Preliminary Physics

Moving About

Week 2

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Week 2 – Theory

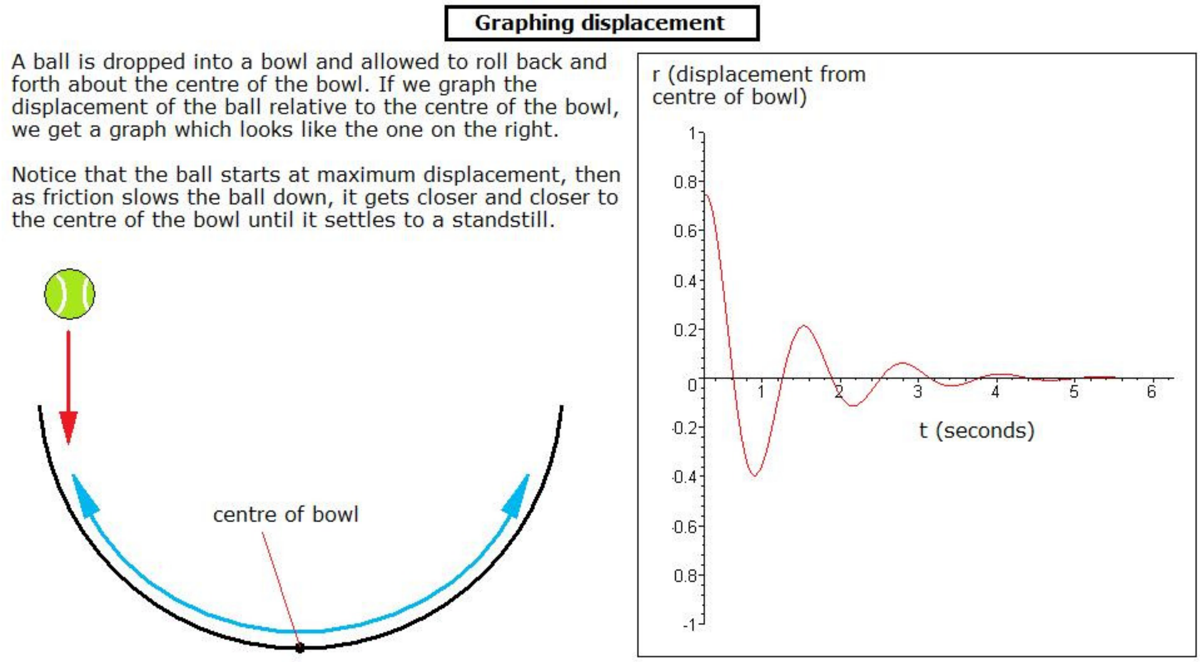
- **<u>Present information graphically of:</u>**
    - **<u>Displacement vs time</u>**
    - **<u>Velocity vs time</u>**

  <u>for objects with uniform and non-uniform linear velocity</u>

Displacement versus time

If we construct a graph of displacement versus time, note that we can have positive and negative values, because displacement is a vector. For example, if we drop a ball into a hemispheric bowl and graph its displacement about the centre of the bowl against time, we get a graph like the one shown below.

This is an example of an object with non-linear velocity, i.e. its velocity is always changing.



Notice **displacement can have both positive and negative values** (in 1 dimension) unlike distance, which can only take on positive values. This is again because displacement is a vector quantity, and its sign (positive / negative) indicates its direction.

