# PHYSICS COURSE – YEAR 11

**MODULE 1: KINEMATICS**

**MECHANICS**

The branch of Physics that is concerned with the motion and equilibrium of bodies in a particular frame of reference is called **“mechanics”**. Mechanics can be divided into three branches: (i) **Statics** – which deals with bodies at rest relative to some given frame of reference, with the forces between them and with the equilibrium of the system; (ii) **Kinematics** - the description of the motion of bodies without reference to mass or force; and (iii) **Dynamics** – which deals with forces that change or produce the motions of bodies.

Some common terms used in the study of mechanics (and indeed many other branches of Physics) are: scalars, vectors and SI Units.

1. **Scalars** – A scalar is a physical quantity defined in terms of **magnitude (size)** only. Eg temperature, mass, volume, density, distance
2. **Vectors** – A vector is a physical quantity defined in terms of **both magnitude and direction**. Eg force, velocity, acceleration, electric field strength. **Diagramatically we can represent a vector by a straight line with an arrow on one end. The length of the line represents the magnitude of the vector quantity and the direction in which the arrow is pointing represents the direction of the vector quantity.** We will say much more about vectors later in this topic.
3. **Systeme International (SI) Units** – The internationally agreed system of units. There are seven fundamental units. The three that we will use in this topic are the **metre (length), the kilogram (mass) and the second (time)**. Various prefixes are used to help express the size of quantities eg a nanometre (1 nm) = 10-9 of a metre, a gigametre (1 Gm) = 109 metres (see Appendix C, p.243 of Excel Preliminary Physics by Warren for a list of some common SI units and prefixes).

Since describing the features of something is usually a lot simpler than explaining how or why it works, we will start our Year 11 Physics course with a look at kinematics.

**MOTION IN A STRAIGHT LINE**

**Inquiry Question:** How is the motion of an object moving in a straight line described and predicted?

The following terms are commonly used to describe motion.

1. **Displacement** – is the distance of a body from a given point in a given direction. It is a vector quantity. The SI unit of displacement is the metre (m).
2. **Speed** – The speed of a body is the rate at which it is covering distance. It is a scalar quantity. The SI units are m/s, which can also be written as ms-1.  
    ****where vav = average speed, d = total distance travelled and t = total time taken to travel distance d.
3. **Velocity** – The velocity of a body is its speed in a given direction. In other words, velocity is the rate of change of displacement with time. It is a vector quantity with the same SI units as speed.  
     
    ****where **vav** = average velocity, **s** = change in displacement and **t** = change in time taken to achieve that change in displacement. Note that the symbol **r** is sometimes used in place of **s** to denote displacement.  
     
   Another way to express average velocity is as the average of the initial and final velocities.  
     
    where vav = average velocity, u = initial velocity of the body and v = final velocity of the body. **Note that this equation applies ONLY when the velocity of the body is increasing or decreasing at a constant rate.**
4. **Acceleration** – The acceleration of a body is the rate of change of the velocity of the body with time. It is a vector quantity, with units of (metres/second)/second, written as ms-2.  
     
      
     
   where aav = average acceleration, v = change in velocity of the body and t = change in time over which the change in velocity took place. Alternatively, we may write:

  
  
where aav = average acceleration, v = final velocity of the body, u = initial velocity of the body, and t = time over which the change in velocity took place.

**Note that a body accelerates when:**

* 1. **It speeds up;**
  2. **It slows down;**
  3. **It changes direction.**

1. **Uniform** – The word **uniform** as used in Physics in reference to motion refers to **constant** motion. So, uniform velocity means constant velocity – a velocity that does not change. Uniform acceleration means constant acceleration. Something that accelerates uniformly, increases or decreases its velocity at a constant rate.
2. **Rectilinear Motion** – Motion that is in a **straight line** is called rectilinear motion. A more precise definition says: Rectilinear motion is a linear motion in which the direction of the velocity remains constant and the path is a straight line.  
     
   When describing rectilinear motion there are only ever two possible directions that we need to consider, backwards and forwards along the line. We usually refer to one of those directions as the positive direction and the other as the negative direction. We can choose either direction to be positive as long as we are consistent once we have made that choice. We usually take motion to the right as positive and to the left as negative, as on a number line. Likewise motion upwards is usually taken as positive and downwards as negative.
3. **Uniformly Accelerated Motion** – Motion that has a **constant acceleration** is called uniformly accelerated motion. eg A car moving with a constant acceleration of 2 ms-2 can be said to be undergoing uniformly accelerated motion. A car moving with a constant velocity is also undergoing uniformly accelerated motion. The acceleration in this example is zero.

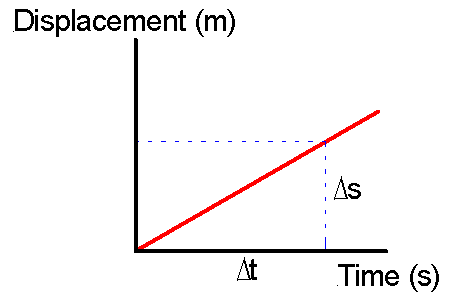
**Now try Worksheet 1 on Kinematics.**

**MOTION GRAPHS**

Often the most effective way to describe the motion of a body is to graph it.

**Displacement-Time Graphs:**

These may be used to gain information about the displacement of an object at various times or about the velocity of the object at various times.

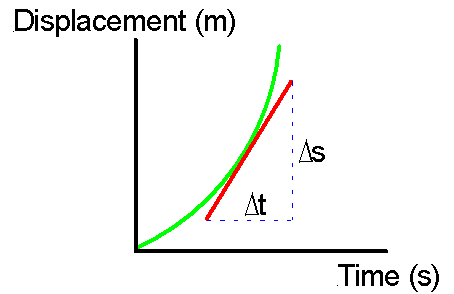


Clearly, the gradient (slope) of a displacement-time graph gives the velocity.

**Gradient =  = velocity**

Note that a positive gradient implies a positive velocity and a negative gradient implies a negative velocity.

For a curved displacement-time graph, the gradient of the tangent to the curve at a particular point equals the gradient of the curve at that point, which in turn equals the velocity of the object at that particular time. Such a velocity, that is, **the velocity at a particular instant in time, is called the instantaneous velocity.**

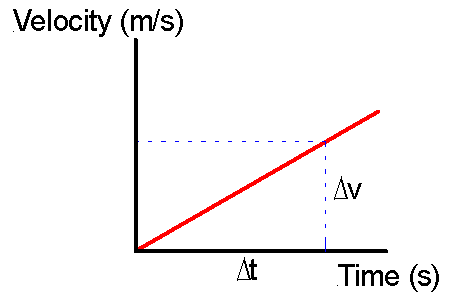


An example of an instrument that measures instantaneous velocity is the speedometer in a car. In older cars the speedometer was linked mechanically to the transmission. These days, however, a device located in the transmission produces a series of electrical pulses whose frequency varies in proportion to the vehicle's speed. The electrical pulses are sent to a calibrated device that translates the pulses into the speed of the car. This information is sent to a device that displays the vehicle's speed to the driver in the form of a deflected speedometer needle or a digital readout.

Note that a straight line displacement-time graph implies that velocity is constant. A curved line displacement-time graph implies that velocity is changing with time (ie the object is accelerating).

**Velocity-Time Graphs:**

These may be used to gain information about the displacement, velocity and acceleration of an object at various times.



The gradient is clearly the acceleration of the object.

**Gradient =  = acceleration**

Note that a positive gradient implies a positive acceleration and a negative gradient implies a negative acceleration.

Also, the area under the graph,



in the case above, has units of: seconds x metres per second = metres. Thus, the area under a velocity-time graph is equal to the displacement travelled by the object in the time t.

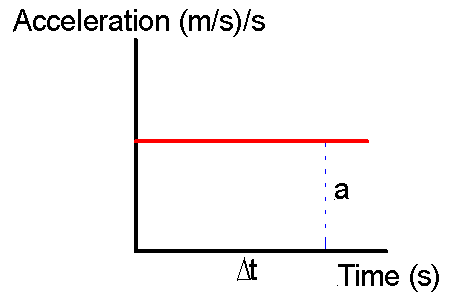
Note that a horizontal straight line velocity-time graph implies that acceleration is zero – ie velocity remains constant.

A non-horizontal, straight line velocity-time graph implies that acceleration is constant and non-zero.

A curved line velocity-time graph implies that acceleration is varying.

**Acceleration-Time Graphs:**

These may be used to gain information about the velocity and acceleration of an object at various times.



The area under an acceleration-time graph gives the velocity of an object. Check the units of the area: (ms-2 x s = ms-1).

A horizontal straight line acceleration-time graph implies that velocity is varying at a constant rate (ie velocity is increasing or decreasing by the same amount each second). That is, acceleration is constant.

**Now try all the graphing exercises on the Kinematics webpage.**

**RELATIVE VELOCITY ALONG A STRAIGHT LINE**

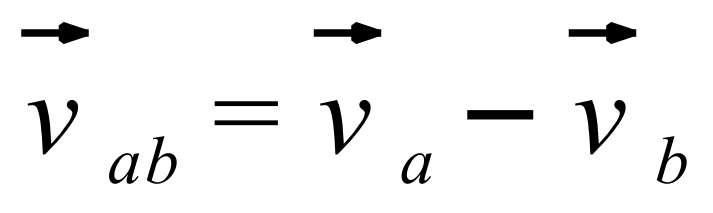
Often it is necessary to compare the velocity of one object to that of another. For instance, two racing car drivers, A and B, may be travelling north at 150 km/h and 160 km/h respectively. We could say that the velocity of car B relative to car A is 10 km/h north. In other words, driver A would see driver B pull away from her with a velocity of 10 km/h north.

Likewise, two jet aircraft, C and D, flying directly at each other in opposite directions (hopefully as part of an aerobatics display) may have velocities of 900 km/h north and 1000 km/h south respectively. We could say that the velocity of D relative to C is 1900 km/h south. In other words, jet C will observe jet D flying towards it at a speed of 1900 km/h.

Clearly, when the objects are travelling in the same direction, the velocity of one relative to the other is the difference between their speeds, taking due care to state the appropriate direction. When the objects are travelling in opposite directions the velocity of one relative to the other is the sum of their speeds, again taking due care to state the correct direction.

There is a **vector equation** which can be used to calculate the relative velocities of objects, even when the objects travel at various angles to one another.

The velocity of Object A relative to Object B is given by:



Where, vab = velocity of A relative to B, va = velocity of A relative to the ground and vb = velocity of B relative to the ground. Note that the arrow above the v denotes that the quantity represented by v is a vector quantity.

Eg A boy is running due north along a straight road at a speed of 9m/s. His friend is running towards him due south at a speed of 5 m/s. Calculate the velocity of the boy relative to his friend.

Solution: Let vb represent the boy and vf  his friend. Then we have that vb = 9 m/s N and vf  = 5 m/s S. Also, let north be the positive direction and south the negative.

From vbf  = vb - vf

We have vbf  = 9 – (-5), the 5 is negative since its direction is south.

Therefore, vbf  = 14 m/s and since it is positive its direction is north.

So, the velocity of the boy relative to his friend is 14m/s north.

This makes sense. If you imagine you are the friend running south towards the boy, the boy is approaching you at 9 m/s and you are approaching the boy at 5 m/s. So, the boy would seem to be approaching you at 14 m/s.

Relative velocity along a straight line can seem trivial. Why even use a formula? **Learn the formula now** as it will prepare you for when we need to calculate the relative velocities of objects travelling at angles to each other rather than along a straight line. The formula is then invaluable.

**Now try the Worksheet on relative velocity along a straight-line, Kinematics Worksheet 2.**

**EQUATIONS OF UNIFORMLY ACCELERATED MOTION**

So far in this module we have defined some basic terms used in the description of motion. We have used various types of motion graphs to gain a better understanding of what those definitions mean. We have learned that graphing motion is a very effective way of gathering data about motion and that motion graphs can be used to further analyse the motion we are studying.

Analysis in kinematics can also be done algebraically using equations. We shall now derive a series of equations for this purpose. They are often referred to as the equations of **uniformly accelerated motion**.

These equations are really vector equations and involve vector addition in straight lines only.

**Derivation**

Assign pronumerals as follows:

u = initial velocity (m/s)

v = final velocity (m/s)

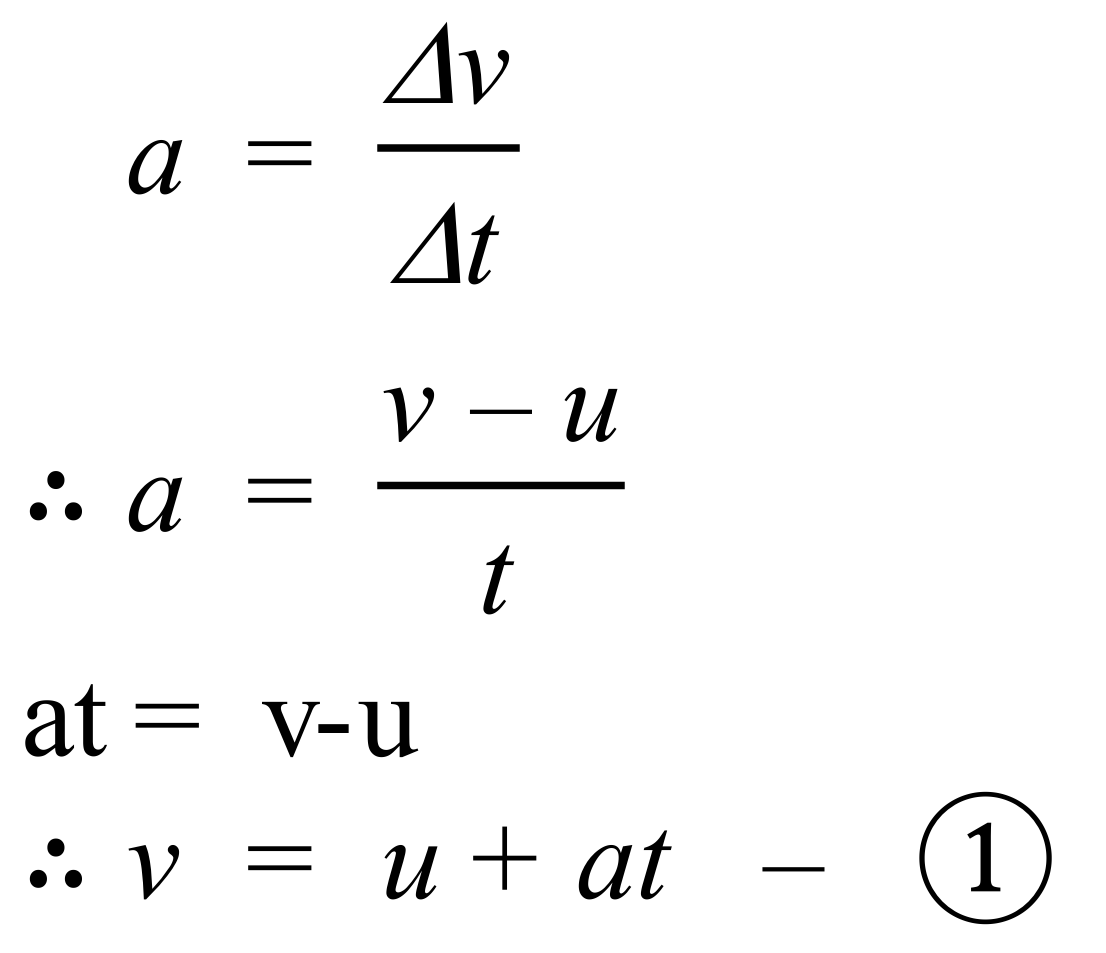
s = displacement (m)

a = acceleration (m/s2)

