

- 1.18. Demonstrate the ambiguity that results when the cross product is used to find the angle between two vectors by finding the angle between $\mathbf{A} = 3\mathbf{a}_x + 2\mathbf{a}_y + 4\mathbf{a}_z$ and $\mathbf{B} = 2\mathbf{a}_x + \mathbf{a}_y + 3\mathbf{a}_z$. Does this ambiguity exist when the dot product is used?

We use the relation $\mathbf{A} \cdot \mathbf{B} = |\mathbf{A}||\mathbf{B}|\cos\theta$. With the given vectors we find

$$\mathbf{A} \cdot \mathbf{B} = 14\mathbf{a}_x + 7\mathbf{a}_y + 12\mathbf{a}_z = 7\sqrt{5} \underbrace{\left[\frac{2\mathbf{a}_x + \mathbf{a}_y}{\sqrt{5}} + \frac{4}{\sqrt{5}}\mathbf{a}_z \right]}_{\mathbf{u}} = \sqrt{5} \sqrt{5} \sqrt{2} \sqrt{1+1+4} \cos\theta$$

where $\mathbf{u}$ is identified as above; we see that $\mathbf{u}$ can be positive or negative, as $\cos\theta$ can be positive or negative. This apparent sign ambiguity is not the real problem. However, as we really want the magnitude of the angle cosine. Choosing the positive sign, we are left with $\cos\theta = 7\sqrt{5}/14\sqrt{2} \sqrt{6} = 0.666$. Two values of θ (75.7° and 284.3°) satisfy this equation, and hence the real ambiguity.

In using the dot product, we find $\mathbf{A} \cdot \mathbf{B} = 14 + 7 + 12 = 33 = |\mathbf{A}||\mathbf{B}|\cos\theta = 14\sqrt{5}\cos\theta$, or $\cos\theta = 33/(14\sqrt{5}) = 0.666$, or $\theta = 75.7^\circ$. Again, the sign ambiguity is not important, as we care only about the angle magnitude. The main point is that only one θ value results when using the dot product, so no ambiguity.

- 1.19. A field is given as

$$\mathbf{G} = \frac{\mathbf{r}}{r^2} \sqrt{r^2 + 2z}$$

Find:

- a unit vector in the direction of $\mathbf{G}$ at $P(3, 4, -2)$. Since $G_x = 25/(25+20) = 5/9$, $G_y = 4/9$, and $G_z = -2/9$. Then $\mathbf{u}_G = (5\mathbf{a}_x + 4\mathbf{a}_y - 2\mathbf{a}_z)/9$.
- the angle between $\mathbf{G}$ and $\mathbf{a}_x$ at P . The angle is found through $\mathbf{u}_G \cdot \mathbf{a}_x = \cos\theta$. So $\cos\theta = (5\mathbf{a}_x + 4\mathbf{a}_y - 2\mathbf{a}_z) \cdot (1, 0, 0) = 5/9$. Then $\theta = 58^\circ$.
- the value of the following double integral in the plane $z = 5$:

$$\begin{aligned} & \iint \mathbf{G} \cdot \mathbf{u}_G \, d\mathbf{r} \\ &= \iint \left[\frac{\mathbf{r}}{r^2} \sqrt{r^2 + 2z} \right] \cdot \mathbf{u}_G \, d\mathbf{r} = \iint \left[\frac{\mathbf{r}}{r^2} \sqrt{r^2 + 10} \right] \cdot \frac{\mathbf{r}}{r^2} \, d\mathbf{r} \\ &= 10 \cdot \frac{1}{2} \left[\ln^2 \left(\frac{r}{2} \right) + \frac{1}{2} \right] = 25 \end{aligned}$$

- 1.20. By representing diagonals as vectors and using the definition of the dot product, find the smaller angle between any two diagonals of a cube, where each diagonal connects diametrically opposite corners, and passes through the center of the cube.

Assuming a side length, 1, two diagonal vectors would be $\mathbf{A} = 2(\mathbf{a}_x + \mathbf{a}_y + \mathbf{a}_z)$ and $\mathbf{B} = 2(\mathbf{a}_x - \mathbf{a}_y + \mathbf{a}_z)$. Then use $\mathbf{A} \cdot \mathbf{B} = |\mathbf{A}||\mathbf{B}|\cos\theta$, or $4(1+1+1) = 4\sqrt{3}\sqrt{3}\cos\theta$, or $\cos\theta = 1/3$, or $\theta = 70.52^\circ$. This result (in magnitude) is the same for any two diagonal vectors.

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