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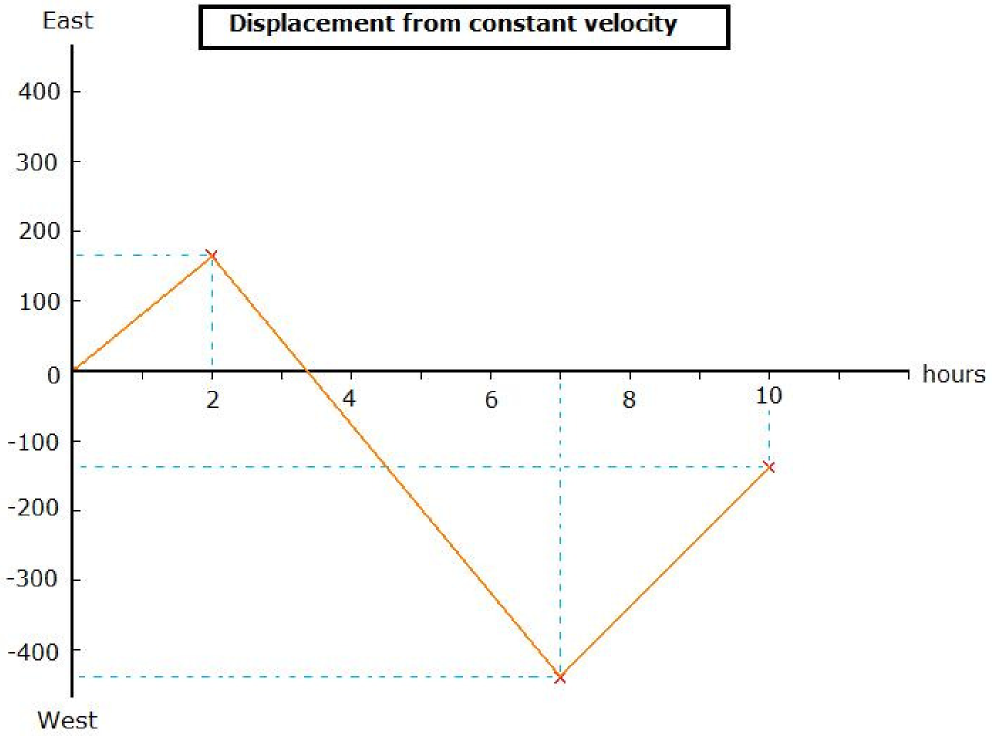
Constant velocity example: *a car moves east at 80km/h for 2 hours, then west at 120km/h for 5 hours, north at 70km/h for 1 hour, then east again at 100km/h for 3 hours. Graph its displacement from the beginning of the journey, in terms of the east / west plane.*



Since we are graphing only on the east/west plane, we ignore the movement north at 70km/h for 1 hour as it has no effect on the east/west displacement. The resultant graph of the displacement on the east/west plane looks like the above graph. Note that for each leg of the journey, the velocity was constant. We will look at graphs involving changing velocity and the effect on displacement in later sections.

Velocity versus time

The graph of velocity versus time is similar to displacement, except it is actually the graph of the first derivative of the displacement graph. Recall that:

$$v_{instantaneous} = \lim_{\Delta t \to 0} \frac{\Delta r}{\Delta t} = \frac{dr}{dt}$$

So if we have the graph of r against t as:

$$r = f(t)$$

Then the graph of velocity should be:

$$v = f'(t) = \frac{df(t)}{dt}$$

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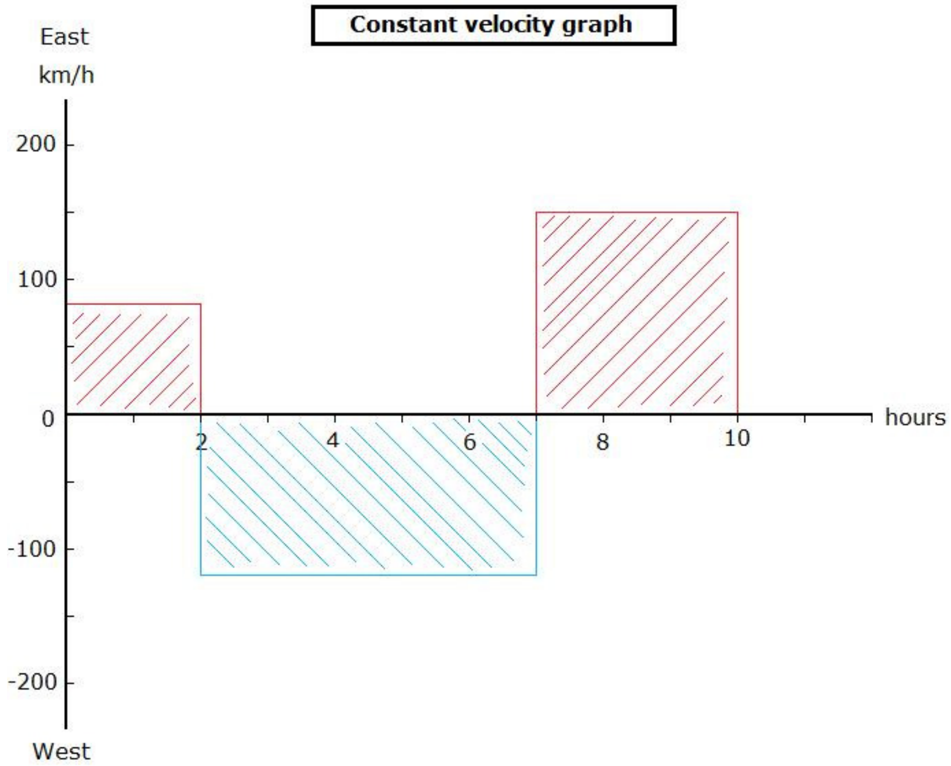
These equations are **not required in the Physics syllabus** but if you do at least 2 unit maths, knowing the calculus relationship makes graphing velocity so much easier.