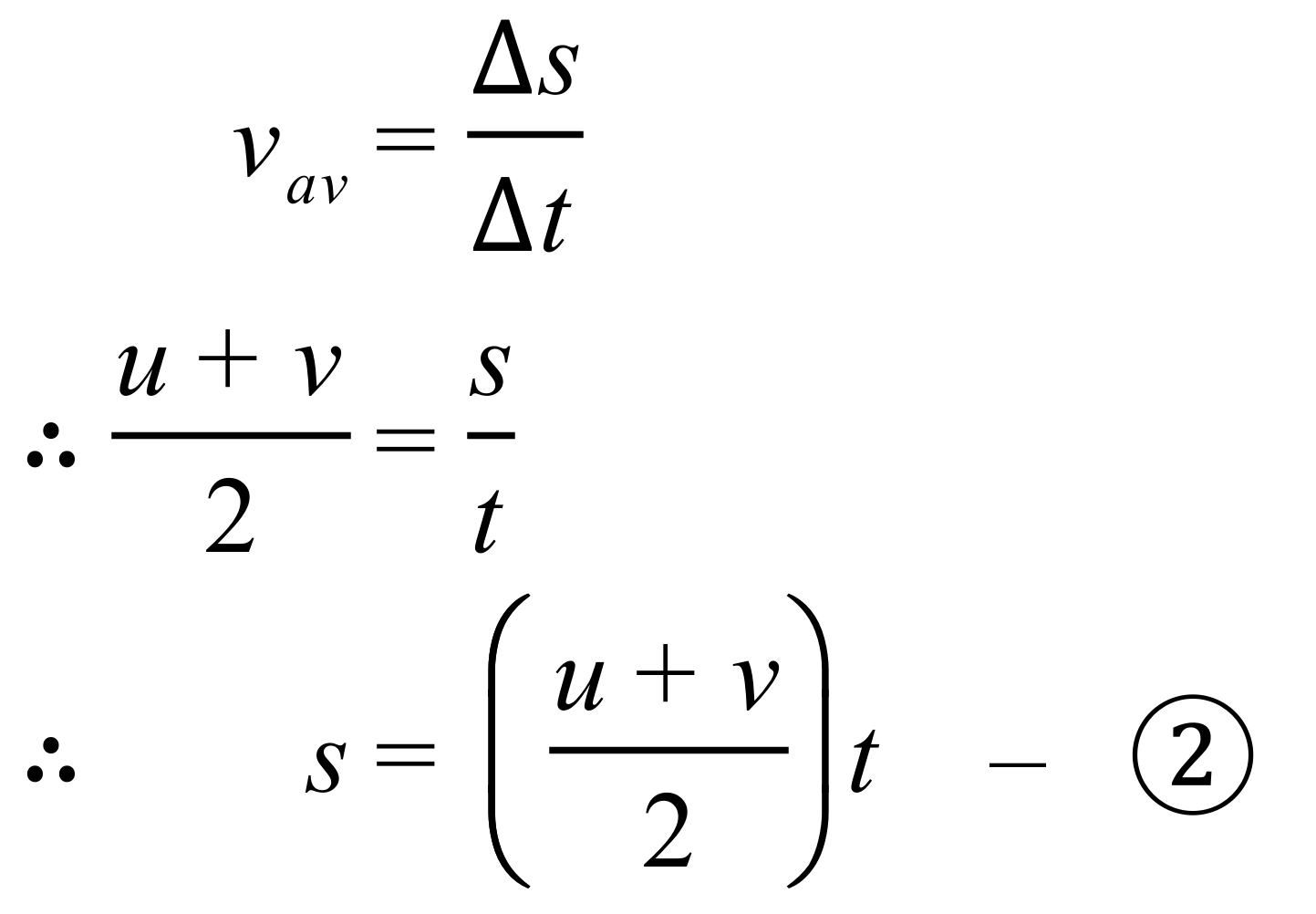
t = time elapsed (s)

Since we are dealing here with uniform (constant) acceleration, the instantaneous acceleration equals the average acceleration at all times.

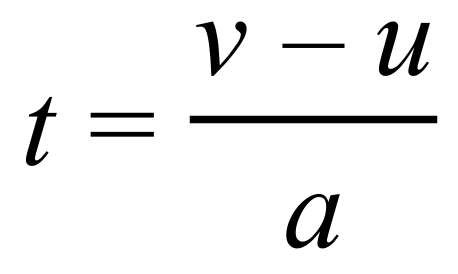
From our definition of average acceleration, we have that average acceleration:



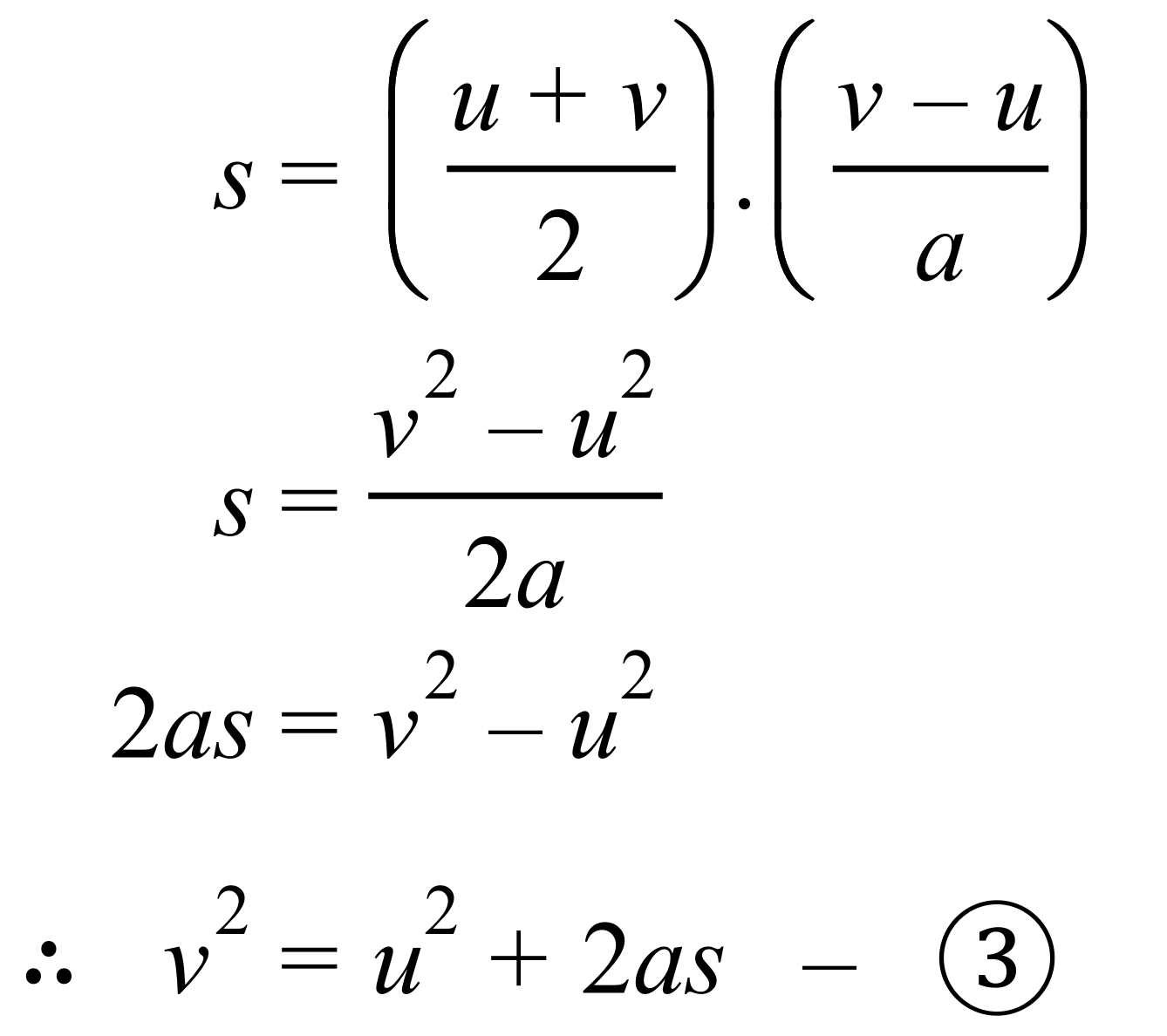
From our definition of average velocity, we have:



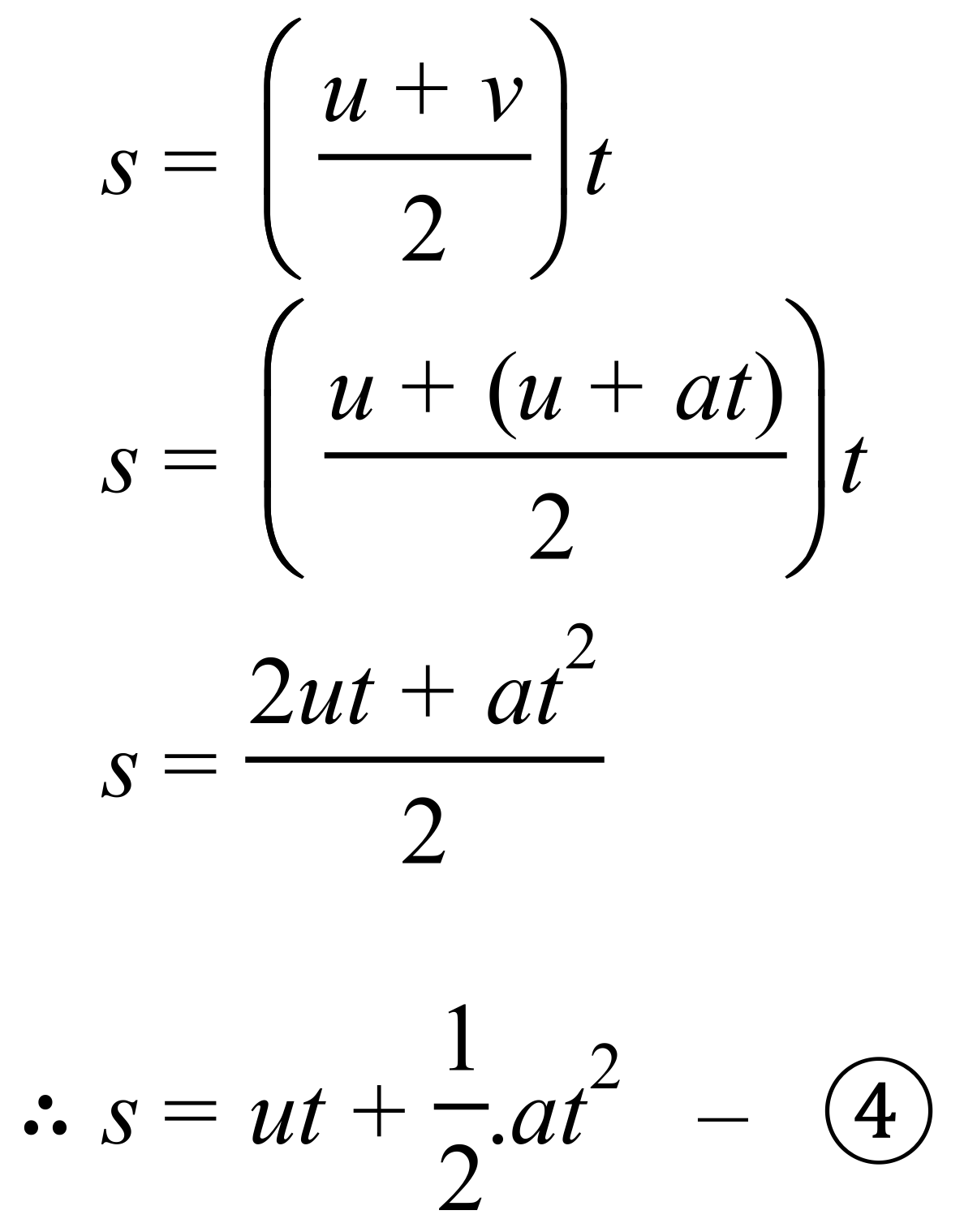
Now from equation 1 above:



So, substituting for t from equation 1 into equation 2, we have:



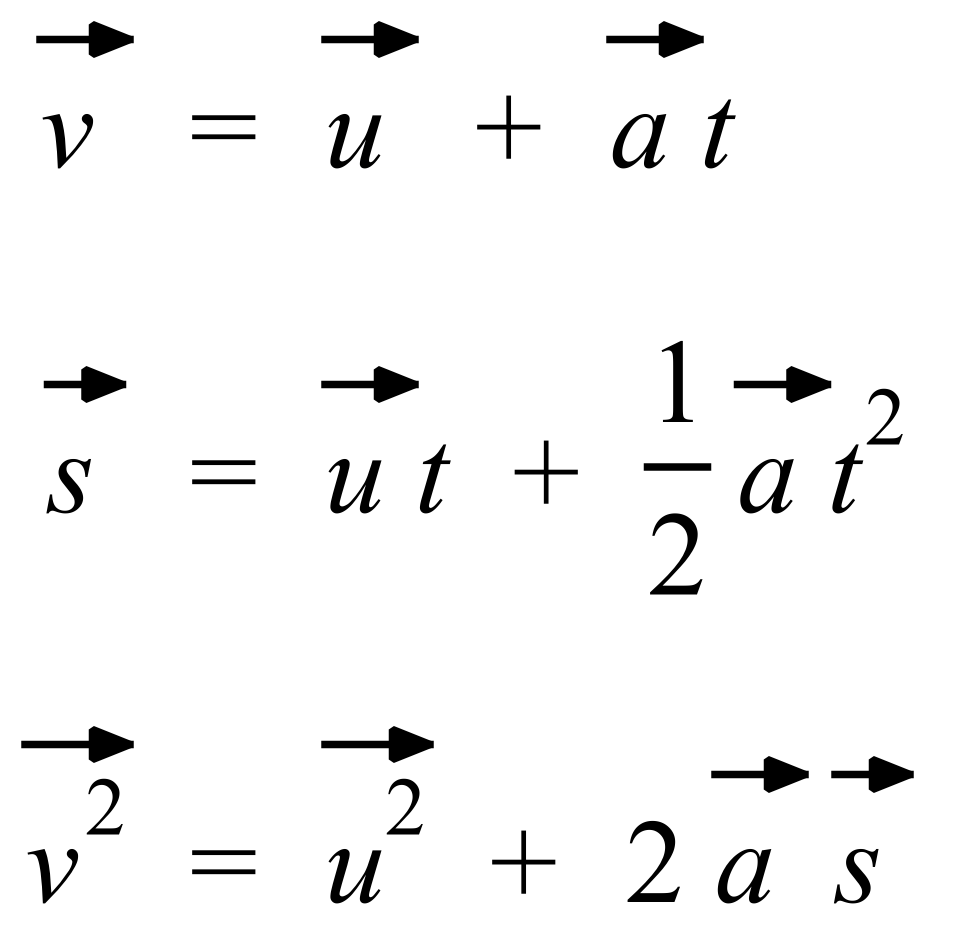
By substituting for v from equation 1 into equation 2 we have:



**Notes:**

* The above equations may be used when the acceleration is uniform (ie constant or zero) and the motion is considered in one dimension.
* The correct sign must accompany each vector quantity in these equations. Time is the only scalar quantity in these equations.
* The data and the unknown quantity (ie four quantities in all) will determine which equation is appropriate.
* In addition, always keep in mind the definitional equations given at the start of this module.

In summary, the three main equations of uniformly accelerated motion are:



**Now try the Worksheet on the equations of uniformly accelerated motion, Kinematics Worksheet 3.**

**MOTION ON A PLANE**

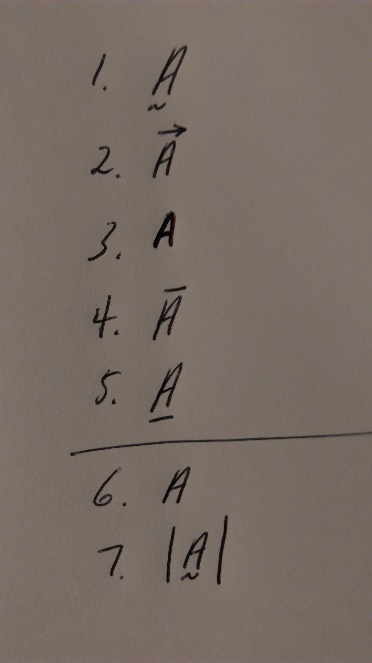
**Inquiry Question:** How is the motion of an object that changes its direction of movement on a plane described?

**VECTOR ANALYSIS**

As stated at the start of this module, a **vector** is a physical quantity defined in terms of both magnitude and direction. Vectors play an extremely important role in Physics. They can be manipulated to enable the analysis of quite complex physical situations and systems. There is an entire branch of mathematics devoted to vectors and vector analysis. If you become a Physicist or an Engineer or work in one of the many fields of Physical Science, vectors will be an important part of your study and work.

**Vector Notation**

Common forms of vector notation include:



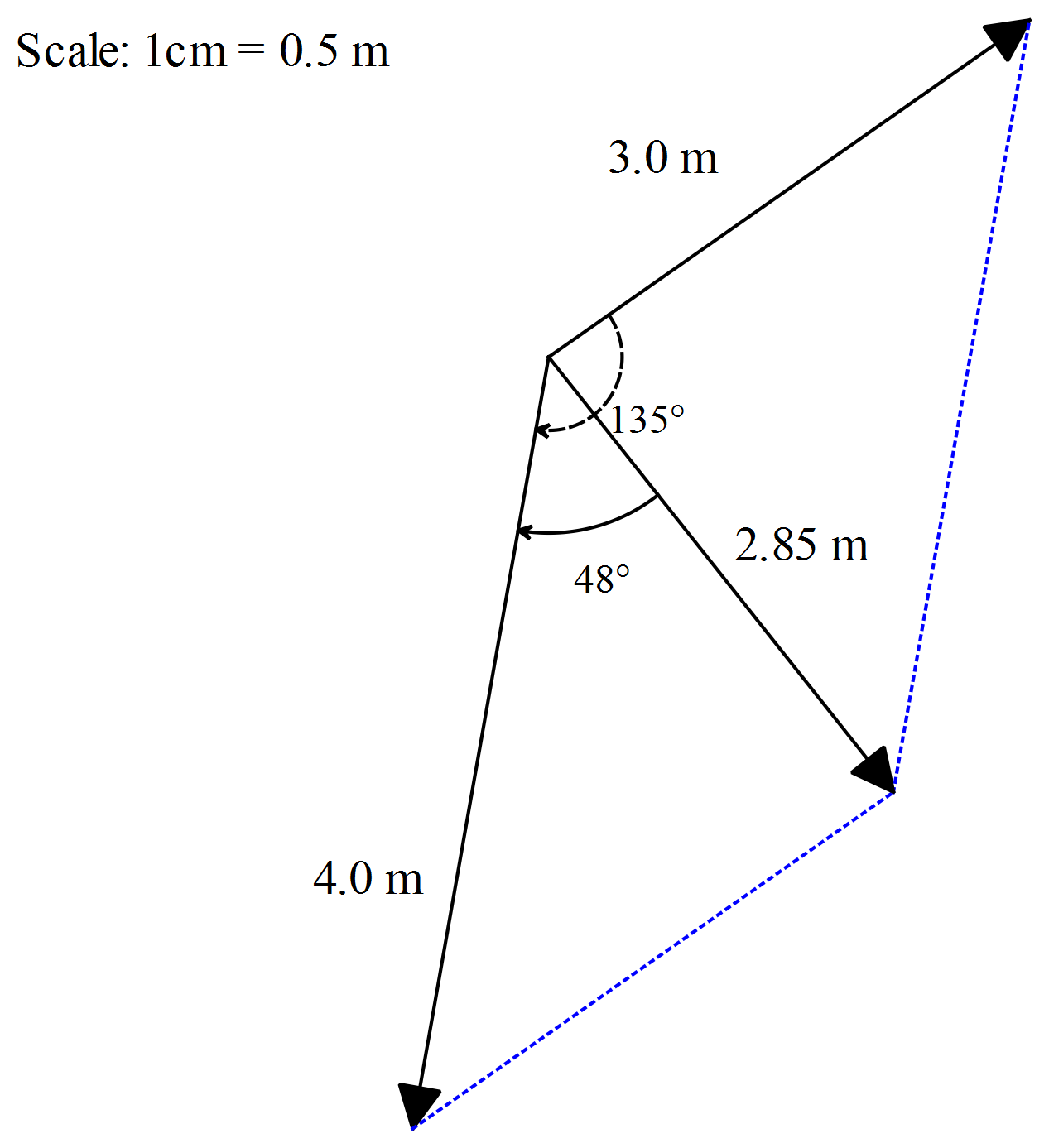
The squiggle under the A in number 1 above is called a tilde (pronounced tilda). The arrow above the A as in 2 above is what is used in the Syllabus document for this course. The heavy print A as in 3 above is often used in text books. The notations in 4 & 5 are less common. The notations in 6 & 7 refer strictly to the **magnitude** of the vector A.

**Vector Addition**

There are two main methods of vector addition: graphical and analytical.

**Graphical Methods**

**Method of Parallelogram of Vectors:** This can be used where there are just two vectors to add together. Form a parallelogram using the two given vectors as sides. The **resultant vector** is formed by drawing in the diagonal of the parallelogram from the point of intersection of the two given vectors. **The diagram must be drawn to scale.**eg Find the resultant of displacements of 3.0 m and 4.0 m inclined at 1350 to each other.

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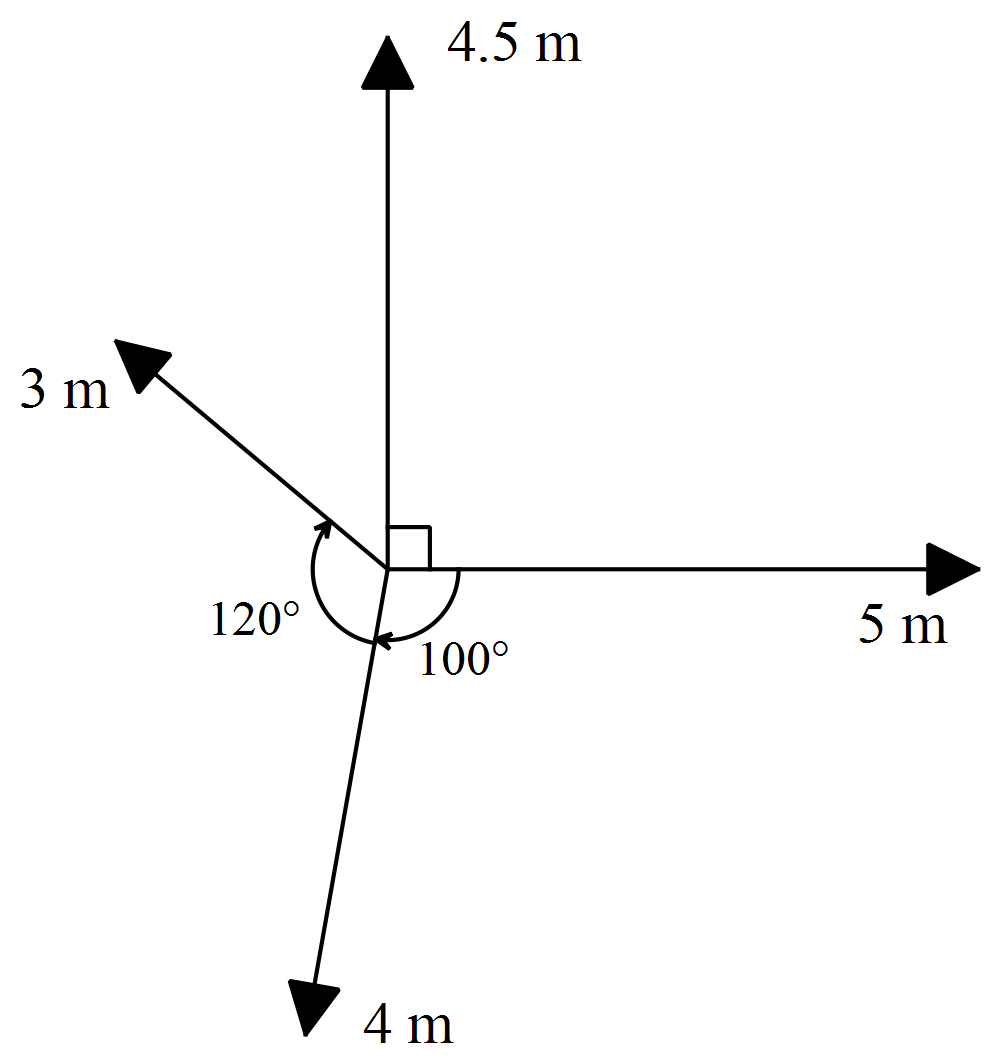
The magnitude of the resultant is found by measuring the length of the resultant vector and using the scale. The direction is found by using a protractor.

So, the resultant is 2.85 m at 480 to the 4.0 m vector as shown.

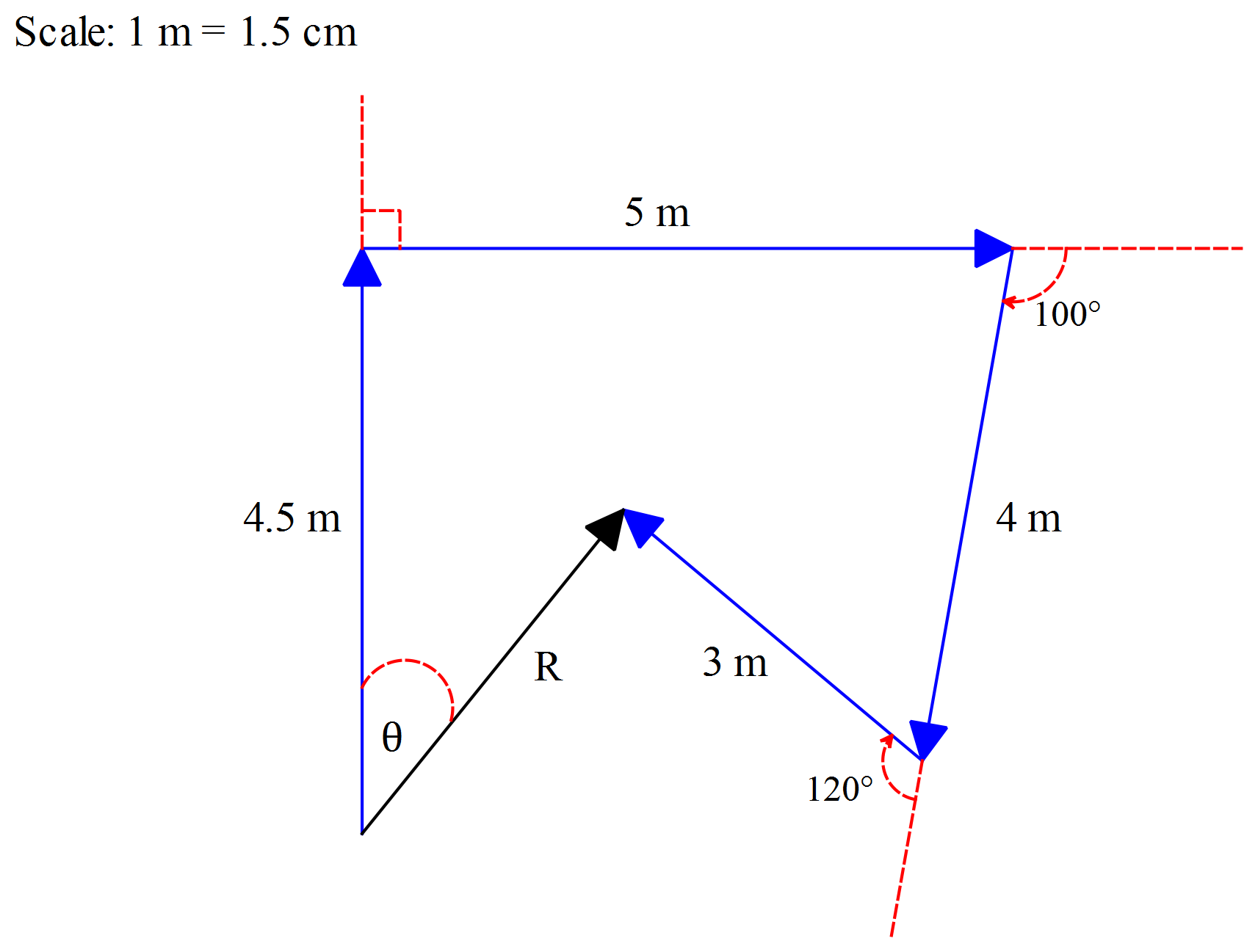
When representing vectors graphically, the magnitude of the vector is given by the length of the line and the direction of the vector is given by the direction in which the arrow on the line is pointing. When using graphical methods to manipulate vectors accuracy in measurement is essential.

