

## Scalar product

The scalar product is used to find the angle between two vectors (or between two lines).

The formula for scalar product is

$$\mathbf{a} \cdot \mathbf{b} = ab \cos \theta \text{ (LEARN THIS!)}$$

where  $a$  is the magnitude of  $\mathbf{a}$ ,  $b$  is the magnitude of  $\mathbf{b}$ , and  $\theta$  is the angle between vectors  $\mathbf{a}$  and  $\mathbf{b}$ .

Note: The angle between two lines is the angle between their direction vectors.

**Example:**

Find the angle between the vectors  $3\mathbf{i} + 2\mathbf{j} - 2\mathbf{k}$  and  $-4\mathbf{i} - \mathbf{j} + 3\mathbf{k}$ .

**Solution:**

Step 1: Find the scalar product:

$$\begin{pmatrix} 3 \\ 2 \\ -2 \end{pmatrix} \cdot \begin{pmatrix} -4 \\ -1 \\ 3 \end{pmatrix} = -12 - 2 - 6 = -20$$

Step 2: Find the magnitude of each vector:

$$\begin{vmatrix} 3 \\ 2 \\ -2 \end{vmatrix} = \sqrt{9+4+4} = \sqrt{17}, \begin{vmatrix} -4 \\ -1 \\ 3 \end{vmatrix} = \sqrt{16+1+9} = \sqrt{26}$$

Step 3: Use the formula for the scalar product:

$$\mathbf{a} \cdot \mathbf{b} = ab \cos \theta$$

$$-20 = \sqrt{17} \times \sqrt{26} \times \cos \theta$$

$$\cos \theta = \frac{-20}{\sqrt{17} \times \sqrt{26}} = -0.9513$$

$$\text{So, } \theta = 162^\circ$$

There is also an acute angle between the lines. This is  $180 - 162 = 18^\circ$ .

# VECTORS

The magnitude of a vector is its length. The

magnitude of the vector  $\begin{pmatrix} a \\ b \\ c \end{pmatrix}$  is  $\sqrt{a^2 + b^2 + c^2}$ .

The distance between 2 points  $A$  and  $B$  is  $|\overrightarrow{AB}|$ .

**Example:** a) Find the vector equation of line  $l_1$  passing through the points  $A(1, -2, 6)$  and  $B(7, 1, -3)$ .

b) A second line  $l_2$  has equation

$$\mathbf{r} = (1+2\mathbf{i} + 3\mathbf{k}) + t(4\mathbf{i} - 6\mathbf{j} + 2\mathbf{k}).$$

Show that line  $l_1$  and  $l_2$  are skew and find the angle between the lines.

**Solution:**

a) The direction of the line is

$$\overrightarrow{AB} = \mathbf{b} - \mathbf{a} = \begin{pmatrix} 7 \\ 1 \\ -2 \end{pmatrix} - \begin{pmatrix} 1 \\ -2 \\ 6 \end{pmatrix} = \begin{pmatrix} 6 \\ 3 \\ -8 \end{pmatrix}.$$

The line passes through  $(1, -2, 6)$ , so the equation is

$$\mathbf{r} = \begin{pmatrix} 1 \\ -2 \\ 6 \end{pmatrix} + t \begin{pmatrix} 6 \\ 3 \\ -8 \end{pmatrix}.$$

b) To show lines are skew we show they can't intersect. We do this by writing the two vector equations equal to each other and attempting to solve the equations:

$$\begin{pmatrix} 1 \\ -2 \\ 6 \end{pmatrix} + t \begin{pmatrix} 6 \\ 3 \\ -8 \end{pmatrix} = \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix} + s \begin{pmatrix} 4 \\ -6 \\ 2 \end{pmatrix}$$

NOTE: It is ESSENTIAL that the lines are written with different parameters.

The vector equation of the line passing through the point  $(a, b, c)$  in the direction of the vector

$$\mathbf{a} + m\mathbf{j} + nk \text{ is: } \mathbf{r} = \begin{pmatrix} a \\ b \\ c \end{pmatrix} + t \begin{pmatrix} 1 \\ m \\ n \end{pmatrix}$$

Note:  $t$  is a parameter and  $\mathbf{r}$  is the position vector of a general point  $(x, y, z)$  on the line.