Constant velocity example: using the same example of the car above, if we graph the velocity graph of that motion, we get:



Notice that if we graph the derivative of the displacement curve, we get the velocity curve above. Likewise, if we find the area under the curve of the velocity graph, we will get the displacement graph (the integral of velocity is displacement).

Non-constant velocity and resultant displacement

Although required by this dot-point, we will look at non-uniform velocity and resultant displacement graphs at a later section (once we learn about acceleration).

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An analysis of the external forces on vehicles helps to understand the effects of acceleration and deceleration

- **Describe the motion of one body relative to another**

All motion is relative

All motion is relative, and motion depends on where you choose the observer to be.

For example, when A walks towards B, is A coming towards B or is B getting closer to A? Actually both are true, because relative to A, B is moving closer towards A, and relative to B, A is moving closer towards B. We can only say 'A is walking towards B' because A is also moving relative to the ground, but B is standing still. If we didn't have the ground to compare with, we would be unable to tell who is actually moving towards who, only that A and B are moving towards each other.

Another example, when 2 cars are travelling in the same direction at the same speed, they are not actually moving relative to each other, even though they are both moving relative to the ground. However, if 2 cars travel in opposite directions, their speed relative to each other is much greater than their individual speeds relative to the ground.

Earth in space

You probably know that a day lasts 24 hours, and each day, the Earth makes a complete 360° rotation about its axis. Given that the equatorial circumference of the Earth is about 40,075km, the equatorial velocity is $v_{equator} = \frac{40074}{24} = 1{,}669.75km/h$! That means if you were standing on the Earth's equator, you'd moving about the centre of the Earth at 1.669.75km/h, 24 hours a day. That's faster than the speed of sound, relative to the centre of the Earth.

The Earth itself orbits the sun at a speed of about 29.783km/s relative to the sun, (faster than anything man-made on Earth), and the sun itself orbits the milky-way galaxy at a speed of around 220km/s ($2.2 \times 10^5 m/s$) relative to the centre of the galaxy.

As you can see, we are never truly 'still'. Whenever we talk about moving from point A to B, we are actually saying we are moving from A to B relative to the Earth. If we stand still, we are actually still moving in many ways, depending on the question: relative to what?

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- **<u>Identify the usefulness of using vector diagrams to assist solving problems</u>**
- **<u>Plan, choose equipment or resources for and perform a first-hand investigation to demonstrate vector addition and subtraction</u>**
- **<u>Solve problems using vector diagrams to determine resultant velocity, acceleration and force</u>**

Vector diagrams

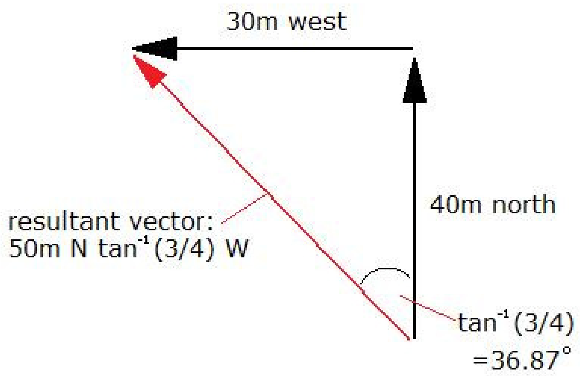
Vector diagrams are a very useful method of visualising the addition and subtraction of vectors. Recall that vectors have a directional component, so when we add vectors, it isn't simply a matter of adding the numbers together.

Adding vectors

Vectors can be added together to obtain a resultant vector. Remember, **when adding vectors, always place vectors head to tail**, meaning when one vector ends (at its head), place the second vector's tail on the first's head. Think of the second vector 'starting' where the first vector 'ended'.