**Method of Vector Polygon:** Usually the sum of a number of vectors is found graphically by drawing a vector polygon. Each of the vectors in the sum is drawn to scale and in the appropriate direction, tail to head. The **equilibrant** is the vector that closes the vector polygon in the same sense as the component vectors. The **resultant** is the vector that closes the polygon in the opposite sense to the component vectors.

Eg Find the resultant of the following four displacements.



To solve this problem, we pick a displacement vector to begin with – it does not matter which one. Let’s start with the 4.5 m vector. We draw it on the page and then following the instructions above, we add the next vector, say the 5 m vector, with its tail touching the head of the 4.5 m vector and in a direction at 900 to the direction of the 4.5 m vector as shown in the diagram above. And so we proceed until we have added all vectors into the sum.



By using ruler & protractor on the vector polygon above we find that:

The resultant displacement vector, R, is 3.2 m at an angle of 390 clockwise from the direction of the 4.5 m displacement.

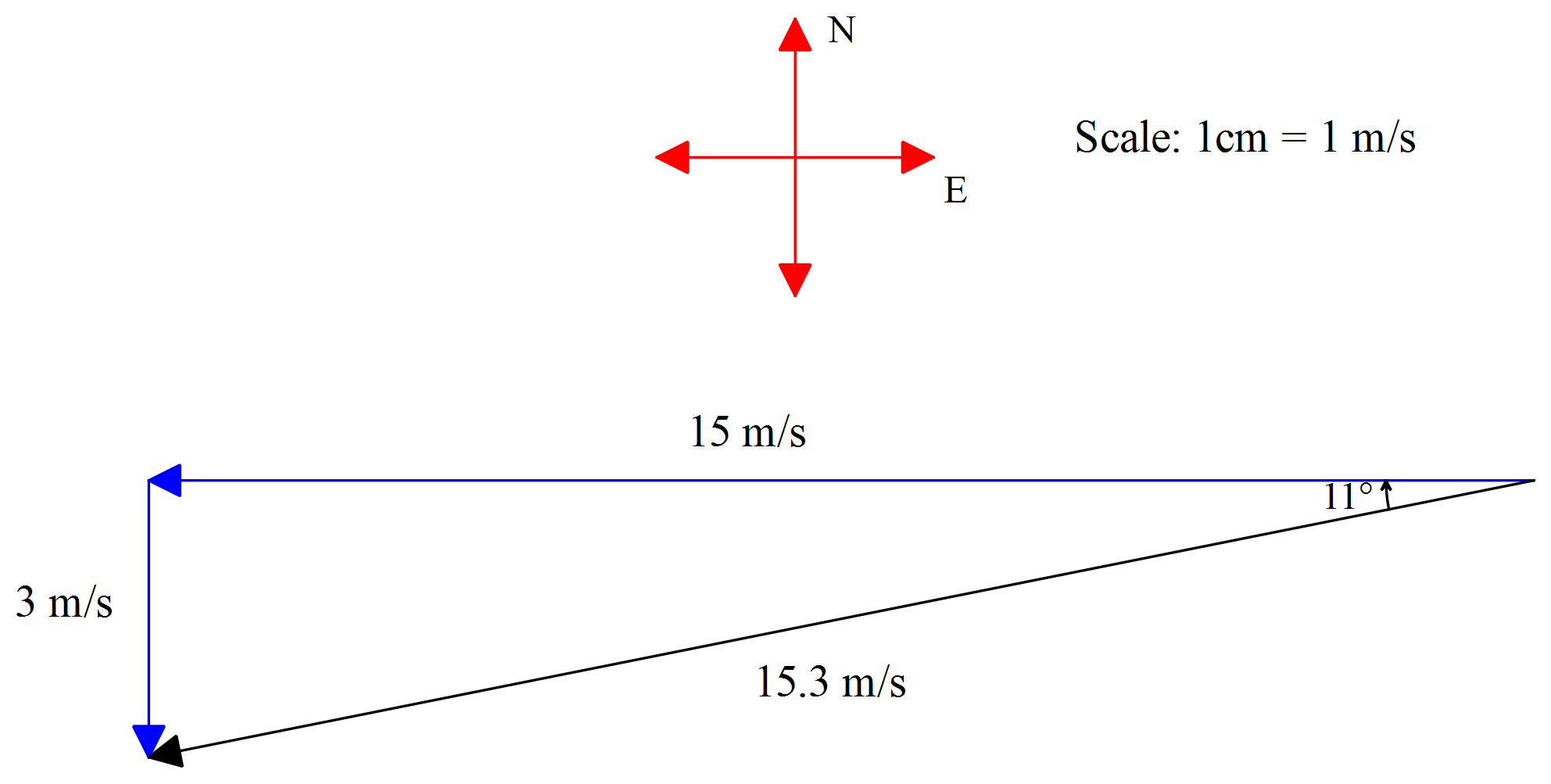
Had the equilibrant vector been asked for, it would be a vector of the same size as the resultant but in the opposite direction to the resultant.

**Note that when using a graphical approach, the scale must be clearly stated on the diagram.** Always choose a sensible numerical scale. Also, choose a scale that will produce a large diagram. The larger the diagram, the more accurate the answer. For the example problem above, the scale used was 1 m = 1.5 cm. This is certainly the smallest scale I would use for this problem. Anything less is too inaccurate. A scale of 1 m = 2 cm would be preferable. The smaller scale was used here to fit the diagram neatly onto this page.

**Note also, that depending on which printer is used to print these notes, there may be a small discrepancy between the stated scale and the actual scale on the page.**

**Practice Problem:** An Aircraft Carrier heads due West at a steady speed of 15m/s. A current of 3 m/s is running due south. Use graphical vector addition to calculate the resultant velocity of the Aircraft Carrier. (Answer: 15.3 m/s W110S or S790W)

**Solution to Practice Problem:** As the ship moves west, the current pushes the ship south. The net effect is that ship moves in a direction that is a little bit south-west.



By measuring the length of the resultant and using the scale we find that the magnitude of the resultant velocity of the aircraft carrier is 15.3 m/s. By using a protractor, we measure the resultant direction of the aircraft carrier as W110S (or S790W or any other equivalent statement of direction).

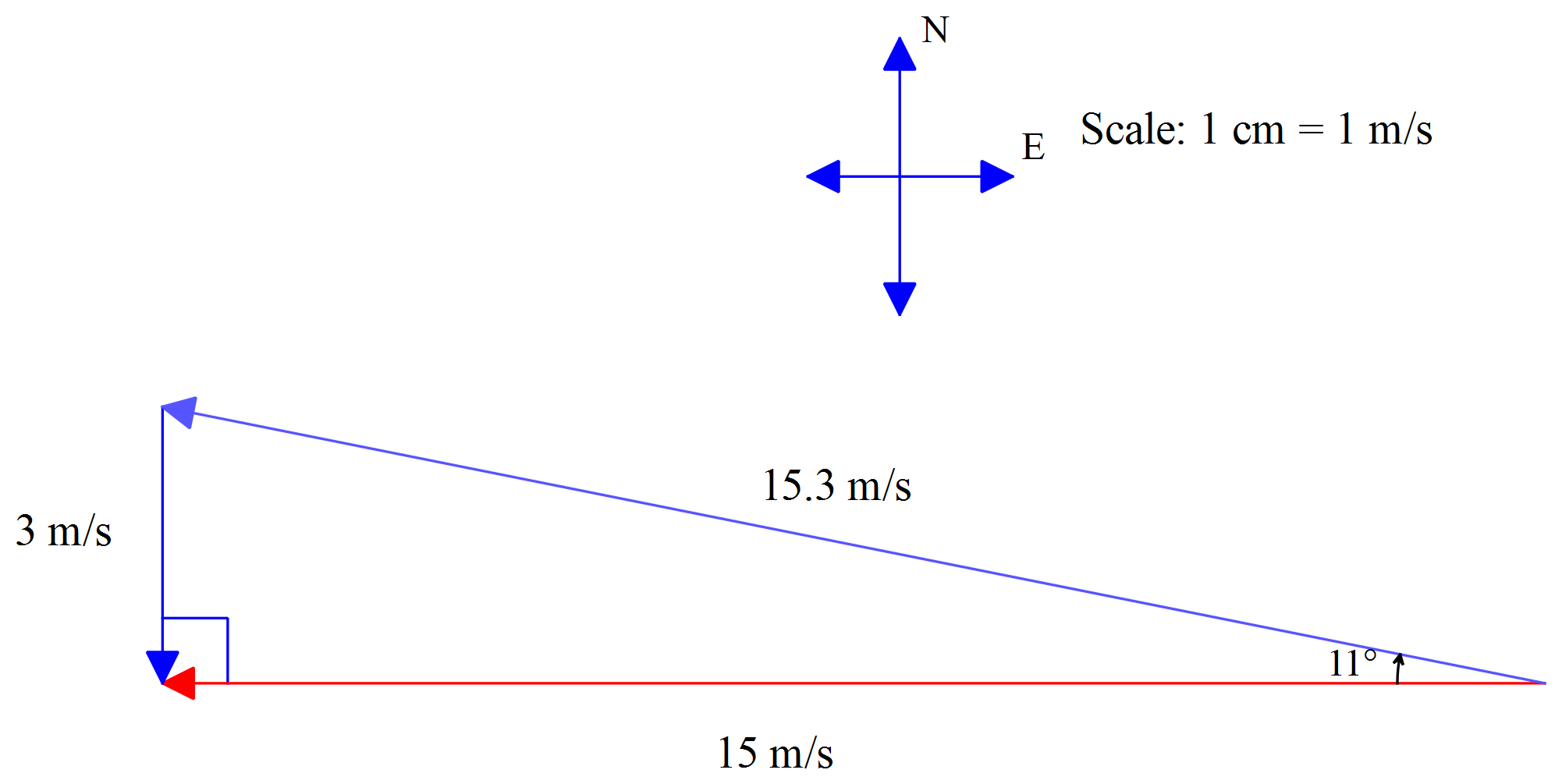
So, although the ship heads west, the current pushes it south. The two velocities add together to give the resultant motion. If you were sitting on the sea-bed looking upwards you would see the ship move in direction slightly south of west.

Note in the vector diagram above, the scale is stated & a compass is marked on the diagram to indicate direction. Do these things every time you draw a graphical solution to a vector problem.

Clearly, if the Captain of the aircraft carrier wants to move west, he or she will have steer the ship in a direction slightly north of west to allow the current to pull the ship back onto a westerly course.

**Practice Problem:** So, if the Captain wanted his or her course to be 15 m/s West, in which direction and at what speed would he or she have to steer the ship? Assume the current remains at 3 m/s South.

**Solution:** This time we know the resultant. We want the ship’s velocity + the current’s velocity to add together to produce a resultant velocity of 15 m/s west. We need to find the ship’s velocity (produced by its engines) that will allow this to happen.



Note that we have added the ship’s velocity to the current’s velocity to produce the resultant velocity. We know the values of the current’s velocity (3 m/s S) & the resultant velocity (15 m/s W). We use the vector diagram to measure the velocity with which the ship must head into the current to allow the current to bring the ship back onto a westerly course.

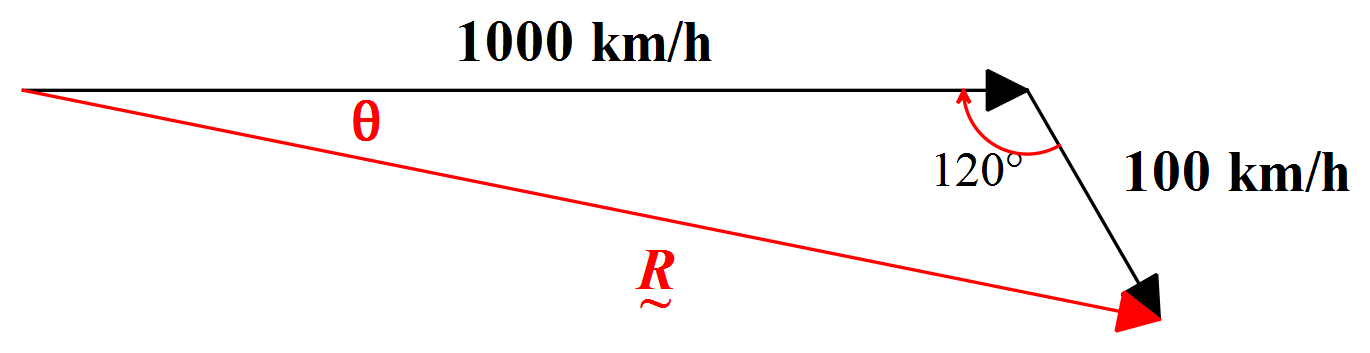
When we complete these measurements, we find that the ship must travel at 15.3 m/s in a direction W110N to achieve a net velocity of 15 m/s W with the help of the current.

This result would be expected. Why?

