General Physics I
(Phys 101)

Chapter 1 : Vectors

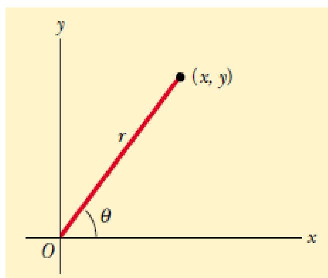
Chapter Outline:

1.1 Coordinate Systems
1.2 Vector and Scalar Quantities
1.3 Some Properties of Vectors
- Equality
- Addition
- Commutative associative
- Negative of a Vector
- Subtracting
- Multiplying a Vector by a Scalar

1.4 Components of a Vector and Unit Vectors

3.1 Coordinate Systems

Cartesian coordinate system
(x, y)



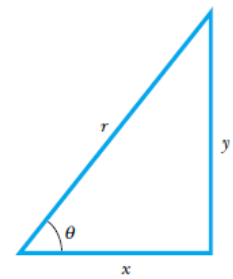
Any point P is labeled with the coordinates (x, y)

polar coordinate system
(r, θ)

$\sin\theta = \frac{y}{r}$

$\cos\theta = \frac{x}{r}$

$\tan\theta = \frac{y}{x}$

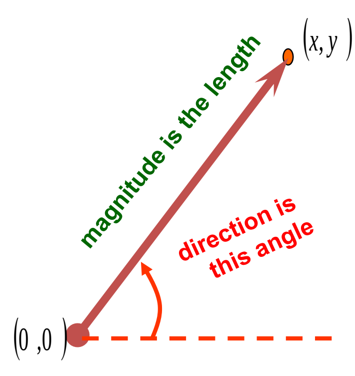


Any point P is labeled with the coordinates (r, θ)

polar coordinate system(r, θ)

In this *polar coordinate system*:

- *r* is the distance from the origin to the point having Cartesian coordinates (*x, y*)
- θ is the angle between a line drawn from the origin to the point and a fixed axis.
- This fixed axis is usually the positive x axis, and θ is Measured **Counterclockwise**



Relations between both systems

Therefore, starting with the plane polar coordinates of any point, we can obtain the Cartesian coordinates