Example 1 (adding displacement): *what do we get when we add 40m north + 30m west?*

We get:



Notice everytime we add vectors, we put the given vectors as **head to tail**.

In Physics, they will always give you sets of perpendicular vectors to add, so in all cases, a right-angled triangle will form from your vector diagram (just like the above example). In these cases, we simply use **Pythagoras' theorem to find the magnitude**, and we note the direction of the resultant vector as well. Depending on the question, some will only require an approximate direction (e.g. 'northwest' for this example), while others require you to evaluate the bearing of the direction (in this case, it is $360° - 36.87° = 323.13°$ true bearing).

Example 2 (adding velocity): *a plane travels at a cruising speed of 900km/h north. At the same time the wind is blowing west at a speed of 100km/h, dragging the plane along. What is the plane's speed and direction relative to the ground?*

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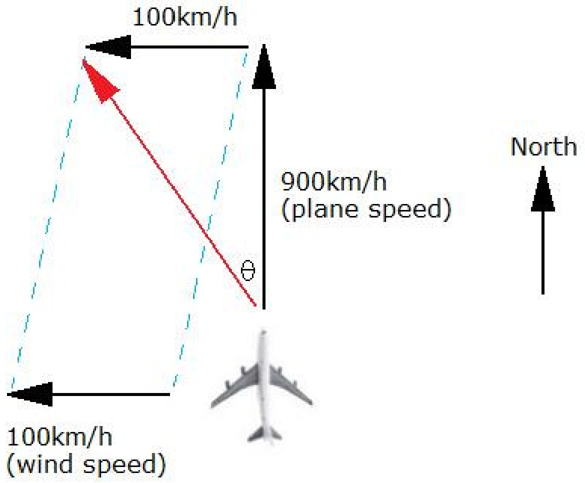


Notice we place head to tail again, because we are adding vectors, so we re-draw the wind vector with its tail at the head of the plane's velocity vector. The resultant vector is the plane's true velocity:

$$v = \sqrt{100^2 + 900^2} = 905.539km/h$$

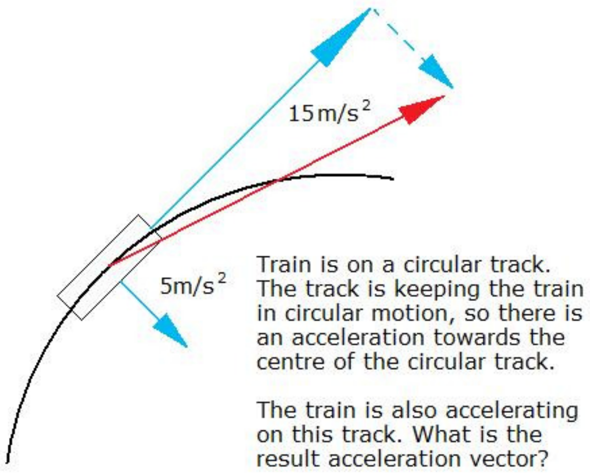
The direction is simply the inverse tan of 'opposite over adjacent':

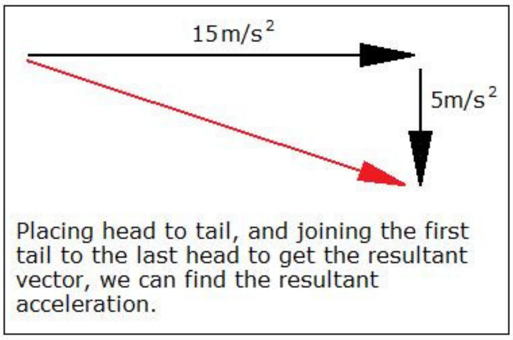
$$\theta = \tan^{-1}\frac{1}{9}$$

The true bearing is therefore:

$$true\ bearing = 360° - \theta = 360° - \tan^{-1}\frac{1}{9} = 353.660°$$

Example 3 (adding acceleration): *suppose a train is on a circular track and is experiencing accelerations as shown:*





The resultant acceleration magnitude is found by using Pythagoras' theorem:

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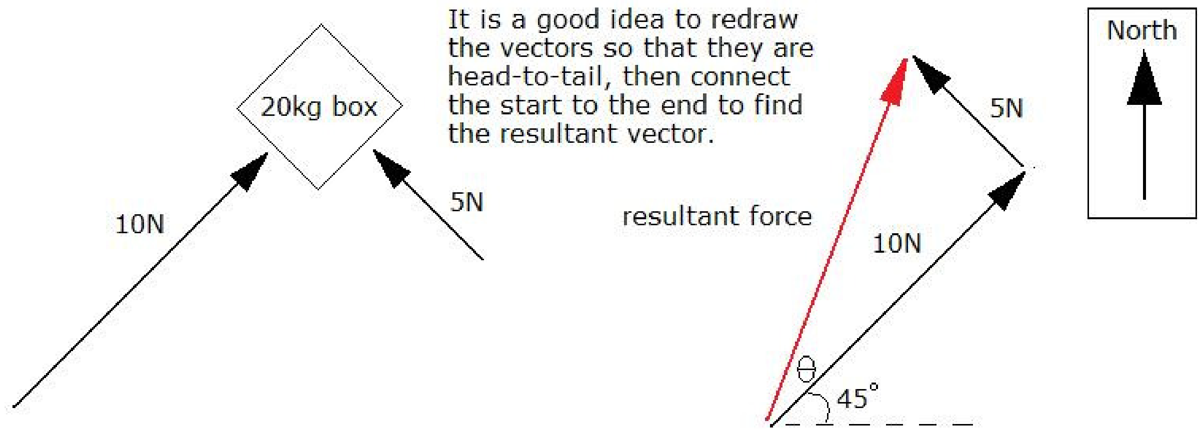
$$v = \sqrt{5^2 + 15^2} = 15.811ms^{-2}$$

Example 4 (adding force): *suppose we have a box on a table, and it is being pushed by two people in different directions with the forces as shown. Calculate the resultant force, direction and the acceleration of the box.*



As before, once we arrange the vectors in head to tail order, we can easily find the resultant vector. The magnitude is:

$$F = \sqrt{5^2 + 10^2} = 11.180N$$

Direction is given as:

$$\theta = \tan^{-1}\frac{1}{2} = 26.565°$$

We know that the 10N vector was in the direction of 45° (true bearing), so we deduce the true bearing of the resultant force to be:

$$90° - 45° - \theta = 18.435°$$

We also know that $F = ma$ (Newton's second law) and we are given the mass of the box to be 20kg. Therefore, the box will be accelerating at:

$$a = \frac{F}{m} = \frac{11.180}{20} = 0.559ms^{-2}$$

in the direction of 18.435° (true bearing).

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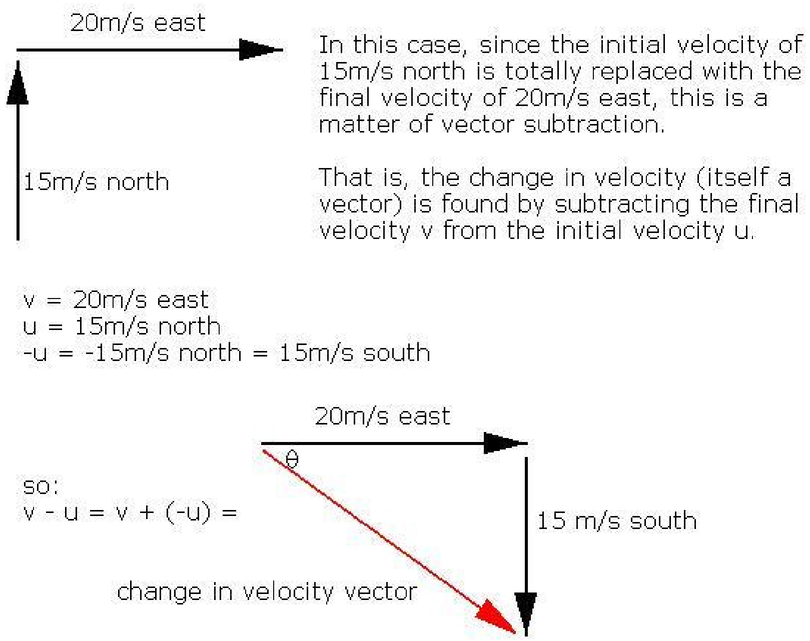
Subtracting vectors

Subtracting vectors is the same as adding the negative of the second vector. Subtracting vectors is particularly useful when dealing with relative velocities. This adds one extra step (flipping the direction of the vector to be subtracted, before adding), but is essentially the same as adding vectors discussed above.