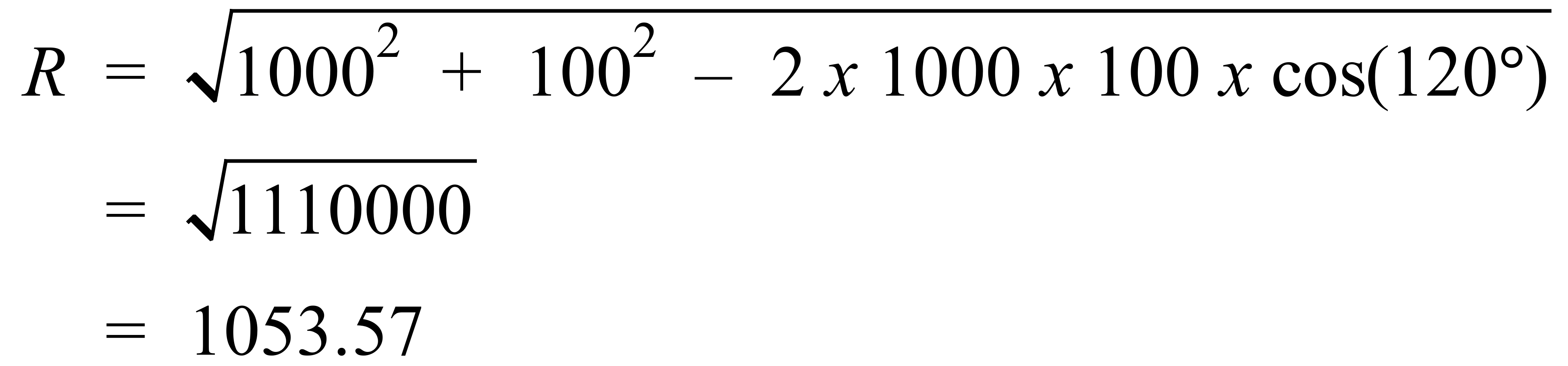
**Analytical Methods**

**Method of Triangle of Vectors:** When given only two vectors to add together we can simply draw the vectors tail to head to form the sides of a triangle. The third side will be the **resultant**. The diagram need not be drawn to scale, since we are going to use mathematics to determine the resultant.

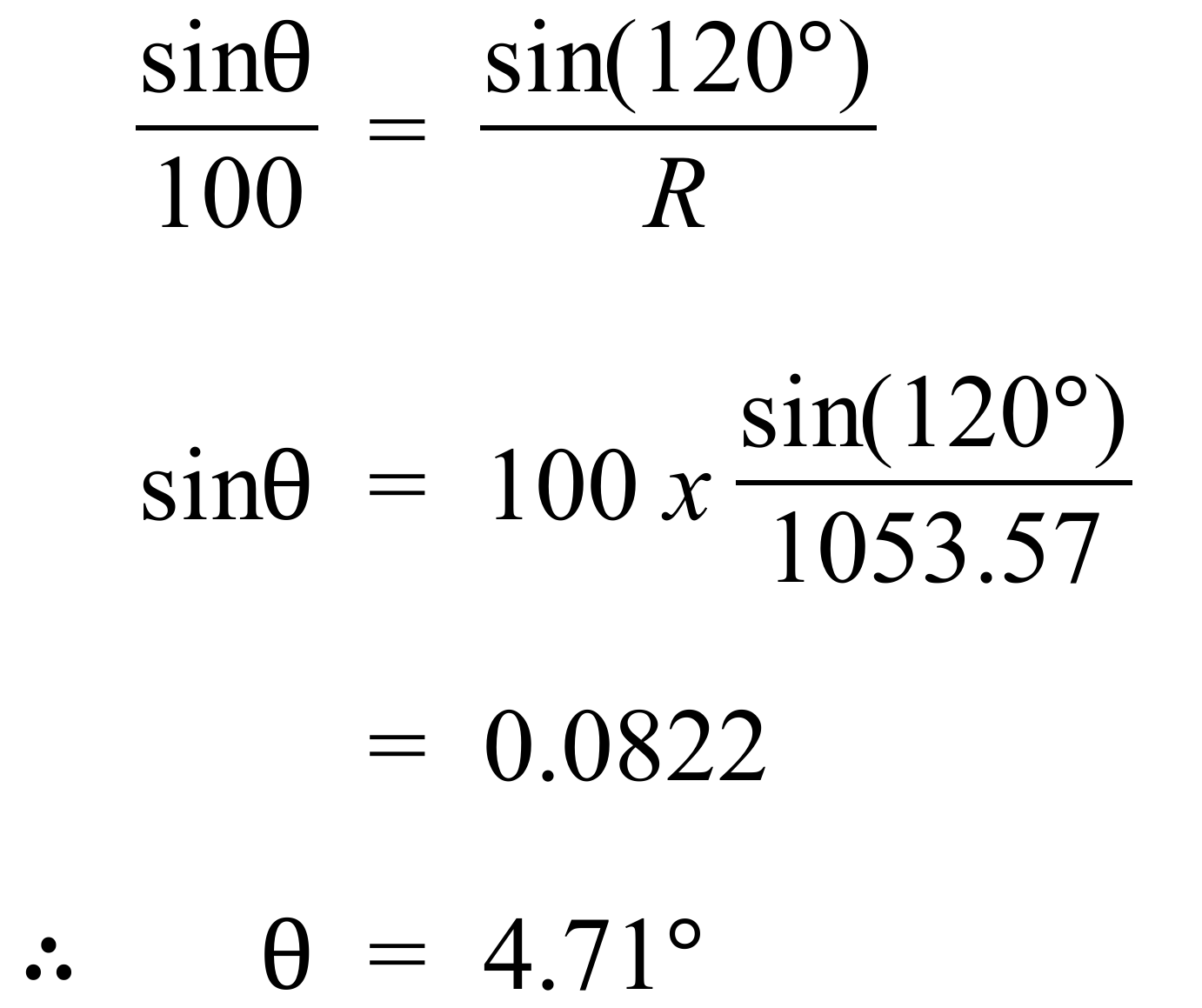
Eg A jet is flying at 1000 km/h due east. There is a cross-wind blowing in a direction East 60o South at 100 km/h. Calculate the velocity of the jet relative to the ground.



By cosine rule:



And by sine rule:

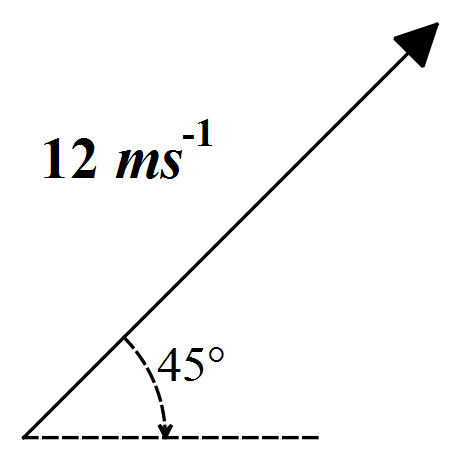


So, the velocity of the jet relative to the ground is 1054 km/h in a direction of East 5o South.

**NOTE: You must be familiar with trigonometric ratios and the sine and cosine rules in order to solve vector problems in Physics.**

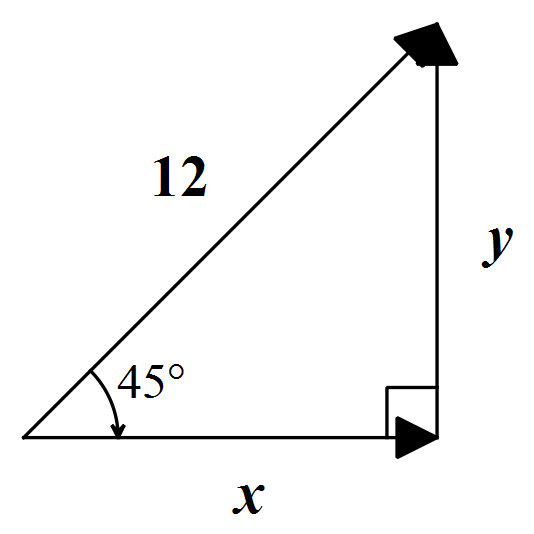
**Method of Resolution of Vectors:** It is often necessary to resolve a vector into two component vectors at right angles to each other, such that the sum of the two component vectors is equal to the original vector. Such components are called the **rectangular components of the vector**.

**Example:** Resolve the velocity vector below into its rectangular components. The vector is 12 ms-1 NE.



**Solution:**

We must resolve this vector into two component vectors at right angles to each other, such that the sum of the two component vectors is equal to the original vector. This can be achieved as follows:



How do we calculate x and y. Use simple trigonometry.

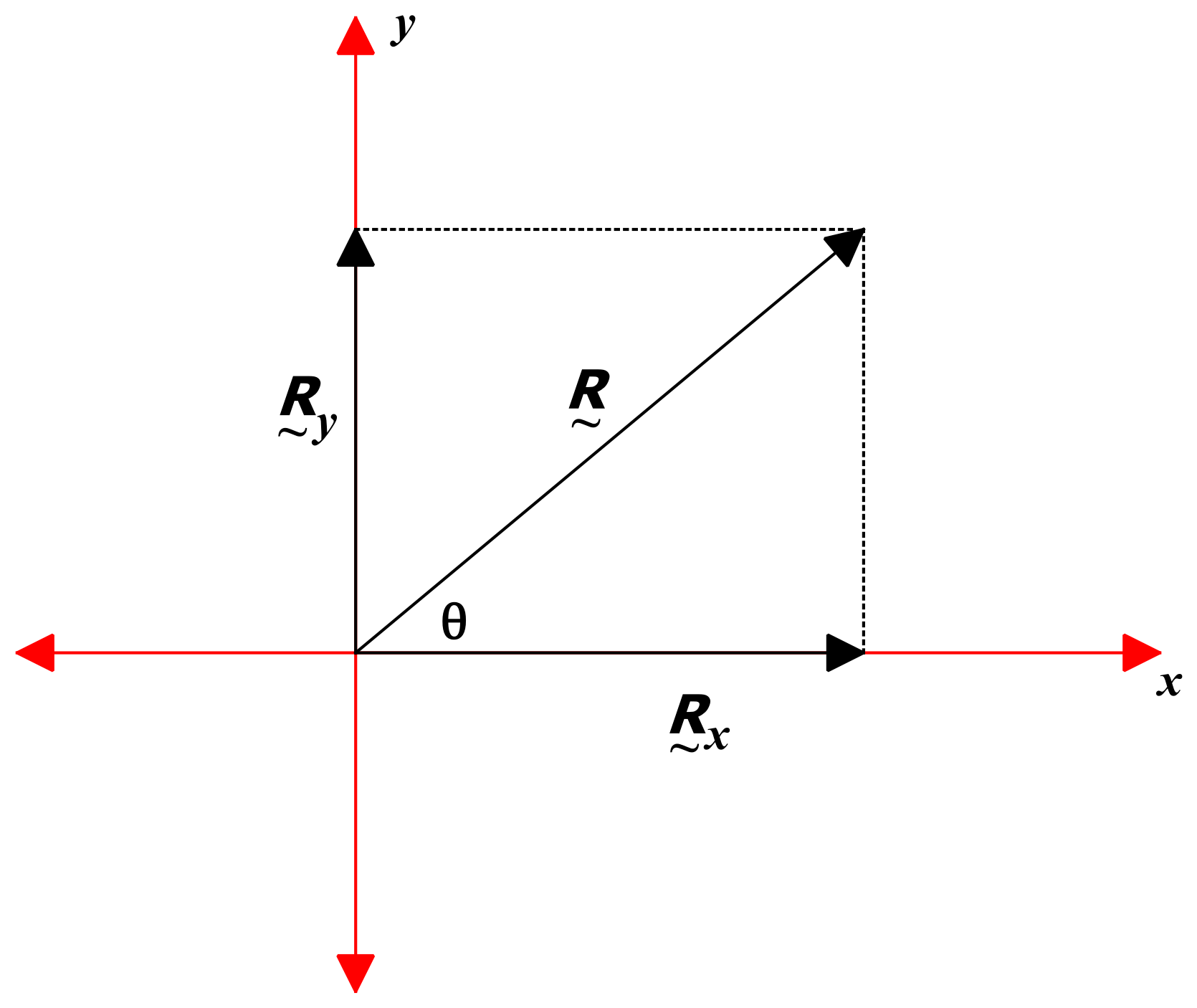
**In the triangle formed above, sin 45° = y / 12, so y = 12 sin 45°**

**Likewise, x = 12 cos 45°.**

We say that the **easterly component** of the velocity is **12 cos 45° = 8.5 m/s** and the **northerly component** of the velocity is **12 sin 45° = 8.5 m/s**.

Being able to resolve vectors into rectangular components is an essential skill that you will use throughout your study of Physics. It is this method that is used in computer programs to perform additions of multiple vectors often involved in complex engineering situations.

**Method of Resolution of Vectors (More Generalised):** We have just seen a specific example of vector resolution. Let us now generalise this method. Consider the vector R̰ as shown below making an angle  with the positive direction of the x-axis.



A̰x and A̰y are the components of A̰ in the x and y directions respectively.

Therefore, Rx = R cos 

Ry = R sin 

And R̰ = R̰x + R̰y

To add two or more vectors together using this method, firstly resolve each vector into its rectangular components. Then sum the x-components to obtain the x-component of the resultant, sum the y-components to obtain the y-component of the resultant and use Pythagoras’ Theorem to calculate the magnitude of the resultant.

eg To find the magnitude of the resultant R̰ of three vectors A̰, B̰ and C̰:

Rx = Ax + Bx + Cx

Ry = Ay + By + Cy

Note that because the x-component of each vector lies along the x-axis we can just add them together to obtain the x-component of the resultant. Similarly, for the y-components to obtain the y-component of the resultant. Be careful to take account of the sign of each component – some may be positive while others are negative.

Once we have the x-component of the resultant and the y-component of the resultant, we can use Pythagoras’ Theorem to calculate the magnitude of the resultant, since the x and y components form two sides of a right-angled triangle, as shown in the diagram above.