Chartesian from Polar

$x = r\cos\theta$

$y = r\sin\theta$

Polar from Chartesian

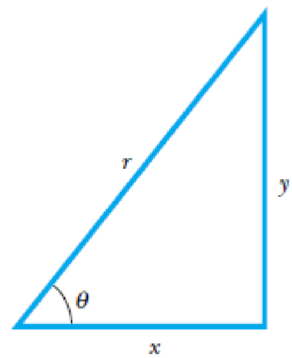
$r = \sqrt{x^2 + y^2}$

$\theta = \tan^{-1}\frac{y}{x}$

$\sin\theta = \frac{y}{r}$

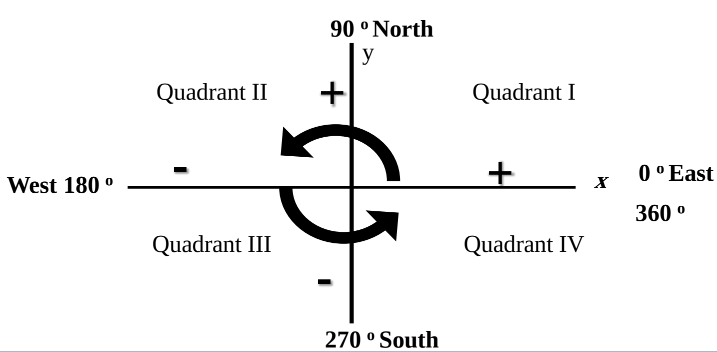
$\cos\theta = \frac{x}{r}$

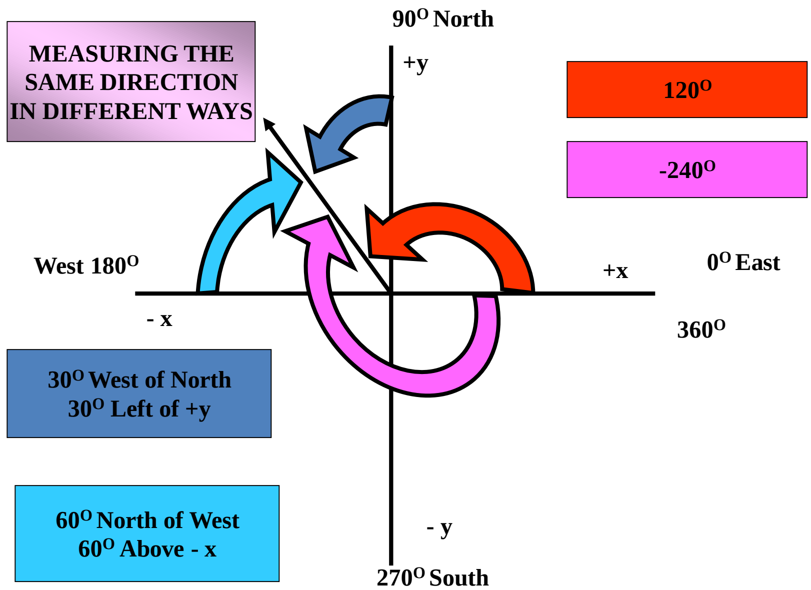
$\tan\theta = \frac{y}{x}$



Mathematics notes

Up = + **Down = -** **Right = +** **Left = -**

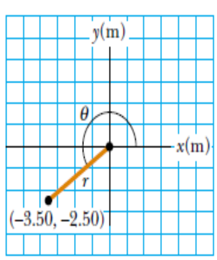




Example

Example 3.1 Polar Coordinates

The Cartesian coordinates of a point in the xy plane are $(x, y) = (-3.50, -2.50)$ m, as shown in Figure 3.3. Find the polar coordinates of this point.

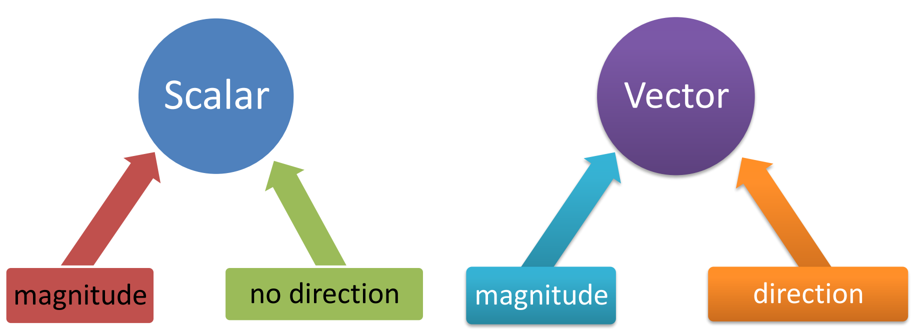


Example

5. If the rectangular coordinates of a point are given by $(2, y)$ and its polar coordinates are $(r, 30°)$, determine y and r.

3.2 Vector and Scalar Quantities

Some physical quantities are scalar quantities whereas others are vector quantities.



101 phys أ. سجى القصير جامعة الامام محمد بن سعود الإسلامية

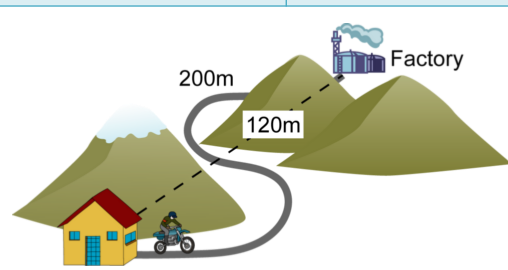
Vector

- To represent a vector quantity **A**:

  an <u>arrow</u> is written over the symbol for the vector $\vec{A}$
- The <u>magnitude</u> of the vector **A** is written either ***A*** or $|\boldsymbol{A}|$
- The magnitude of a vector has physical units, such as meters for displacement or meters per second for velocity. The magnitude of a vector is *always* a positive number.

