2}(\mathbf{a}-\mathbf{d}) = \frac{1}{2}(\mathbf{c}-\mathbf{b})$$

$$\overrightarrow{AD} = \overrightarrow{BC}$$

$$\text{same} \Rightarrow \overrightarrow{AB} = \overrightarrow{DC}$$

38-f

38-g

PS 9-2

1-10 INNER PRODUCT

Let $\mathbf{a} = [1, -3, 5]$, $\mathbf{b} = [4, 0, 8]$, $\mathbf{c} = [-2, 9, 1]$.
Find:

1. $\mathbf{a} \cdot \mathbf{b}$, $\mathbf{b} \cdot \mathbf{a}$, $\mathbf{b} \cdot \mathbf{c}$
2. $(-3\mathbf{a} + 5\mathbf{c}) \cdot \mathbf{b}$, $15(\mathbf{a} - \mathbf{c}) \cdot \mathbf{b}$
3. $|\mathbf{a}|$, $|\mathbf{2b}|$, $|-c|$
4. $|\mathbf{a} + \mathbf{b}|$, $|\mathbf{a}| + |\mathbf{b}|$
5. $|\mathbf{b} + \mathbf{c}|$, $|\mathbf{b}| + |\mathbf{c}|$
6. $|\mathbf{a} + \mathbf{c}|^2 + |\mathbf{a} - \mathbf{c}|^2 - 2(|\mathbf{a}|^2 + |\mathbf{c}|^2)$
7. $|\mathbf{a} \cdot \mathbf{c}|$, $|\mathbf{a}||\mathbf{c}|$
8. $5\mathbf{a} \cdot 13\mathbf{b}$, $65\mathbf{a} \cdot \mathbf{b}$
9. $15\mathbf{a} \cdot \mathbf{b} + 15\mathbf{a} \cdot \mathbf{c}$, $15\mathbf{a} \cdot (\mathbf{b} + \mathbf{c})$
10. $\mathbf{a} \cdot (\mathbf{b} - \mathbf{c})$, $(\mathbf{a} - \mathbf{b}) \cdot \mathbf{c}$

$$5. |\mathbf{b} + \mathbf{c}| = \sqrt{2^2 + 9^2 + 9^2} = \sqrt{166}$$

$$|\mathbf{b}| + |\mathbf{c}| = 4\sqrt{5} + \sqrt{86}$$

$$6. (1+36+36) + (9+144+16) \\ - 2(35+86) = 0$$

$$7. |\mathbf{a} \cdot \mathbf{c}| = |-2 - 27 + 5| = 24 \\ |\mathbf{a}| |\mathbf{c}| = \sqrt{35} \cdot \sqrt{86}$$

$$8. 5\mathbf{a} \cdot 13\mathbf{b} = 65\mathbf{a} \cdot \mathbf{b} = 2860$$

$$9. 15\mathbf{a} \cdot \mathbf{b} + 15\mathbf{a} \cdot \mathbf{c} = 15\mathbf{a}(\mathbf{b} + \mathbf{c}) \\ = 15 \cdot \mathbf{a} \cdot (2, 9, 9) = 300$$

$$10. \mathbf{a} \cdot (\mathbf{b} - \mathbf{c}) = \mathbf{a} \cdot (16, -9, 7) \\ = 68$$

$$(\mathbf{a} - \mathbf{b}) \cdot \mathbf{c} = (-3, -3, -3) \cdot \mathbf{c} \\ = 6 - 27 - 3 = -24$$

$$1. \mathbf{a} \cdot \mathbf{b} = 4 + 0 + 40 = 44$$

$$\mathbf{b} \cdot \mathbf{a} = 44$$

$$\mathbf{b} \cdot \mathbf{c} = -8 + 0 + 8 = 0$$

$$2. (-3\mathbf{a} + 5\mathbf{c}) \cdot \mathbf{b} = (-3, 5, 4) \cdot \mathbf{b} \\ = -52 + 0 - 80 = -132$$

$$15(\mathbf{a} - \mathbf{c}) \cdot \mathbf{b} = 15(-3, -2, 4) \cdot \mathbf{b}$$

$$= 15 \cdot (-12 + 0 + 32) = 300$$

$$3. |\mathbf{a}| = \sqrt{1+9+25} = \sqrt{35}$$

$$|\mathbf{2b}| = 2 \cdot \sqrt{16+64} = 8\sqrt{5}$$

$$|-c| = \sqrt{4+81+1} = \sqrt{86}$$

$$4. |\mathbf{a} + \mathbf{b}| = \sqrt{25+9+164} = \sqrt{203}$$

$$|\mathbf{a}| + |\mathbf{b}| = \sqrt{35} + \sqrt{16+64} = \sqrt{35} + 4\sqrt{5}$$