Lines are called skew if they do not intersect and if they are not parallel. So to prove that two lines are skew you prove they don't intersect.

We can form equations:

$$1 + 6t = 1 + 4s \rightarrow 6t - 4s = 0 \quad (1)$$

$$-2 + 3t = 2 - 6s \rightarrow 3t + 6s = 4 \quad (2)$$

$$6 - 8t = 3 + 2s \rightarrow 8t + 2s = 3 \quad (3)$$

Solving equations (1) and (2):

$$6t - 4s = 0 \quad (1)$$

$$6t + 12s = 8 \quad (2) \times 2$$

Subtract equations to remove  $t$ :  $16s = 8$

$$\text{So } s = 0.5.$$

From equation (1), we then get  $t = 1/3$ .

To show they are skew lines, we must check that these values do not work in the 3<sup>rd</sup> equation:

$$8t + 2s = 8 \times \frac{1}{3} + 2 \times 0.5 \neq 3$$

Therefore the lines are skew.

We find the angle between the direction vectors:

$$\begin{pmatrix} 6 \\ 3 \\ -8 \end{pmatrix} \cdot \begin{pmatrix} 4 \\ -6 \\ 2 \end{pmatrix} = 24 - 18 - 16 = -10$$

$$\begin{vmatrix} 6 \\ 3 \\ -8 \end{vmatrix} = \sqrt{36+9+64} = \sqrt{109} \quad \text{and} \quad \begin{vmatrix} 4 \\ -6 \\ 2 \end{vmatrix} = \sqrt{16+36+4} = \sqrt{56}$$

$$\text{So, } -10 = \sqrt{109} \times \sqrt{56} \times \cos \theta$$

$$\text{Therefore } \cos \theta = -0.12799 \Rightarrow \theta = 97.4^\circ$$

So the acute angle is  $82.6^\circ$ .

# Calculus And Vectors Formula Sheet

**Michael Sullivan**

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## **Table of Contents Calculus And Vectors Formula Sheet**

1. Understanding the eBook Calculus And Vectors Formula Sheet
  - The Rise of Digital Reading Calculus And Vectors Formula Sheet
  - Advantages of eBooks Over Traditional Books
2. Identifying Calculus And Vectors Formula Sheet
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Calculus And Vectors Formula Sheet
  - User-Friendly Interface
4. Exploring eBook Recommendations from Calculus And Vectors Formula Sheet
  - Personalized Recommendations
  - Calculus And Vectors Formula Sheet User Reviews and Ratings

- Calculus And Vectors Formula Sheet and Bestseller Lists
- 5. Accessing Calculus And Vectors Formula Sheet Free and Paid eBooks
  - Calculus And Vectors Formula Sheet Public Domain eBooks
  - Calculus And Vectors Formula Sheet eBook Subscription Services
  - Calculus And Vectors Formula Sheet Budget-Friendly Options
- 6. Navigating Calculus And Vectors Formula Sheet eBook Formats
  - ePUB, PDF, MOBI, and More
  - Calculus And Vectors Formula Sheet Compatibility with Devices
  - Calculus And Vectors Formula Sheet Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Calculus And Vectors Formula Sheet
  - Highlighting and Note-Taking Calculus And Vectors Formula Sheet
  - Interactive Elements Calculus And Vectors Formula Sheet
- 8. Staying Engaged with Calculus And Vectors Formula Sheet
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Calculus And Vectors Formula Sheet
- 9. Balancing eBooks and Physical Books Calculus And Vectors Formula Sheet
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Calculus And Vectors Formula Sheet
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Calculus And Vectors Formula Sheet
  - Setting Reading Goals Calculus And Vectors Formula Sheet
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Calculus And Vectors Formula Sheet
  - Fact-Checking eBook Content of Calculus And Vectors Formula Sheet
  - Distinguishing Credible Sources

13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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