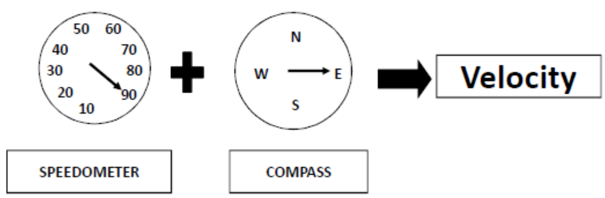
Distance and Displacement

	Distance	Displacement
Definition	The distance traveled by an object is the total length that is traveled by that object.	Displacement of an object from a point of reference, O is the shortest distance of the object from point O in a specific direction.
SI unit	meter (m)	meter (m)
Quantity	Scalar	Vector



Speed and Velocity

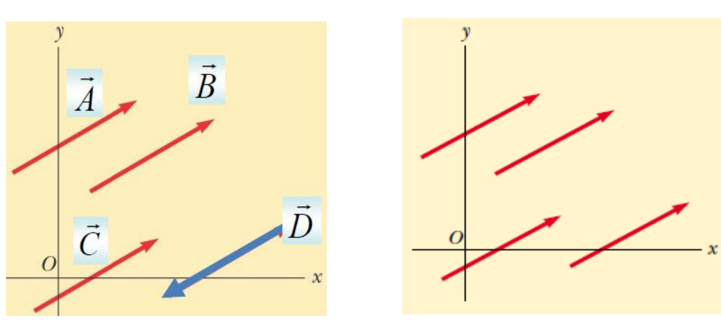
	Speed	Velocity
Definition	The rate of change in distance with respect to time Speed tells us how fast we are going but not which way	The rate of change in displacement with respect to time. Velocity requires a direction
SI unit	Meter\sec	Meter\sec
Quantity	Scalar	Vector



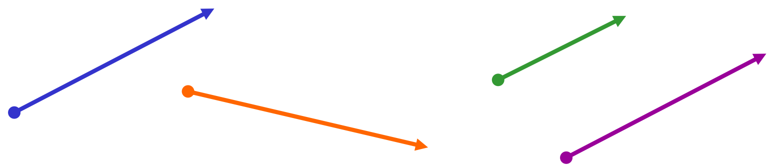
3.3 Some Properties of Vectors

1-Equality of Two Vectors:

Two vectors A and B may be defined to be equal if they have the same magnitude and point in the same direction.



3.3 Some Properties of Vectors



Blue and orange vectors have same magnitude but different direction.

Blue and purple vectors have same magnitude and direction so they are equal.

Blue and green vectors have same direction but different magnitude.

Two vectors are equal if they have the same direction and magnitude (length).

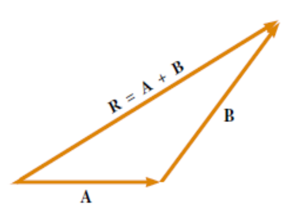
3.3 Some Properties of Vectors

2-Adding Vectors:

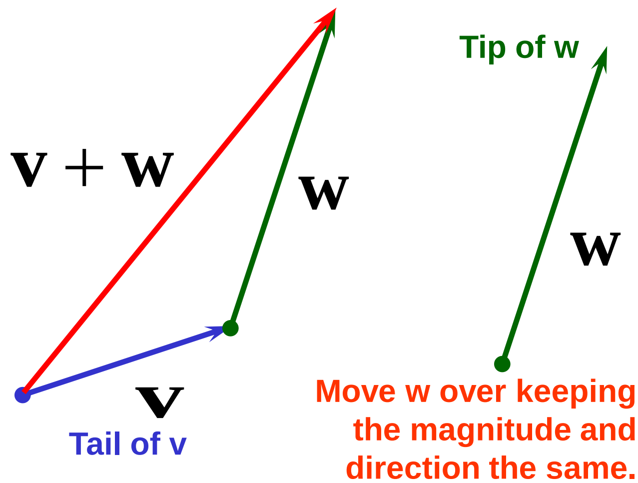
Head to Tail Method or (tip to tail)

To add vector B to vector A, first draw vector A on graph paper, with its magnitude represented by a convenient length scale, and then draw vector B to the same scale with its tail starting from the tip of A, as shown in Figure. The resultant vector R = A + B is the vector drawn from the tail of A to the tip of B.

R is the vector drawn from the tail of the first vector to the tip of the last vector.