11-16 GENERAL PROBLEMS

11. What laws do Probs. 1 and 4-7 illustrate?
12. What does $\mathbf{u} \cdot \mathbf{v} = \mathbf{u} \cdot \mathbf{w}$ imply if $\mathbf{u} = \mathbf{0}$? If $\mathbf{u} \neq \mathbf{0}$?
13. Prove the Cauchy-Schwarz inequality.
14. Verify the Cauchy-Schwarz and triangle inequalities for the above \mathbf{a} and \mathbf{b} .
15. Prove the parallelogram equality. Explain its name.
16. **Triangle inequality.** Prove Eq. (7). Hint. Use Eq. (3) for $|\mathbf{a} + \mathbf{b}|$ and Eq. (6) to prove the square of Eq. (7), then take roots.

11-1 $\mathbf{a} \cdot \mathbf{b} = \mathbf{b} \cdot \mathbf{a}$
 $\mathbf{a} \cdot \mathbf{b} = 0$, orthogonality

4-5) $|\mathbf{a} + \mathbf{b}| \leq |\mathbf{a}| + |\mathbf{b}|$ (Triangle inequality).

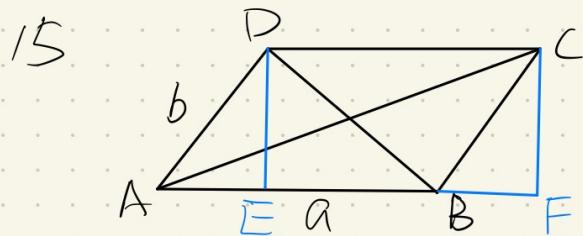
6) $|\mathbf{a} + \mathbf{b}|^2 + |\mathbf{a} - \mathbf{b}|^2 = 2(|\mathbf{a}|^2 + |\mathbf{b}|^2)$ (Parallelogram equality).

7) $|\mathbf{a} \cdot \mathbf{b}| \leq |\mathbf{a}| |\mathbf{b}|$ (Cauchy-Schwarz inequality).

12. if $\mathbf{u} = \mathbf{0}$, We know nothing about $\mathbf{u} \cdot \mathbf{w}$.
if $\mathbf{u} \neq \mathbf{0}$, $P = \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{b}|}$. So \mathbf{v}, \mathbf{w} belongs
to a set B that the projections of
 \mathbf{u} on the vector multiple the magnitude of
the vector is a constant.

13. projection \leq itself. ($\cos \theta \leq 1$)

14. 4-5, and 7



$$1) AE = BF, DE = CF,$$

$$2) AC^2 + BD^2 = (AE + BF)^2 + CF^2 \\ + (AF - AE)^2 + DE^2 \\ = 2(a^2 + b^2)$$

$$16. |a+b|^2 = (a+b)(a+b) \\ = a^2 + b^2 + 2ab$$

$$\leq |a|^2 + |b|^2 + 2|a||b| \\ = (|a| + |b|)^2$$

17-20 WORK

Mistake

Find the work done by a force \mathbf{p} acting on a body if the body is displaced along the straight segment \overline{AB} from A to B. Sketch \overline{AB} and \mathbf{p} . Show the details.

17. $\mathbf{p} = [2, 5, 0]$, A: (1, 3, 3), B: (3, 5, 5)

18. $\mathbf{p} = [-1, -2, 4]$, A: (0, 0, 0), B: (6, 7, 5)

19. $\mathbf{p} = [0, 4, 3]$, A: (4, 5, -1), B: (1, 3, 0)

20. $\mathbf{p} = [6, -3, -3]$, A: (1, 5, 2), B: (3, 4, 1)

21. **Resultant.** Is the work done by the resultant of two forces in a displacement the sum of the work done by each of the forces separately? Give proof or counterexample.

17. $W = \mathbf{P} \cdot \mathbf{d} = \mathbf{P} \cdot (2, 2, 2) = 14$

18. $W = \mathbf{P} \cdot (6, 7, 5) = 0$

19. $W = \mathbf{P} \cdot (-3, -2, 1) = -5$

Negative, because of direction.