So, **R = √ (Rx2 + Ry2)**

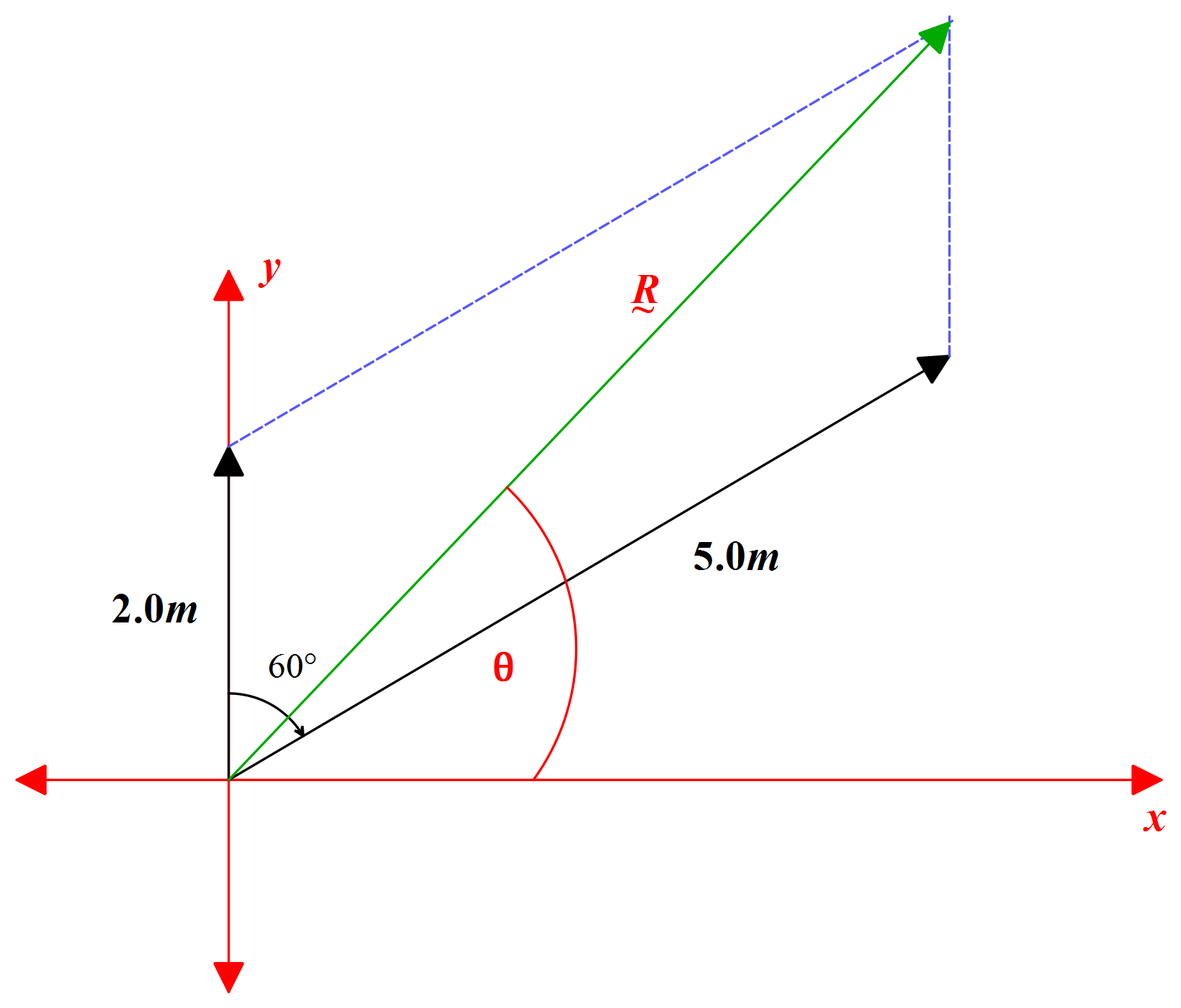
The angle , made by the resultant with the positive direction of the x-axis is given by:

tan-1(Ry / Rx)

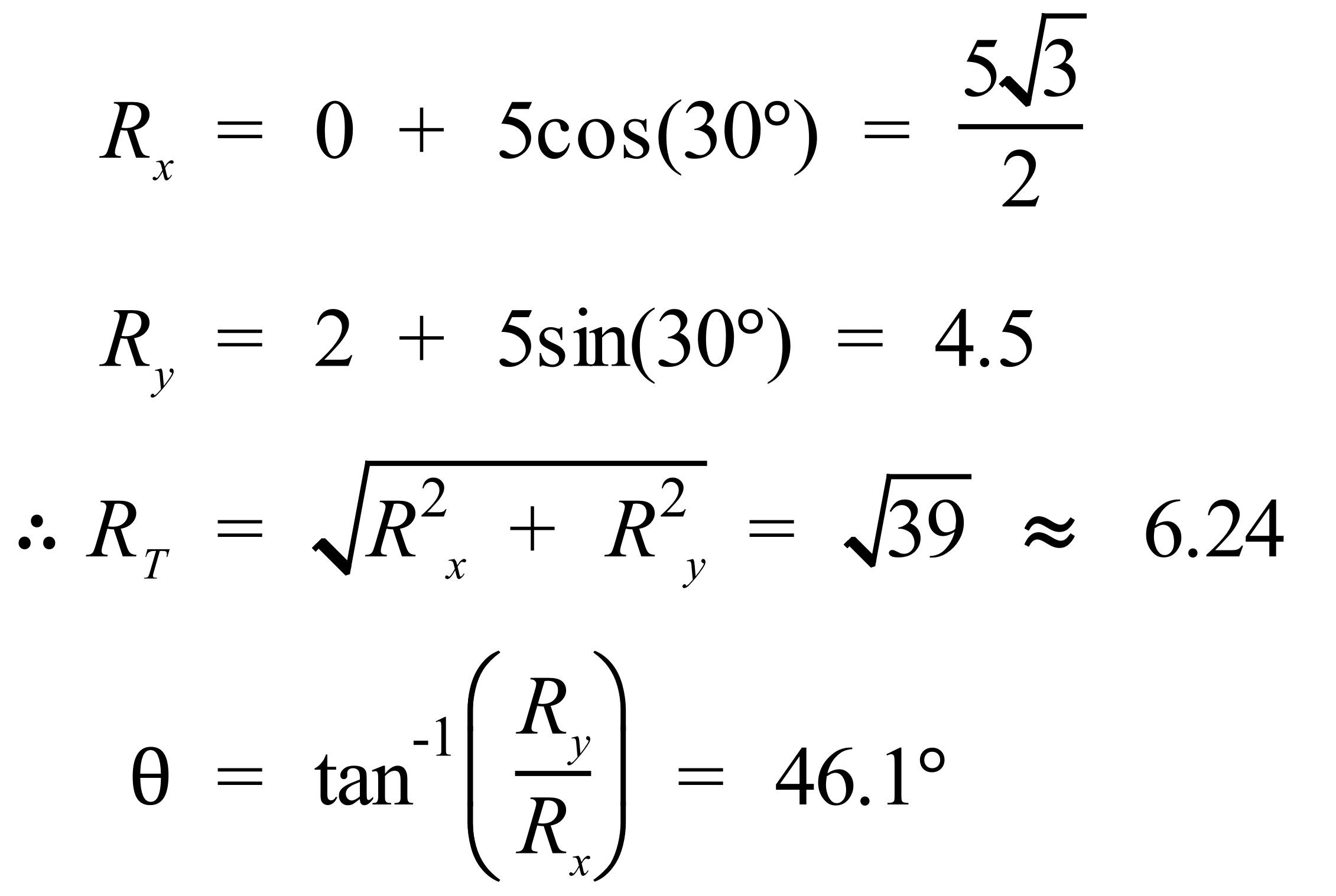
Clearly, this method of vector addition lends itself easily to being programmed into a computer to sum any number of vectors.

**Example Problem:** A girl walks north for 2.0 m and then turns in a direction N60°E and walks a further 5.0 m. Find the resultant displacement of the girl from her start point.

Firstly, draw the vectors on an x-y plane, as below. We need each vector drawn from the origin because we want to resolve each vector into its rectangular components. The vectors need not be to scale and the angle between them does not need to be accurately measured. It does help if the given vectors are drawn roughly to the right relative sizes and angles just by eye, as below. This helps you to assess whether the size and relative direction of the resultant seems correct. Also, if possible draw one of the vectors along the x or y axis. This simplifies the calculations a little. Draw in the resultant vector (marked as R̰ at an angle θ below). Then proceed with the calculations as shown below the vector resolution diagram.



Next, we look at the vector resolution diagram above and determine the x and y components of each of the vectors we are trying to sum. Then we can calculate the magnitude and direction of the resultant displacement.



**Therefore, the girl’s resultant displacement is 6.2 m E460N from her start point.**

Note that we have quoted the answer above to no more decimal places than were stated in the question, when it gave us the magnitudes and directions of the girl’s displacement vectors. The magnitude of the resultant displacement is expressed to one decimal place and the angle is expressed to the nearest full degree. For an explanation of why this is important, see the section on Significant Figures in the notes on **Measurement** available on my website: <https://www.bobemeryphysics.com/measurement>

We have now covered all four standard methods for the addition of vectors. No matter what vectors you come across from now on, be they displacements or forces or momenta or electric field strength, you can successfully perform **vector addition**. Which method should you use? Sometimes, the question will demand that you use a particular method. If this is not the case, use whichever method provides the easiest solution. You will come to know this instinctively.

Now we turn our attention to **vector subtraction**. You may have already guessed how we handle this. If so, well done.

**Vector Subtraction**

If the vector A̰ is as shown below

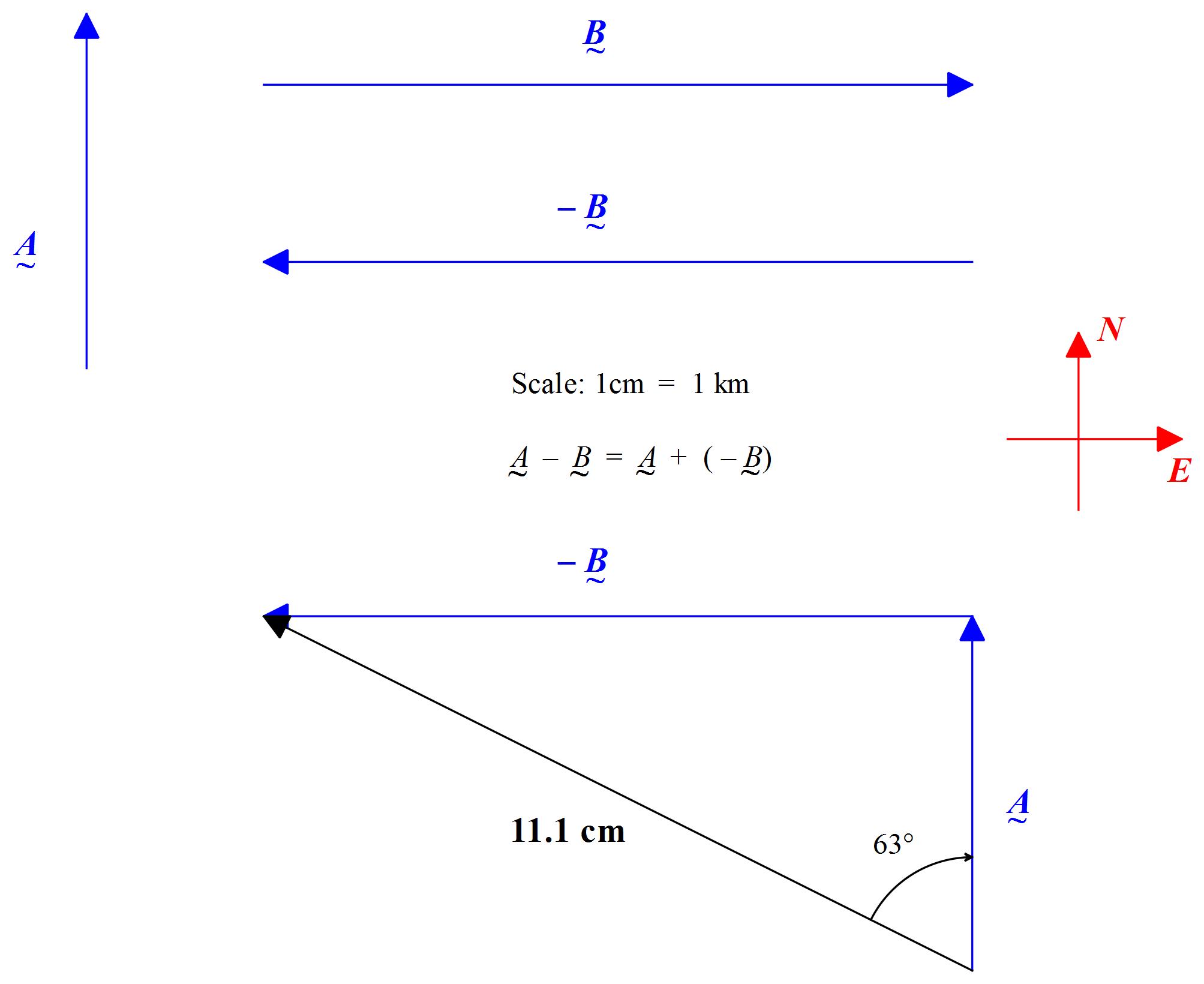


Then the vector -A̰ is a vector of the same magnitude as A̰ but in the opposite direction.



**In order to find the difference of two vectors, add the negative of the second vector to the first.**

Example Question: If A̰ = 5 km North and B̰ = 10 km East, find the resultant of A̰ - B̰.



So, A̰ - B̰ = 11 km N630W (to the correct number of significant figures)

Vector subtraction is important because we often need to calculate changes in vector quantities. When we need to determine the **change in displacement** of an object or its **change in velocity** we do so by vector subtraction.