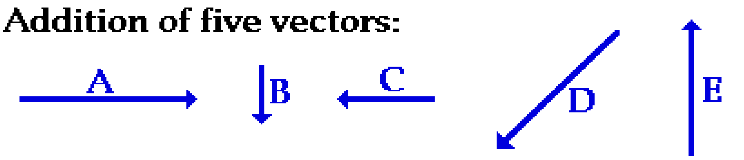


3.3 Some Properties of Vectors



3.3 Some Properties of Vectors

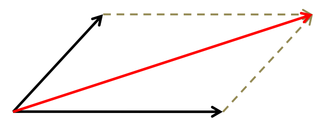
Addition of five vectors:



3.3 Some Properties of Vectors

parallelogram method

When two vectors are joined tail to tail. Complete the parallelogram. The resultant is found by drawing the diagonal



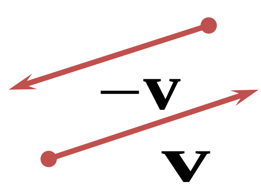
3.3 Some Properties of Vectors

3-Negative of a Vector:

The negative of the vector v is defined as the vector that when added to v gives zero for the vector sum. That is,

$$v + (-v) = 0.$$

The vectors v and - v have the same magnitude but point in opposite directions.

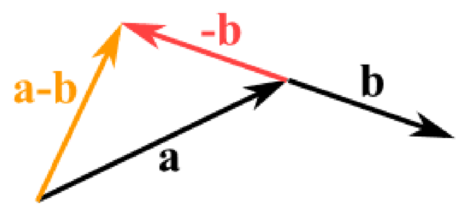


3.3 Some Properties of Vectors

4-Subtracting Vectors:

The operation of vector subtraction makes use of the definition of the negative of a vector. We define the operation A - B as vector -B added to vector A:

$$A - B = A + (-B)$$



3.3 Some Properties of Vectors

4-Multiplying a Vector by a Scalar

The product of a scalar m and a vector A equals (m A)

Direction of *m* *A*

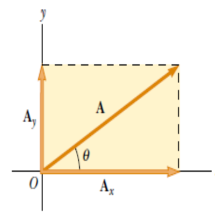
- In the same direction of *A* if *m* = +*ve*
- In opposite direction to *A* if *m* = -*ve*

3.4 Components of a Vector

Consider a vector A lying in the x-y plane and making an arbitrary angle θ with the positive x-direction.
Vector A can be represented as:

$$\vec{A} = \vec{A}_x + \vec{A}_y$$

$\vec{A}_x$ and $\vec{A}_y$ are called vector components.



Where,

$$\vec{A}_x = A\cos\theta$$

$$\vec{A}_y = A\sin\theta$$

Magnitude of $\vec{A} \Rightarrow |\vec{A}| = \sqrt{A_x^2 + A_y^2}$

Direction of $\vec{A} \Rightarrow \theta = \tan^{-1}\frac{A_y}{A_x}$

3.4 Components of a Vector

Note that the signs of the components Ax and Ay depend on the angle θ.
For example, if:
Θ= 120°, then A_x is negative and A_y is positive.
If
Θ= 225°, then A_x is negative and A_y is negative.

	y	
A_x negative, A_y positive		A_x positive, A_y positive
	x	
A_x negative, A_y negative		A_x positive, A_y negative

101 phys أ. سجى القصير جامعة الامام محمد بن سعود الإسلامية

3.4 Unit Vectors

Vector quantities often are expressed in terms of unit vectors

Properties of unit vectors

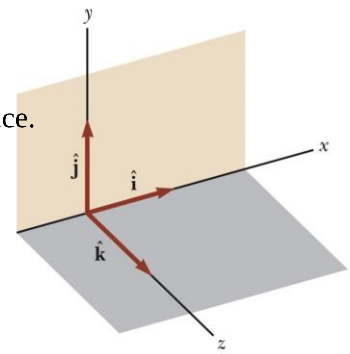
1) is a vector of magnitude exactly equal one

2) is dimensionless vector (have no units).

2) Are used to specify a given direction in space.

3) Units vectors along *x, y, and z directions,*

are called $\hat{\imath}$, $\hat{\jmath}$ *and* k

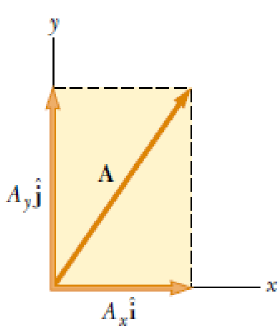


$$\vec{i} \perp \vec{j} \perp \vec{k}$$
$$i = j = k = 1$$

3.4 Unit Vectors

- A vector's components can be used with unit vectors.

$$\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$$



Adding Vectors Using Unit Vectors

Suppose that we wish to add vector B to vector A.