20. $W = \mathbf{P} \cdot (2, -1, -1) = 18$

21. Yes.

$$W = \mathbf{P}_1 \cdot \mathbf{d} + \mathbf{P}_2 \cdot \mathbf{d}$$

$$= (\mathbf{P}_1 + \mathbf{P}_2) \cdot \mathbf{d}$$

22. $\cos \alpha = \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{a}| |\mathbf{b}|} = \frac{3+2}{\sqrt{2} \sqrt{14}}$

$$\alpha = \arccos\left(\frac{\sqrt{5}}{14}\right)$$

23. $\cos \alpha = \frac{\mathbf{b} \cdot \mathbf{c}}{|\mathbf{b}| |\mathbf{c}|} = \frac{3+2}{\sqrt{14} \sqrt{5}}$

$$\alpha = \arccos\left(\frac{\sqrt{70}}{14}\right)$$

24. $W \leq \frac{(\mathbf{a} + \mathbf{c}) \cdot (\mathbf{b} + \mathbf{c})}{|\mathbf{a} + \mathbf{c}| \cdot |\mathbf{b} + \mathbf{c}|}$

$$= \frac{(4, 3, 1) \cdot (4, 2, 3)}{\sqrt{16+9+1} \cdot \sqrt{16+4+9}}$$

$$= \frac{16+6+3}{\sqrt{26} \cdot \sqrt{29}} = \frac{25}{\sqrt{26} \sqrt{29}}$$

$$\alpha = \arccos\left(\frac{25}{\sqrt{26} \sqrt{29}}\right)$$

22-30 ANGLE BETWEEN VECTORS

Let $\mathbf{a} = [1, 1, 0]$, $\mathbf{b} = [3, 2, 1]$, and $\mathbf{c} = [1, 0, 2]$. Find the angle between:

22. \mathbf{a}, \mathbf{b}

23. \mathbf{b}, \mathbf{c}

24. $\mathbf{a} + \mathbf{c}, \mathbf{b} + \mathbf{c}$

25. What will happen to the angle in Prob. 24 if we replace c by nc with larger and larger n ?

26. **Cosine law.** Deduce the law of cosines by using vectors \mathbf{a} , \mathbf{b} , and $\mathbf{a} - \mathbf{b}$.

27. **Addition law.** $\cos(\alpha - \beta) = \cos \alpha \cos \beta + \sin \alpha \sin \beta$. Obtain this by using $\mathbf{a} = [\cos \alpha, \sin \alpha]$, $\mathbf{b} = [\cos \beta, \sin \beta]$ where $0 \leq \alpha \leq \beta \leq 2\pi$.

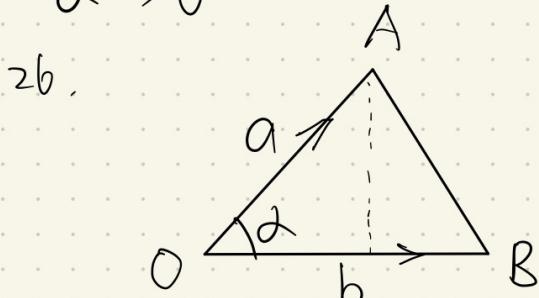
28. **Triangle.** Find the angles of the triangle with vertices $A: (0, 0, 2)$, $B: (3, 0, 2)$, and $C: (1, 1, 1)$. Sketch the triangle.

29. **Parallelogram.** Find the angles if the vertices are $(0, 0), (6, 0), (8, 3)$, and $(2, 3)$.

30. **Distance.** Find the distance of the point $A: (1, 0, 2)$ from the plane $P: 3x + y + z = 9$. Make a sketch.

$$25. \lim_{n \rightarrow \infty} \frac{(a+nc)(b+nc)}{|(a+nc)| \cdot |(b+nc)|} = \frac{c \cdot c}{|c|^2} = 1$$

$$\angle \rightarrow 0$$



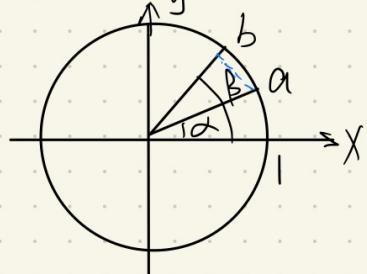
$$(\overrightarrow{BA})^2 = (a-b)^2 =$$

$$(a \sin \alpha)^2 + (b - a \cos \alpha)^2$$

$$= a^2 \sin^2 \alpha + b^2 + a^2 \cos^2 \alpha - 2ab \cos \alpha$$

$$= a^2 + b^2 - 2ab \cos \alpha$$

$$27. a \cdot b = \cos \alpha \cos \beta + \sin \alpha \sin \beta$$



the projection of a on b is

$$P \approx a \cdot b = \cos(\beta - \alpha) = \cos(\alpha - \beta)$$

$$28. \overrightarrow{AB} = (3, 0, 0) = a$$

$$\overrightarrow{BC} = (-2, 1, -1) = b$$

$$\overrightarrow{CA} = (-1, -1, 1) = c$$

$$\cos \alpha = \frac{-ab}{|a||b|} = \frac{-6}{3\sqrt{6}} = \frac{\sqrt{6}}{3}$$

$$\cos \beta = \frac{-bc}{|b||c|} = \frac{2-1-1}{\sqrt{5}\sqrt{5}} = 0$$

$$\cos \gamma = \frac{-ca}{|c||a|} = \frac{+3}{3\sqrt{3}} = \frac{\sqrt{3}}{3}$$

$$29. \tan \alpha = \frac{3}{2} \quad \alpha = \arctan \frac{3}{2}$$

$$\cos \alpha = \frac{(2 \cdot 3)(6 \cdot 0)}{\sqrt{4+9} \cdot 6} = \frac{2}{\sqrt{13}}$$