**Change in Displacement**

The change in displacement of an object is defined as:

Δs̰ = s̰f - s̰i

Where Δs̰ = change in displacement of object

s̰f  = final displacement of object

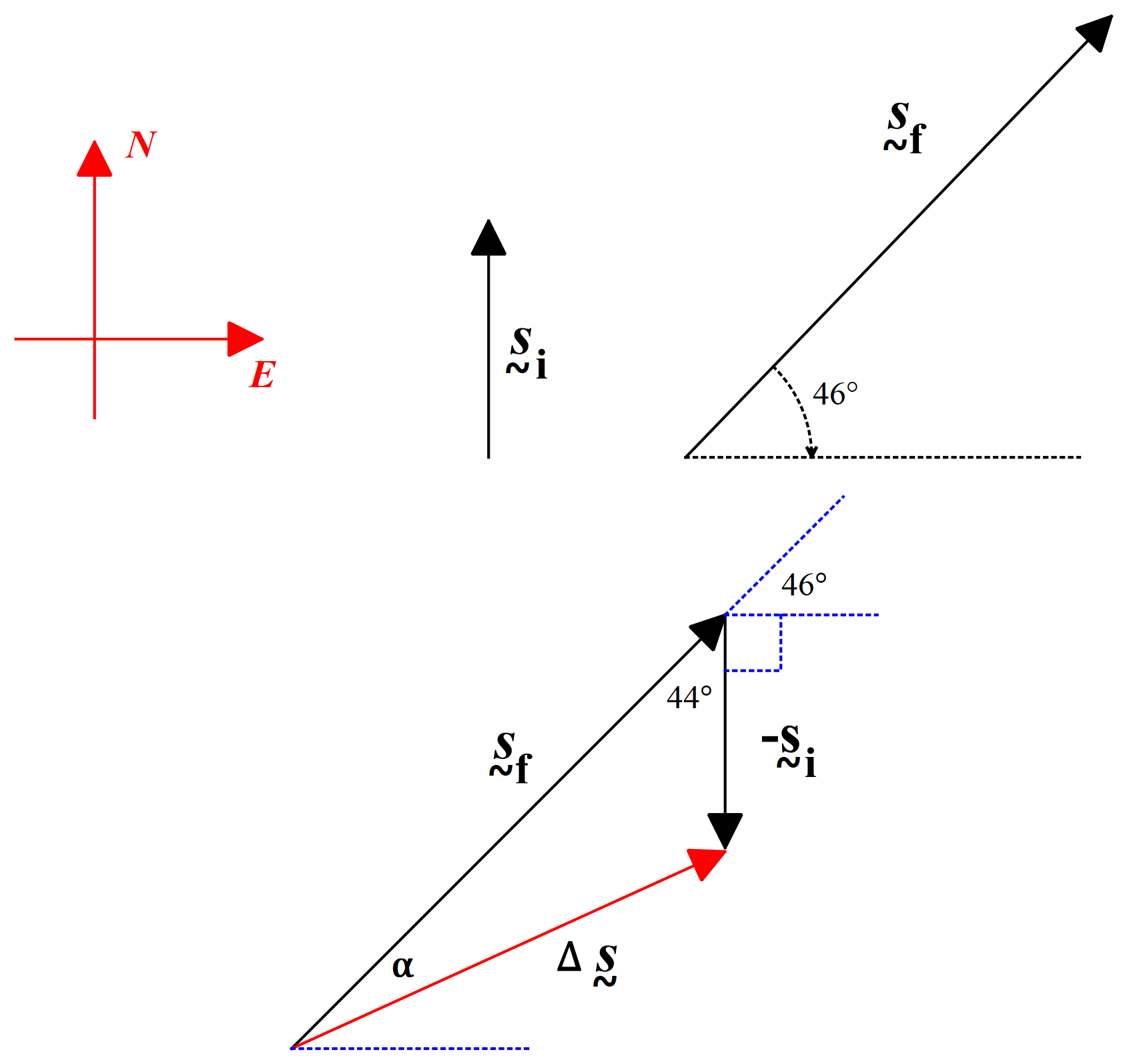
s̰i = initial displacement of object

**Example:** A girl walks due north for 2.0 m from her start point and then stops. Then the girl starts walking again. A short time later she stops again and now her displacement from her start point is 6.2 m E460N.

1. Determine the change in displacement between these two stops.
2. Explain if it is possible to determine the distance travelled by the girl between these two stops.

**Solution:**

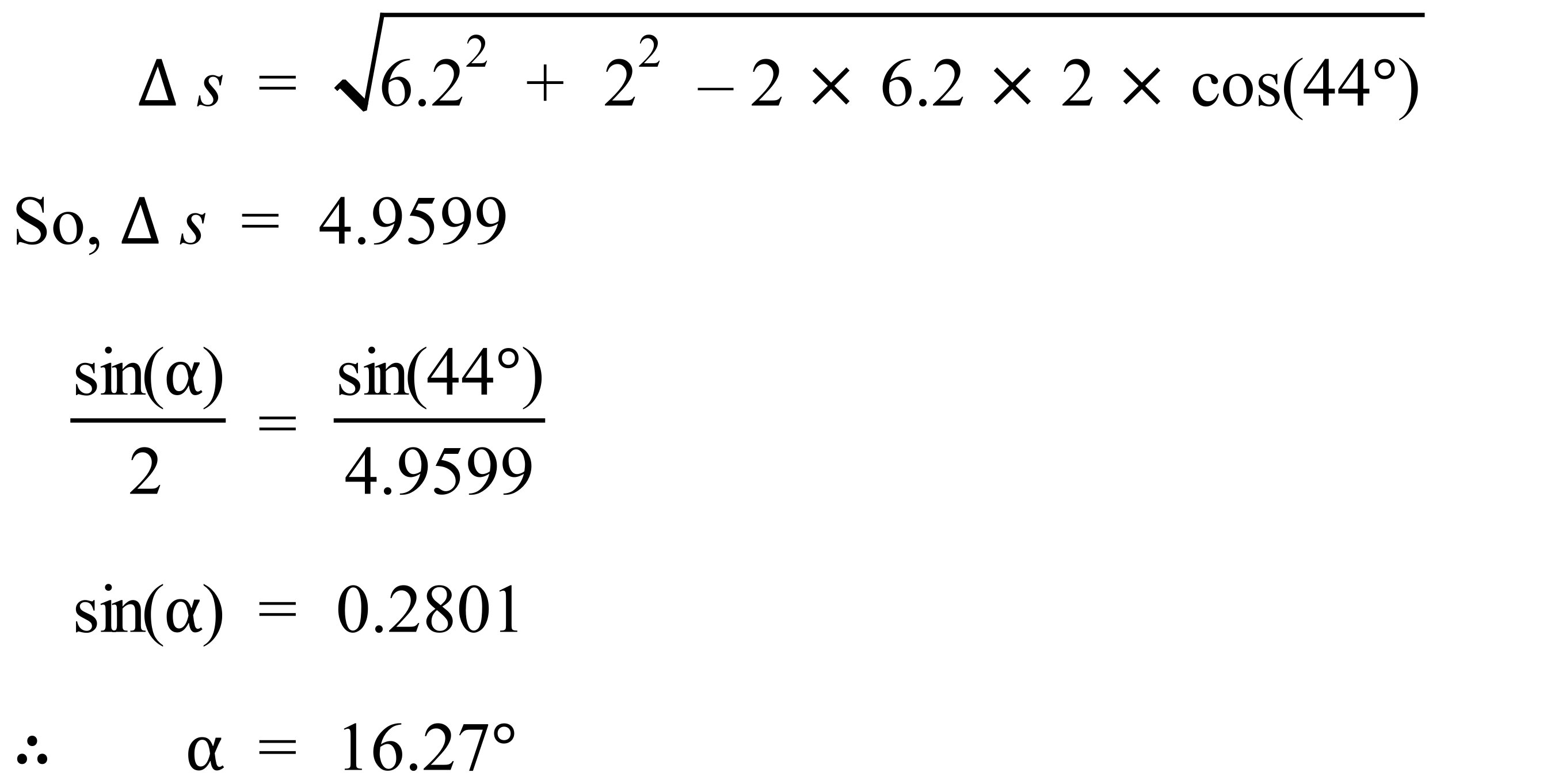
1. Using Δs̰ = s̰f - s̰i and the method of triangle of vectors, we create the following vector diagram.



sf = 6.2 m and si = 2 m

The vector sf has a direction E460N. So, the angle between the vectors sf and -si is 440.

Cosine rule can now be used to determine the magnitude of Δs and sine rule for the direction. (That is why we do not need a scale on the vector diagram. We are working completely mathematically here.)



So, writing the answer to the correct number of significant figures, we have that the **change in displacement between the two stops is 5 m in a direction E300N**.

Note how well this answer agrees with the example given in the section on Resolution of Vectors (as it should, seeing it is the same situation).

1. Now, can we say how far the girl walked on the second leg of her journey? **The answer is no.** Although we know the final displacement from her start point, we do not know that she walked from her first stop to her second stop in one straight line. She could have zig-zagged all over the place and still ended up at her second stop at a displacement of 6.2 m in a direction E460N of her start point. Distance and displacement are not the same quantity. The former is a scalar, the latter a vector. (Note that we can be sure the girl walked a distance of exactly 2 m on the first leg of her journey because we were told she walked for 2 m in a direction due north – one straight line.)

**Change in Velocity**

The change in velocity of an object is defined as:

Δv̰ = v̰f - v̰i

Where Δv̰ = change in velocity of object

v̰f  = final velocity of object

v̰i = initial velocity of object

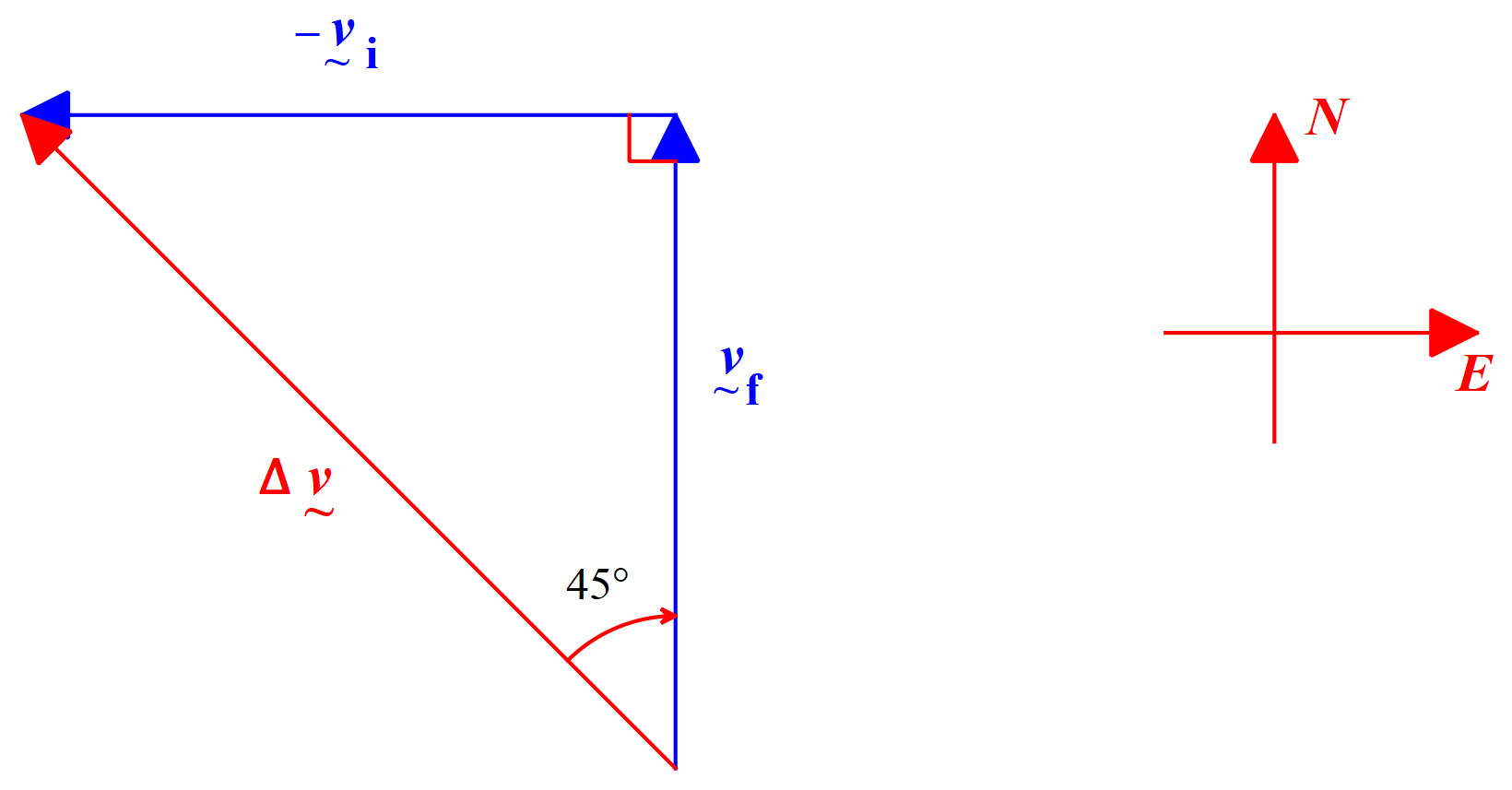
Have you picked up the pattern? Just as for scalar quantities, the change in any vector quantity is always the final value of the vector minus the initial. The difference is that to calculate the change in a vector quantity we usually have to draw a vector diagram.

**Example:** An object is moving due east at 20 ms-1. Ten seconds later it is moving due north at 20 ms-1. Calculate the change in velocity of the object. Find the average rate of change of velocity over the ten second interval.

**Solution:**

We know that vi = 20 m/s E and vf = 20 m/s N.

Using Δv̰ = v̰f - v̰i, we draw the following vector diagram.



Δv = √(202 + 202 = 28.28 m/s

As the vector triangle is isosceles (two equal sides), the angle marked is 450.

**So, the change in velocity of the object is 28 ms-1 in a direction NW.**

**The average rate of change of velocity (the average acceleration) over the ten second interval** is given by:

**a = 28 ms-1 / 10 s**

**So, a = 2.8 ms-2**

**Relative Velocity**

We introduced the concept of relative velocity earlier when we were dealing with motion in a straight line in one dimension. You may like to review the notes in that section before proceeding.

We are now going to focus on the relative velocity of objects that move at angles to one another in two dimensions. You will note that we use the same formula as before. Don’t be concerned that the vector notation used is different. The equation is the same as that in the earlier section.