Example 1 (subtracting velocities): *suppose a car makes a 90° turn. It has an initial velocity of 15m/s north, and after turning, it has a velocity of 20m/s east. Calculate the change in velocity.*



The change in velocity is itself a velocity vector, and is found by vector subtraction:

$$change\ in\ velocity = \Delta v = v - u$$

Which is the same as:

$$v + (-u)$$

So the negative of u is therefore a vector of the same magnitude, but opposite direction, i.e. 15m/s south. Therefore we apply the same method of vector addition to the opposite vector.

$$v = \sqrt{20^2 + 15^2} = 25m/s$$

$$\theta = \tan^{-1} 0.75 = 36.87°$$

$$\therefore true\ bearing = 90° + \theta = 126.87°$$

We will revisit subtracting velocity vectors when we talk about acceleration in terms of changing velocity.

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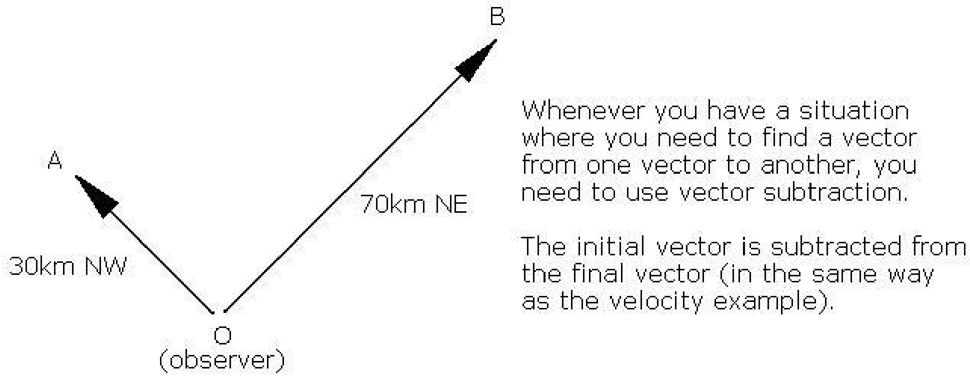
Example 2: when we want to know the displacement of one place *from* another, we also use vector subtraction. *For example, from one observer's point of view, town A is 30km northwest. Town B is 70km northeast. What is the displacement of B from A?*



$\vec{AB} = \vec{OB} - \vec{OA}$ = 70km NE - 30km NW

= 70km NE + 30km SE

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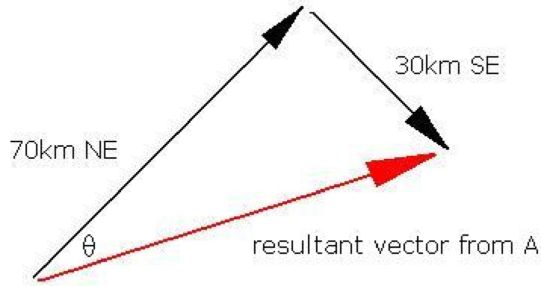

When we try to find the displacement of B from A in the diagram above, it is obvious that the vector is simply the arrow pointing from A to B (head at B, tail at A). This is intuitive, but you should know that whenever we have a situation where we want to find the vector from any two points A to B, we find it by subtracting the initial vector $\overrightarrow{OA}$ from the final vector $\overrightarrow{OB}$.

That is

$$\overrightarrow{AB} = \overrightarrow{OB} - \overrightarrow{OA}$$

Remember before, to do this, we flip the negative vector so instead of 30km NW, we have 30km SE to add to 70km NE.

The resultant vector $\overrightarrow{AB}$ is therefore:

$$\overrightarrow{AB} = \sqrt{70^2 + 30^2} = 76.158km$$

$$\theta = \tan^{-1}\frac{3}{7} = 23.199°$$

$$\therefore true\ bearing = 45° + \theta = 68.199°$$

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Week 2 – Homework

- **Present information graphically of:**
  - **Displacement vs time**
  - **Velocity vs time**

  for objects with uniform and non-uniform linear velocity

1. A car travels north at a speed of 20m/s for 90 minutes, then 25m/s for 20 minutes. The car then turns around and travels 50m/s for 130 minutes. Draw a graph representing:
   a. Displacement vs time **[3 marks]**

   b. Velocity vs time **[3 marks]**

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2. By finding the area under a velocity vs time graph, we can graph displacement vs time. Explain why this statement is true. **[3 marks]**

