

# LaTeX to PDF and MathJax: Example 2

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## Using this document

This is a second example of a document compiled from L<sup>A</sup>T<sub>E</sub>X into multiple formats.

- Standard print PDF
- Clearer print PDF
- Accessible web format

The outputs can be used to test setups and as a second example for students to try out.

# 1 The scalar product

Consider two vectors  $\mathbf{a}$  and  $\mathbf{b}$  drawn so their tails are at the same point.

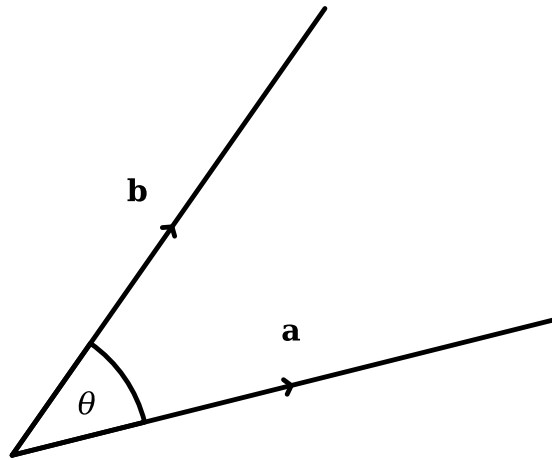


Figure 1: Two vectors with angle between them.

We define the scalar product of  $\mathbf{a}$  and  $\mathbf{b}$  as follows.

**Definition 1.1** (Scalar product). The *scalar product* of  $\mathbf{a}$  and  $\mathbf{b}$  is

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

where

- $|\mathbf{a}|$  is the modulus of  $\mathbf{a}$ ,
- $|\mathbf{b}|$  is the modulus of  $\mathbf{b}$ , and
- $\theta$  is the angle between  $\mathbf{a}$  and  $\mathbf{b}$ .

*Remark 1.2.* It is important to use the dot symbol for the scalar product (also called the dot product). You must not use a  $\times$  symbol as this denotes the vector product which is defined differently.

*Example 1.3.* Let

$$\mathbf{a} = \begin{pmatrix} 2 \\ 2 \end{pmatrix} \quad \text{and} \quad \mathbf{b} = \begin{pmatrix} 4 \\ 0 \end{pmatrix}.$$

The angle between these vectors is  $\theta = 45^\circ$ . Then  $|\mathbf{a}| = \sqrt{8}$  and  $|\mathbf{b}| = 4$ . So,

$$\begin{aligned} \mathbf{a} \cdot \mathbf{b} &= \begin{pmatrix} 2 \\ 2 \end{pmatrix} \cdot \begin{pmatrix} 4 \\ 0 \end{pmatrix} = |\mathbf{a}||\mathbf{b}| \cos \theta \\ &= \sqrt{8} \times 4 \times \cos 45^\circ \\ &= 4\sqrt{8} \times \frac{1}{\sqrt{2}} = 4 \frac{\sqrt{8}}{\sqrt{2}} = 4\sqrt{4} = 8. \end{aligned}$$

Note that the result is a scalar, not a vector.

## 1.1 Vectors in cartesian form

When vectors are given in cartesian form there is an alternative formula for calculating the scalar product.

**Proposition 1.4.** *If  $\mathbf{a} = a_1\mathbf{i} + a_2\mathbf{j}$  and  $\mathbf{b} = b_1\mathbf{i} + b_2\mathbf{j}$  then*

$$\mathbf{a} \cdot \mathbf{b} = a_1b_1 + a_2b_2.$$

*Proof.* Consider the vector  $\mathbf{b} - \mathbf{a} = \begin{pmatrix} b_1 - a_1 \\ b_2 - a_2 \end{pmatrix}$ . The modulus of this is

$$|\mathbf{b} - \mathbf{a}| = \sqrt{(b_1 - a_1)^2 + (b_2 - a_2)^2}.$$

Note from figure 2 that the vectors  $\mathbf{a}$ ,  $\mathbf{b}$  and  $\mathbf{b} - \mathbf{a}$  form a triangle:

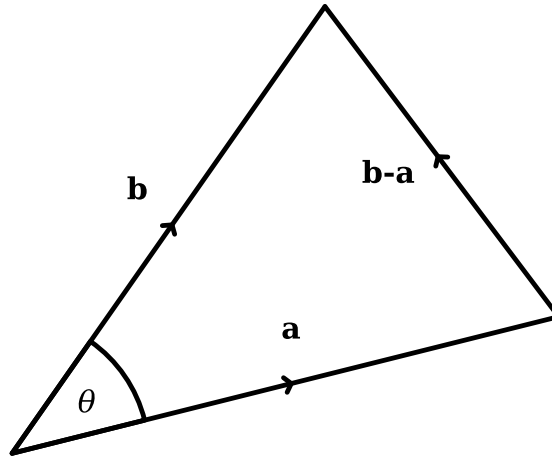


Figure 2: A triangle is formed by two vectors and their difference.

Let  $\theta$  denote the angle between  $\mathbf{a}$  and  $\mathbf{b}$ . Then, the cosine rule yields:

$$|\mathbf{b} - \mathbf{a}|^2 = |\mathbf{a}|^2 + |\mathbf{b}|^2 - 2|\mathbf{a}||\mathbf{b}|\cos\theta. \quad (1)$$

Substituting the definition of the scalar product of  $\mathbf{a}$  and  $\mathbf{b}$  into equation 1 gives:

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

Rearranging:

$$(\mathbf{a} \cdot \mathbf{b}) = \frac{1}{2} (|\mathbf{a}|^2 + |\mathbf{b}|^2 - |\mathbf{b} - \mathbf{a}|^2).$$

Writing this in terms of components produces:

$$\begin{aligned} (\mathbf{a} \cdot \mathbf{b}) &= \frac{1}{2} (a_1^2 + a_2^2 + b_1^2 + b_2^2 - (b_1 - a_1)^2 - (b_2 - a_2)^2) \\ &= \frac{1}{2} (a_1^2 + a_2^2 + b_1^2 + b_2^2 - b_1^2 + 2b_1a_1 - a_1^2 - b_2^2 + 2b_2a_2 - a_2^2) \\ &= \frac{1}{2} (2b_1a_1 + 2b_2a_2) \\ &= a_1b_1 + a_2b_2 \end{aligned}$$

as required. □

*Example 1.5.* Consider again the vectors

$$\mathbf{a} = \begin{pmatrix} 2 \\ 2 \end{pmatrix} \quad \text{and} \quad \mathbf{b} = \begin{pmatrix} 4 \\ 0 \end{pmatrix}.$$

Calculating the scalar product using the components:

$$\mathbf{a} \cdot \mathbf{b} = a_1 b_1 + a_2 b_2 = 2 \times 4 + 2 \times 0 = 8.$$

Note that if we are given vectors in this form, the scalar product may be used to calculate the angle between them. Since  $\mathbf{a} \cdot \mathbf{b} = 8$  and we have:

$$\begin{aligned} |\mathbf{a}| &= \sqrt{8} \\ |\mathbf{b}| &= 4. \end{aligned}$$

Hence,

$$\begin{aligned} 8 &= \mathbf{a} \cdot \mathbf{b} = |\mathbf{a}| |\mathbf{b}| \cos \theta \\ &= 4\sqrt{8} \cos \theta. \end{aligned}$$

Rearranging:

$$\theta = \cos^{-1} \left( \frac{8}{4\sqrt{8}} \right) = 45^\circ.$$

## 2 Using Matlab

To calculate the scalar product in Matlab the `dot` function is used.

Create two vectors:

```
> A = [4 -1 2];  
> B = [2 -2 -1];
```

Calculate the scalar product:

```
> C = dot(A,B)
```

```
C = 8
```