30. mapping to (x_1, y_1, z_1)

$$A = (0, 0, 0)$$

$$P = 3x - 3 + y + z - 2 = 0$$

$$3x + y + z = 14$$

per example 6,

$$P = \frac{C}{|AT|} = \frac{14}{\sqrt{11}}$$

31-35 ORTHOGONALITY is particularly important, mainly because of orthogonal coordinates, such as **Cartesian coordinates**, whose **natural basis** [Eq. (9), Sec. 9.1], consists of three orthogonal unit vectors.

31. For what values of a_1 are $[a_1, 4, 3]$ and $[3, -2, 12]$ orthogonal?
32. **Planes.** For what c are $3x + z = 5$ and $8x - y + cz = 9$ orthogonal?
33. **Unit vectors.** Find all unit vectors $\mathbf{a} = [a_1, a_2]$ in the plane orthogonal to $[4, 3]$.
34. **Corner reflector.** Find the angle between a light ray and its reflection in three orthogonal plane mirrors, known as *corner reflector*.
35. **Parallelogram.** When will the diagonals be orthogonal? Give a proof.

$$31. 3a_1 - 8 + 36 = 0$$

$$a_1 = -\frac{28}{3}$$

$$32. (3, 0, 1) \cdot (8, -1, c) = 0$$

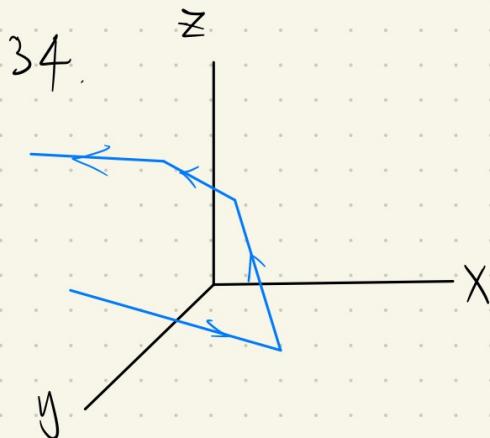
$$24 + c = 0 \quad c = -24$$

$$33. 4a_1 + 3a_2 = 0$$

$$a_2 = -\frac{4}{3}a_1$$

$$a_1^2 + \frac{16}{9}a_1^2 = 1$$

$$a_1 = \frac{3}{5}, \quad \left[\frac{3}{5}, -\frac{4}{5} \right]$$



$[a, b, c]$ Reflect on XY plane,

$\Rightarrow [a, b, -c]$ Reflect on XZ plane

$\Rightarrow [a, -b, -c]$ R on ZY plane

$[-a, -b, -c]$

$$35. (a+b)(a-b) = 0$$

$$a^2 - b^2 = 0 \quad a^2 = b^2$$

diamond shape. answer is wrong.

36-40 COMPONENT IN THE DIRECTION OF A VECTOR

Find the component of \mathbf{a} in the direction of \mathbf{b} . Make a sketch.

36. $\mathbf{a} = [1, 1, 1]$, $\mathbf{b} = [2, 1, 3]$

37. $\mathbf{a} = [3, 4, 0]$, $\mathbf{b} = [4, -3, 2]$

38. $\mathbf{a} = [8, 2, 0]$, $\mathbf{b} = [-4, -1, 0]$

39. When will the component (the projection) of \mathbf{a} in the direction of \mathbf{b} be equal to the component (the projection) of \mathbf{b} in the direction of \mathbf{a} ? First guess.

40. What happens to the component of \mathbf{a} in the direction of \mathbf{b} if you change the length of \mathbf{b} ?

$$36. P = \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{b}|} = \frac{2+1+3}{\sqrt{14}} = \frac{3\sqrt{14}}{7}$$

$$37. P = \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{b}|} = \frac{12-12+0}{\sqrt{5}} = 0 \quad \text{perpendicular}$$

$$38. P = \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{b}|} = \frac{-32-2}{\sqrt{17}} = -2\sqrt{17}$$

On the opp direction,

$$39. |\mathbf{a}| = |\mathbf{b}| \text{ or } \mathbf{a} \cdot \mathbf{b} = 0$$

$$40. P = \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{b}|} = \frac{\mathbf{a} \cdot k\mathbf{b}}{k|\mathbf{b}|}$$

nothing change.