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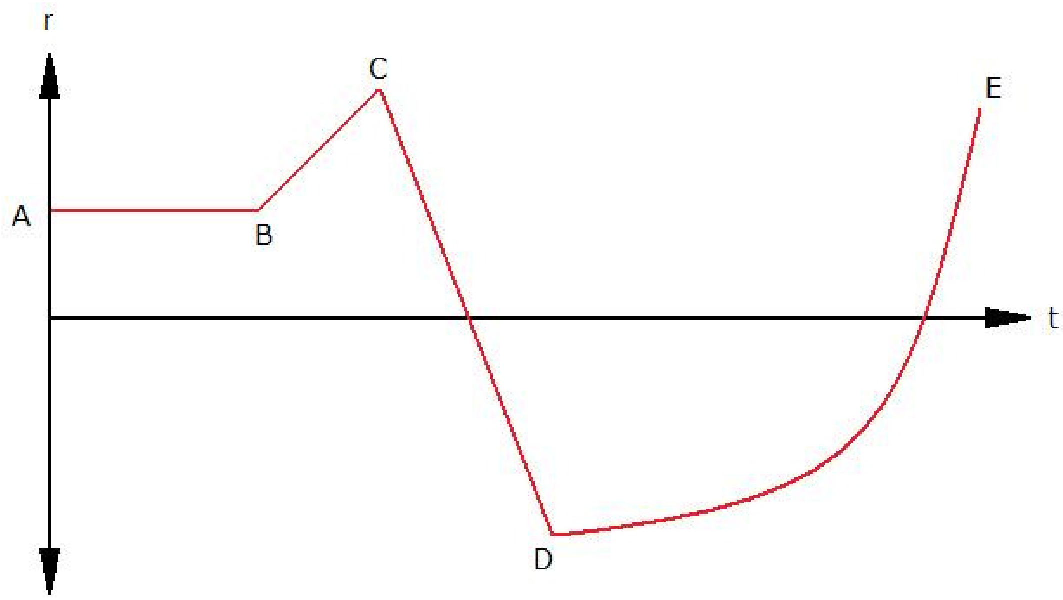
3. Below is a graph of displacement vs time.



a. Identify the velocity between AB (zero, uniform, increasing, decreasing etc). **[1 mark]**

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b. Similarly, identify the velocity at BC, CD and DE. **[3 marks]**

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c. Draw a velocity vs time graph for this movement. Fully label your graph. **[3 marks]**

4. Explain the significance of the gradient of the tangent at any point on a displacement vs time curve. **[2 marks]**

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5. Explain the significance of the gradient of the tangent at any point on a velocity vs time curve. **[2 marks]**

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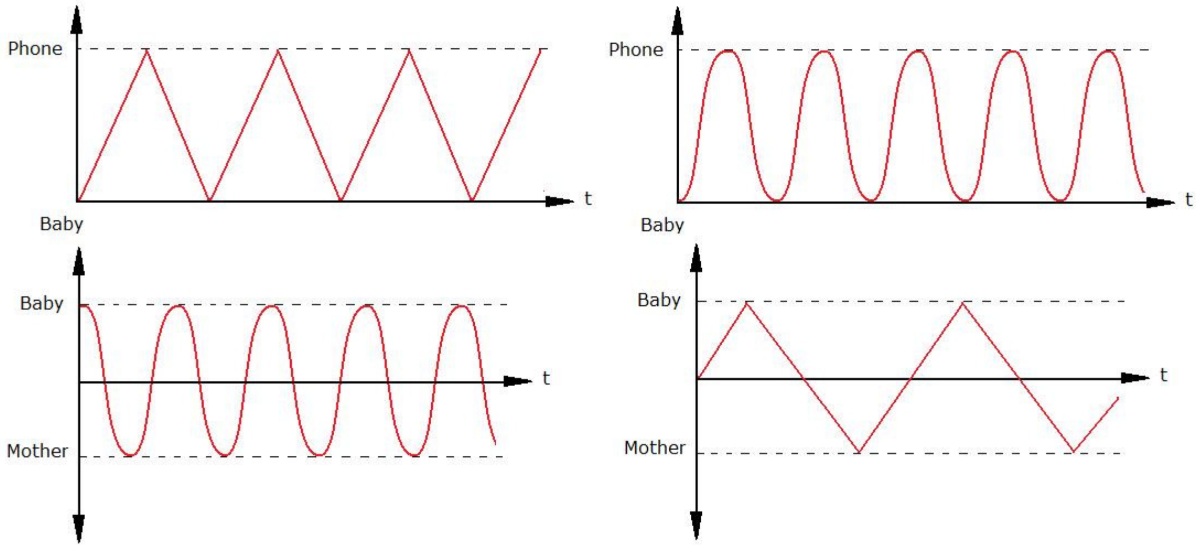
6. A busy mother needs to walk back and forth between her baby and the phone. Choose the displacement graph that best describes the mother's displacement from the baby (circle the correct one). Briefly explain your choice over the others. **[2 marks]**



