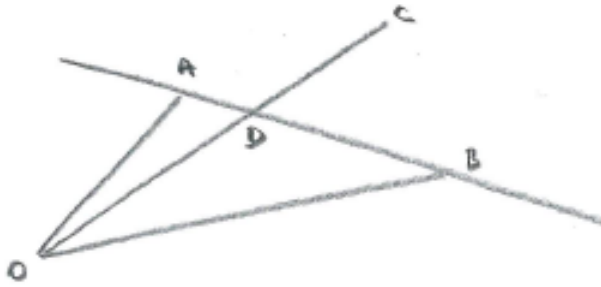


STEP: Vector Methods (4 pages; 14/3/2015)

(1) Referring to the diagram below, if $\overrightarrow{OA} = \mathbf{a}$ etc, then

\mathbf{d} can be written as $\lambda\mathbf{a} + (1-\lambda)\mathbf{b}$, where $\frac{DB}{AB} = \lambda$

(consider $\lambda = 1$, if in doubt)



(2) Again referring to the diagram in (1),

\mathbf{d} can be written as $\mu\mathbf{c}$

In other words, the fact that D lies somewhere on the line OC can be used to generate an expression for \mathbf{d} . This may not seem to be of much use, because an extra parameter has been introduced. However, the result in (3) enables two equations to be generated, so that the extra parameter can be eliminated, leaving one new equation!

Another example, also using the diagram in (1):

\mathbf{d} can be written as $\mathbf{a} + \mu\overrightarrow{AB}$

This is obviously just a variant of (1), but is a quick way of taking account of the fact that D lies on the line through AB. See also the Example in (5) below.

This leads on to idea (3):

(3) Once again, referring to the diagram in (1):

One of the basic vector techniques is to find an alternative route to a particular point.

$$\text{So, for example: } \overrightarrow{OD} = \overrightarrow{OA} + \overrightarrow{AD} = \overrightarrow{OA} + \lambda \overrightarrow{AB}$$

This takes account of the fact that D lies on AB, without having to solve any simultaneous equations. See Example in (5) below.

(4) If \mathbf{a} and \mathbf{b} are non-parallel vectors, and $p\mathbf{a} + q\mathbf{b} = r\mathbf{a} + s\mathbf{b}$, then it follows that $p = r$ and $q = s$.

We are used to using this for the unit vectors \mathbf{i} and \mathbf{j} , but it may appear to be counter-intuitive for other \mathbf{a} and \mathbf{b} : it seems as though we are equating coefficients of \mathbf{a} and \mathbf{b} , even though \mathbf{a} and \mathbf{b} are fixed (normally the method of equating coefficients is only valid if the relation is to hold for all values of the variable)! The reason it works for \mathbf{i} and \mathbf{j} is just that the vector equation $p\mathbf{i} + q\mathbf{j} = r\mathbf{i} + s\mathbf{j}$ is really a pair of equations: one for the \mathbf{i} dimension and one for the \mathbf{j} dimension, and the same applies to any \mathbf{a} and \mathbf{b} (provided they aren't parallel).

For example, referring again to the diagram in (1), if we are told that $\mathbf{c} = \alpha\mathbf{a} + \beta\mathbf{b}$, then we have the following information about \mathbf{d} :

$$(i) \mathbf{d} = \lambda\mathbf{a} + (1-\lambda)\mathbf{b}$$

$$(ii) \mathbf{d} = \mu(\alpha\mathbf{a} + \beta\mathbf{b})$$

Then equating the coefficients of \mathbf{a} and \mathbf{b} gives:

$$\lambda = \mu\alpha \quad \text{and} \quad 1-\lambda = \mu\beta$$

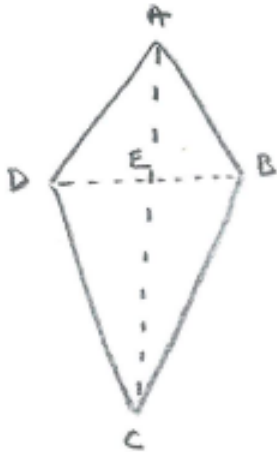
and μ can be eliminated to give the relation $\frac{\alpha}{\beta} = \frac{\lambda}{1-\lambda} = \frac{DB}{AD}$

See, for example, STEP Paper 2, 2007, Q8 (on which the above example is based).