**The velocity of Object A relative to Object B is the velocity of Object A minus the velocity of Object B.**

v̰AB = v̰A - v̰B

Where v̰AB = velocity of Object A relative to Object B

v̰A  = velocity of Object A relative to the ground

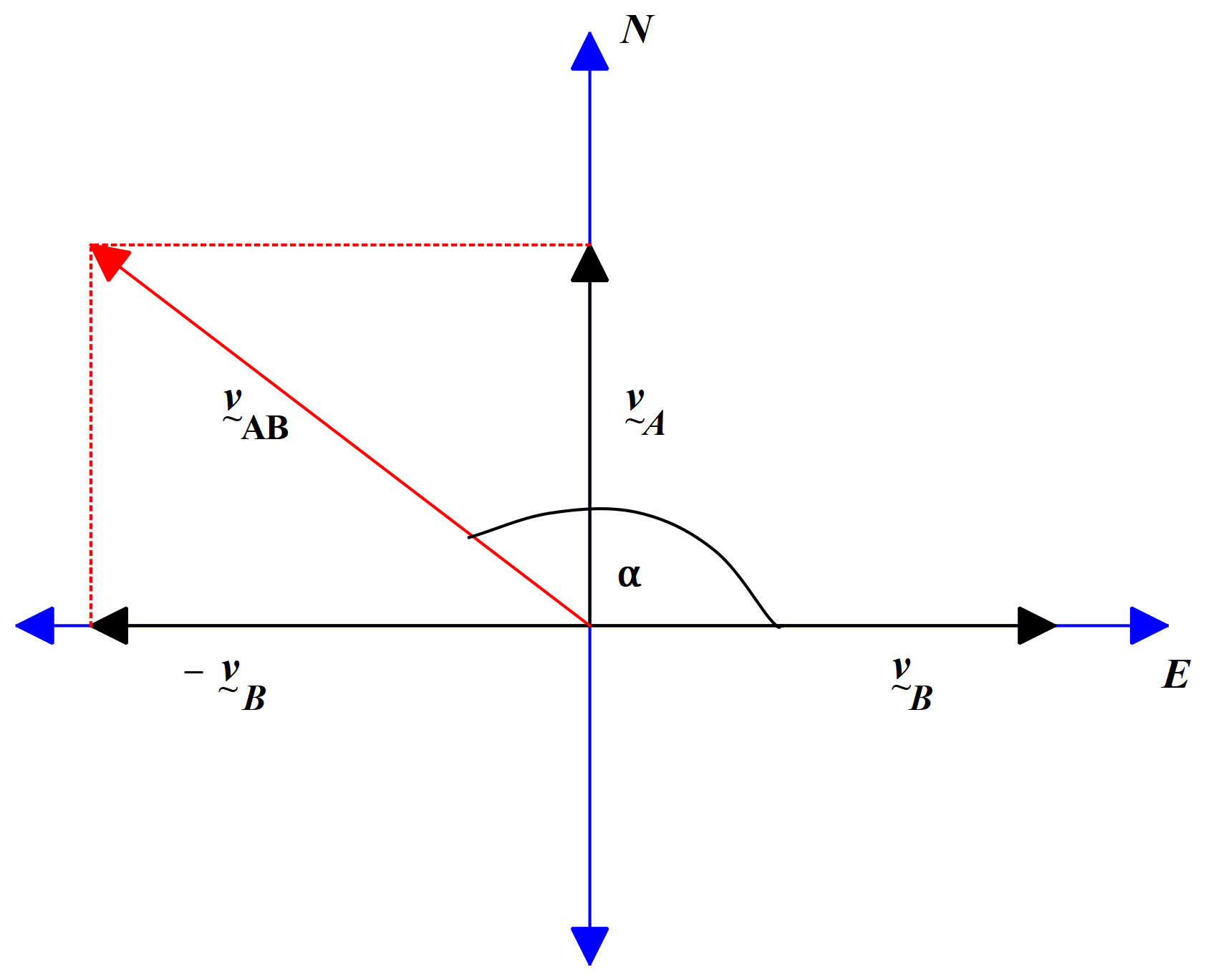
v̰B = velocity of Object B relative to the ground

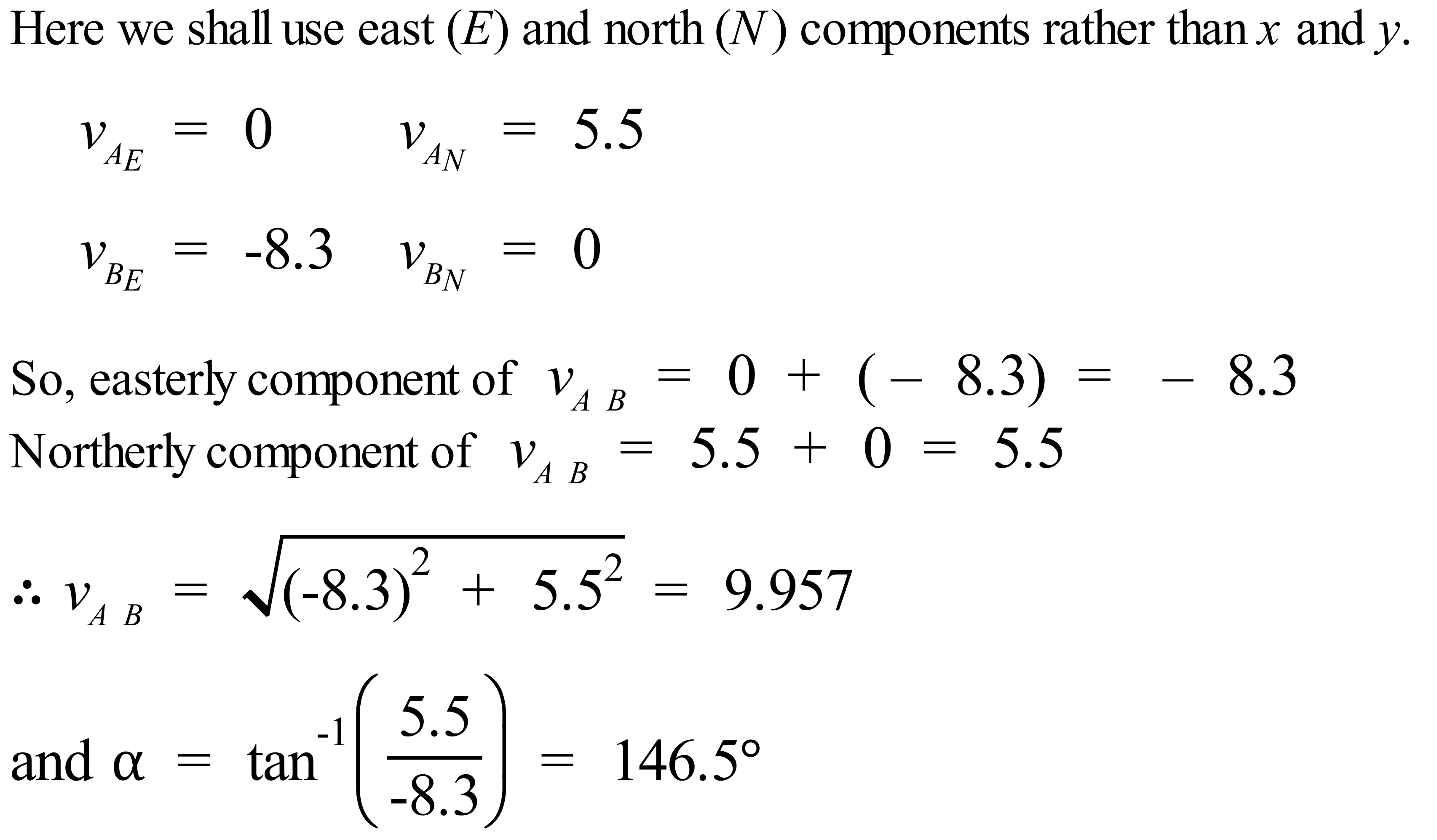
**Example:** A battleship, A, is moving due north at a speed of 5.5 m/s. Nearby at the same time, a submarine, B, is cruising on the surface at a speed of 8.3 m/s due east. Calculate the velocity of the battleship relative to the submarine.

Solution is on next page.

**Solution:** For practice, we shall use the resolution of vectors method. The equation we are using is: v̰AB = v̰A - v̰B

Firstly, construct the relevant vector resolution diagram. Draw in v̰A and v̰B. Then draw -v̰B. Add v̰A to -v̰B to produce v̰AB. Then we can do the maths below the diagram.



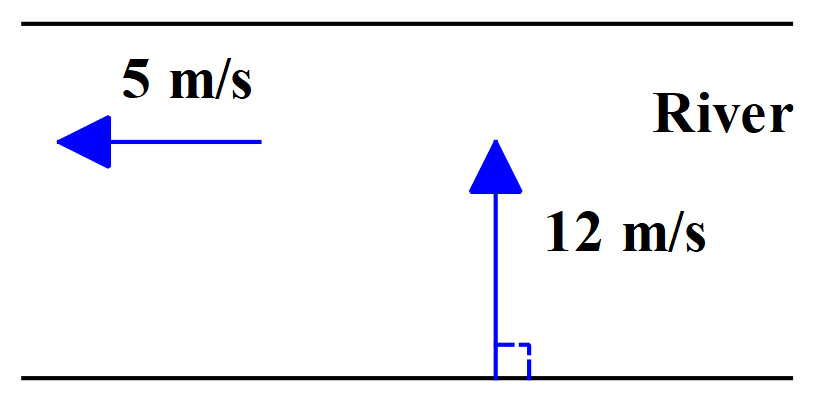


Therefore, the **velocity of the battleship relative to the submarine** is 10.0 ms-1 in a direction W330N or N570W or a bearing of 3030 (whichever way you like to give the angle – usual to use the same method as in the question).

**Think for a moment about the answer to this example. Does it make sense to you? If you think about the original situation, if you were on the submarine heading due east, it would appear that the battleship was moving both north and away from you in a westerly direction. So, yes, it would seem that the battleship was heading in a north-west sort of direction. Also, as that puts the sub and the ship almost moving in opposite directions, you would expect the speed of the ship relative to the sub to be higher than the sub’s speed. You should always think about your answers – do they make sense. Physics is logical.**

**Practice Problems – Relative Motion in Two Dimensions**

The solutions to these questions are contained in the pdf document “Practice Problems – Solutions” in the Worksheets section on the Kinematics Module page of this website.

1. A motor boat sets out from one bank of a flowing river and heads for the other side, as shown in the diagram below. The boat heads in a direction perpendicular to the bank from which it left at its top speed of 12 ms-1. The river current is flowing downstream at 5 ms-1.  
     
     
     
     
     
     
     
     
     
     
     
   Assume the banks of this section of river are straight and parallel to each other.
   1. Calculate the velocity of the boat as seen by someone standing on the bank from which it left.
   2. If it takes 10 minutes for the boat to reach the other bank, determine how far downstream the boat travels before reaching the other bank.
   3. Following on from part (b) above, how wide is the river?
   4. In which direction should the boat head at its top speed in order to reach the other bank exactly opposite the point from which it left.
   5. In part (d) above, what is the net speed of the boat perpendicular to the banks.
2. A Maserati is travelling at 25ms-1 in a direction due East. A Lamborghini is travelling at 18ms-1 in a direction N300E. Find the velocity of the Maserati relative to the Lamborghini.
3. An F-16 fighter jet is travelling with a true airspeed of 195 ms-1 in a direction S450W. A strong cross-wind is blowing at 30 ms-1 in a direction S450E. Calculate the velocity of the F-16 relative to the ground.   
     
   **NOTE:** For aircraft, the true airspeed (TAS) is the actual speed of the aircraft through the air (the speed of the aircraft relative to the air).  The wind speed is usually measured relative to the ground. Groundspeed is the speed of the aircraft relative to the ground.  The groundspeed of the aircraft is the vector sum of the true airspeed and the wind speed.

### **APPENDIX A**

**Statement of Syllabus Content Covered in these Notes**

The following indicates the specific content from the **Stage 6 Physics Syllabus** that has been covered in the notes, worksheets & practicals provided on the Kinematics Module web page.

The resources on this website are meant to supplement the work you do in class NOT replace it. The notes will always provide you with a comprehensive and accurate set of notes on the Module under study. The worksheets will provide some introduction & practice to appropriate problem-solving skills for the topic. You will need to do much more problem-solving practice than just what is provided on this website. The practicals section will provide some experiments relevant to the topic but again you will need to do more than just what is suggested here. Your teacher should provide you with much more problem-solving & practical experience than you will find on this website.

The content statements that are **ticked** have been covered. Those left without a tick have either not been covered at all or have been only partially covered. These are mainly content statements requiring practical work of some kind.

### Content

#### Motion in a Straight Line

**Inquiry question:** How is the motion of an object moving in a straight line described and predicted?

Students:

* describe uniform straight-line (rectilinear) motion and uniformly accelerated motion through:
  + qualitative descriptions ✓
  + the use of scalar and vector quantities (ACSPH060) ✓
* conduct a practical investigation to gather data to facilitate the analysis of instantaneous and average velocity through:  Information and communication technology capability icon
  + quantitative, first-hand measurements
  + the graphical representation and interpretation of data (ACSPH061) Numeracy icon
* calculate the relative velocity of two objects moving along the same line using vector analysis ✓
* conduct practical investigations, selecting from a range of technologies, to record and analyse the motion of objects in a variety of situations in one dimension in order to measure or calculate:  Information and communication technology capability icon Numeracy icon
  + time
  + distance
  + displacement
  + speed
  + velocity
  + acceleration
* use mathematical modelling and graphs**,** selected from a range of technologies,to analyse and derive relationships between time, distance, displacement, speed, velocity and acceleration in rectilinear motion, including:
  + = t + t2 ✓
  + = + t ✓
  + 2 = 2 + 2 (ACSPH061)  Information and communication technology capability icon Numeracy icon ✓

#### Motion on a Plane

**Inquiry question**:How is the motion of an object that changes its direction of movement on a plane described?

Students:

* analyse vectors in one and two dimensions to:
  + resolve a vector into two perpendicular components ✓
  + add two perpendicular vector components to obtain a single vector (ACSPH061) Numeracy icon ✓
* represent the distance and displacement of objects moving on a horizontal plane using:
  + vector addition ✓
  + resolution of components of vectors (ACSPH060)  Information and communication technology capability icon Numeracy icon ✓
* describe and analyse algebraically, graphically and with vector diagrams, the ways in which the motion of objects changes, including:  Information and communication technology capability icon
  + velocity ✓
  + displacement (ACSPH060, ACSPH061) Numeracy icon ✓
* describe and analyse, using vector analysis, the relative positions and motions of one object relative to another object on a plane (ACSPH061) ✓
* analyse the relative motion of objects in two dimensions in a variety of situations, for example:
  + a boat on a flowing river relative to the bank ✓
  + two moving cars ✓
  + an aeroplane in a crosswind relative to the ground (ACSPH060, ACSPH132)  Information and communication technology capability icon Numeracy icon ✓