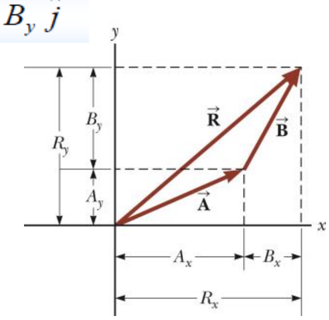
$$\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$$

- A has the components A_x , A_y $\quad \vec{A} = A_x\,\hat{i} + A_y\,\hat{j}$
- B has the components B_x , B_y $\quad \vec{B} = B_x\,\hat{i} + B_y\,\hat{j}$

Then $\vec{\mathbf{R}} = \left(A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}\right) + \left(B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}}\right)$

$$\vec{\mathbf{R}} = \left(A_x + B_x\right)\hat{\mathbf{i}} + \left(A_y + B_y\right)\hat{\mathbf{j}}$$

$$\vec{\mathbf{R}} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}}$$



So $R_x = A_x + B_x$ and $R_y = A_y + B_y$

$$R = \sqrt{R_x^2 + R_y^2} \qquad \theta = \tan^{-1}\frac{R_y}{R_x}$$

Example

Example 3.3 The Sum of Two Vectors

Find the sum of two vectors **A** and **B** lying in the *xy* plane and given by

$$\mathbf{A} = (2.0\hat{\mathbf{i}} + 2.0\hat{\mathbf{j}})\text{ m} \quad \text{and} \quad \mathbf{B} = (2.0\hat{\mathbf{i}} - 4.0\hat{\mathbf{j}})\text{ m}$$

(i) adding, $\vec{a}+\vec{b}$?

(ii) subtracting, $\vec{a}-\vec{b}$?

Example

Example 3.4 The Resultant Displacement

A particle undergoes three consecutive displacements: $\mathbf{d}_1 = (15\hat{\mathbf{i}} + 30\hat{\mathbf{j}} + 12\hat{\mathbf{k}})$ cm, $\mathbf{d}_2 = (23\hat{\mathbf{i}} - 14\hat{\mathbf{j}} - 5.0\hat{\mathbf{k}})$ cm and $\mathbf{d}_3 = (-13\hat{\mathbf{i}} + 15\hat{\mathbf{j}})$ cm. Find the components of the resultant displacement and its magnitude.

Example 3.5 Taking a Hike

Interactive

A hiker begins a trip by first walking 25.0 km southeast from her car. She stops and sets up her tent for the night. On the second day, she walks 40.0 km in a direction 60.0° north of east, at which point she discovers a forest ranger's tower.

(A) Determine the components of the hiker's displacement for each day.

Solution We *conceptualize* the problem by drawing a sketch as in Figure 3.19. If we denote the displacement vectors on the first and second days by **A** and **B**, respectively, and use the car as the origin of coordinates, we obtain the vectors shown in Figure 3.19. Drawing the resultant **R**, we can now *categorize* this as a problem we've solved before—an addition of two vectors. This should give you a hint of the power of categorization—many new problems are very similar to problems that we have already solved if we are careful to conceptualize them.

We will *analyze* this problem by using our new knowledge of vector components. Displacement **A** has a magnitude of 25.0 km and is directed 45.0° below the positive *x* axis. From Equations 3.8 and 3.9, its components are

$$A_x = A\cos(-45.0°) = (25.0\text{ km})(0.707) = 17.7\text{ km}$$

$$A_y = A\sin(-45.0°) = (25.0\text{ km})(-0.707) = -17.7\text{ km}$$

The negative value of A_y indicates that the hiker walks in the negative *y* direction on the first day. The signs of A_x and A_y also are evident from Figure 3.19.

The second displacement **B** has a magnitude of 40.0 km and is 60.0° north of east. Its components are

$$B_x = B\cos 60.0° = (40.0 \text{ km})(0.500) = \boxed{20.0 \text{ km}}$$

$$B_y = B\sin 60.0° = (40.0 \text{ km})(0.866) = \boxed{34.6 \text{ km}}$$

(B) Determine the components of the hiker's resultant displacement **R** for the trip. Find an expression for **R** in terms of unit vectors.

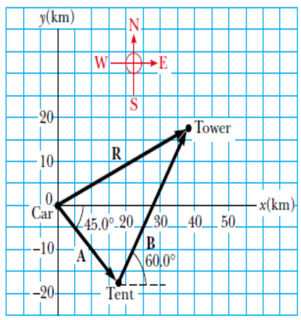


Figure 3.19 (Example 3.5) The total displacement of the hiker is the vector **R** = **A** + **B**.