(5) Example [AEA, June 2009, Q7(d)]

In the diagram below, ABCD is a kite. Find \overrightarrow{OD} if

$$\overrightarrow{OA} = \begin{pmatrix} -1 \\ 4/3 \\ 7 \end{pmatrix}, \quad \overrightarrow{OB} = \begin{pmatrix} 4 \\ 4/3 \\ 2 \end{pmatrix} \quad \& \quad \overrightarrow{OC} = \begin{pmatrix} 6 \\ 16/3 \\ 2 \end{pmatrix}$$



We need to take account of the special features of this case, namely that AC is perpendicular to BD (*) and bisects BD (**) (which enables D to be uniquely determined from A, B & C).

We can take an alternative route to D, in order to involve the other points, writing:

$$\overrightarrow{OD} = \overrightarrow{OB} + 2\overrightarrow{BE} \quad [\text{this takes account of (**)}]$$

To record the fact that E lies on AC, we write $\overrightarrow{BE} = \overrightarrow{BA} + \lambda\overrightarrow{AC}$

We also need to take account of (*): $\overrightarrow{BE} \cdot \overrightarrow{AC} = 0$

$$\text{Now } \overrightarrow{BA} = \begin{pmatrix} -5 \\ 0 \\ 5 \end{pmatrix} \quad \text{and} \quad \overrightarrow{AC} = \begin{pmatrix} 7 \\ 4 \\ -5 \end{pmatrix}$$

$$\text{so that } \overrightarrow{BE} = \begin{pmatrix} -5 + 7\lambda \\ 4\lambda \\ 5 - 5\lambda \end{pmatrix}$$

$$\overrightarrow{BE} \cdot \overrightarrow{AC} = 0 \quad \text{gives} \quad 7(-5+7\lambda) + 4(4\lambda) - 5(5-5\lambda) = 0$$

$$\text{so that } 90\lambda = 60 \quad \text{and} \quad \lambda = 2/3$$

Hence

$$\overrightarrow{BE} = \begin{pmatrix} -1/3 \\ 8/3 \\ 5/3 \end{pmatrix}$$

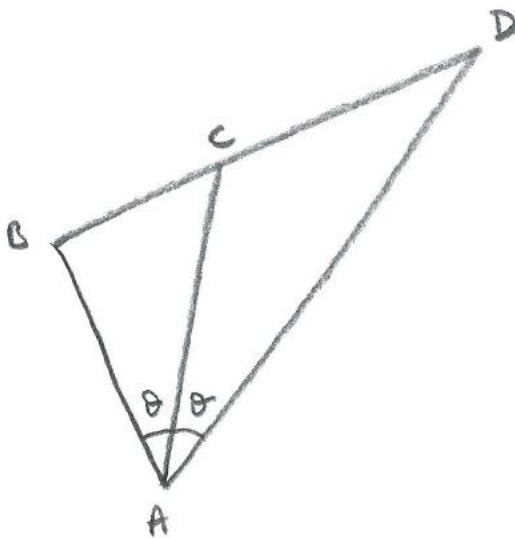
$$\text{Then } \overrightarrow{OD} = \overrightarrow{OB} + 2\overrightarrow{BE} = \begin{pmatrix} 4 - 2/3 \\ \frac{4}{3} + 16/3 \\ 2 + 10/3 \end{pmatrix} = \begin{pmatrix} 10/3 \\ 20/3 \\ 16/3 \end{pmatrix} = 2/3 \begin{pmatrix} 5 \\ 10 \\ 18 \end{pmatrix}$$

(6) The Sine and Cosine rules can sometimes be applied to triangles formed from vectors (ie the problem becomes one of simple geometry).

See, for example, STEP Paper 2, 2008, Q8 (1st part).

In particular, use can be made of the Angle Bisector Theorem

Referring to the diagram below, $\frac{CD}{AD} = \frac{BC}{AB}$



Proof

By the Sine rule, $\frac{BC}{\sin\theta} = \frac{AB}{\sin\angle BCA}$, so that $\frac{BC}{AB} = \frac{\sin\theta}{\sin\angle BCA}$

Also, $\frac{CD}{\sin\theta} = \frac{AD}{\sin\angle ACD} = \frac{AD}{\sin\angle BCA}$, and so $\frac{CD}{AD} = \frac{\sin\theta}{\sin\angle BCA} = \frac{BC}{AB}$