Solution The resultant displacement for the trip **R** = **A** + **B** has components given by Equation 3.15:

$$R_x = A_x + B_x = 17.7 \text{ km} + 20.0 \text{ km} = \boxed{37.7 \text{ km}}$$

$$R_y = A_y + B_y = -17.7 \text{ km} + 34.6 \text{ km} = \boxed{16.9 \text{ km}}$$

In unit–vector form, we can write the total displacement as

$$\mathbf{R} = \boxed{(37.7\hat{\mathbf{i}} + 16.9\hat{\mathbf{j}}) \text{ km}}$$

Using Equations 3.16 and 3.17, we find that the vector **R** has a magnitude of 41.3 km and is directed 24.1° north of east.

Let us *finalize*. The units of **R** are km, which is reasonable for a displacement. Looking at the graphical representation in Figure 3.19, we estimate that the final position of the hiker is at about (38 km, 17 km) which is consistent with the components of **R** in our final result. Also, both components of **R** are positive, putting the final position in the first quadrant of the coordinate system, which is also consistent with Figure 3.19.

Example 3.6 Let's Fly Away!

A commuter airplane takes the route shown in Figure 3.20. First, it flies from the origin of the coordinate system shown to city A, located 175 km in a direction 30.0° north of east. Next, it flies 153 km 20.0° west of north to city B. Finally, it flies 195 km due west to city C. Find the location of city C relative to the origin.

Solution Once again, a drawing such as Figure 3.20 allows us to *conceptualize* the problem. It is convenient to choose the coordinate system shown in Figure 3.20, where the *x* axis points to the east and the *y* axis points to the north. Let us denote the three consecutive displacements by the vectors **a**, **b**, and **c**.

We can now *categorize* this problem as being similar to Example 3.5 that we have already solved. There are two primary differences. First, we are adding three vectors instead of two. Second, Example 3.5 guided us by first asking for the components in part (A). The current Example has no such guidance and simply asks for a result. We need to *analyze* the situation and choose a path. We will follow the same pattern that we did in Example 3.5, beginning with finding the components of the three vectors **a**, **b**, and **c**. Displacement **a** has a magnitude of 175 km and the components

$$a_x = a\cos(30.0°) = (175 \text{ km})(0.866) = 152 \text{ km}$$

$$a_y = a\sin(30.0°) = (175 \text{ km})(0.500) = 87.5 \text{ km}$$

Displacement **b**, whose magnitude is 153 km, has the components

$$b_x = b\cos(110°) = (153 \text{ km})(-0.342) = -52.3 \text{ km}$$

$$b_y = b\sin(110°) = (153 \text{ km})(0.940) = 144 \text{ km}$$

Finally, displacement **c**, whose magnitude is 195 km, has the components

$$c_x = c\cos(180°) = (195 \text{ km})(-1) = -195 \text{ km}$$

$$c_y = c\sin(180°) = 0$$

Therefore, the components of the position vector **R** from the starting point to city C are

$$R_x = a_x + b_x + c_x = 152 \text{ km} - 52.3 \text{ km} - 195 \text{ km}$$

$$= \boxed{-95.3 \text{ km}}$$

$$R_y = a_y + b_y + c_y = 87.5 \text{ km} + 144 \text{ km} + 0 = \boxed{232 \text{ km}}$$

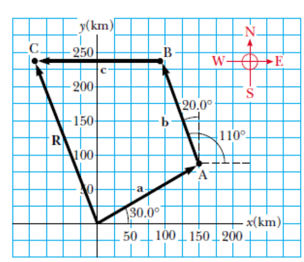


Figure 3.20 (Example 3.6) The airplane starts at the origin, flies first to city A, then to city B, and finally to city C.

Vectors product

Scalar (dot)

- $A \cdot B = |A||B| \cos\theta$
- The result of the product is scalar
- The result equal zero if: $\theta = 90° \; or \; 270°$
- $i \cdot i = j \cdot j = k \cdot k = 1$
- $i \cdot j = j \cdot k = k \cdot i = 0$

$$\vec{A} \cdot \vec{B} = A_x B_x + A_y B_y + A_z B_z$$

Find: $\vec{A} \times \vec{B}$ Where:

$\vec{A} = 2\hat{i} + 3\hat{j}$ $\vec{B} = -\hat{i} + 2\hat{j}$