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7. Identify using diagrams the basic shape of displacement vs time curves in each of the following situations: **[1 mark]**
   a. A car with uniform positive velocity
   b. A car with zero velocity.
   c. A car with uniform negative acceleration

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8. Identify using diagrams the basic shape of velocity vs time curves in each of the following situations: **[1 mark each]**
   a. A car with uniform positive velocity
   b. A car with uniform positive acceleration.
   c. A car with uniform negative acceleration

- **<u>Describe the motion of one body relative to another</u>**

1. "All motion is relative". Explain this statement with reference to real life examples. **[3 marks]**

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2. Explain why we can never be truly still, with reference to the motion of the Earth. **[2 marks]**

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- **<u>Identify the usefulness of using vector diagrams to assist solving problems</u>**
- **<u>Plan, choose equipment or resources for and perform a first-hand investigation to demonstrate vector addition and subtraction</u>**
- **<u>Solve problems using vector diagrams to determine resultant velocity, acceleration and force</u>**

1. A car travels 30km north and 40km east. Draw a displacement vector diagram for the journey, and hence calculate the displacement vector. **[2 marks]**

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2. A cyclist travels north 550m, then west 330m, then south 200m. Draw a vector diagram for this journey and hence calculate the displacement of the journey. **[2 marks]**

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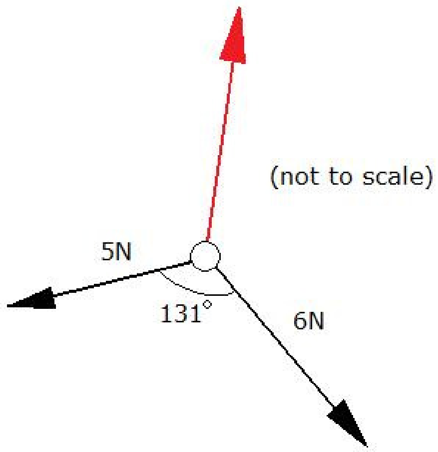
3. Three students fight over a physics textbook. They each pull the textbook in one direction, as shown below. The pulling force by A and B are given. For the book to stay still, calculate the pulling force C must provide. (Hint: you may need to use the cosine rule) **[3 marks]**



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4. A boy is travelling in a car going north at 60km/h. The boy throws a piece of garbage out of the window northeast at 20km/h. Draw a vector diagram for this situation and hence calculate the velocity of the piece of garbage. **[3 marks]**

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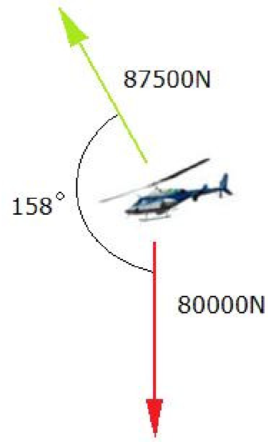
5. Helicopters move forward by tilting the angle of its blades. Look at the diagram below and calculate the net force acting on the helicopter. (Hint: remember to place vectors head to tail when adding) Conclude whether it will rise or fall. **[3 marks]**



6. A person walks 50m east, then turns 45° and walks another 50m northeast. Draw a displacement vector diagram for this journey and hence calculate the net displacement of the journey. **[2 marks]**

7. A train is on a circular track. Its engines are providing forwards force of 21000N, but the track is pushing the train sideways with a force of 14000N. Draw a vector diagram for this situation and hence calculate the net force acting on the train. **[3 marks]**

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8. A car is heading west at 20m/s. It makes a left hand turn and by the end of the turn, it is travelling at 32m/s south. Draw a vector diagram for this situation and using vector subtraction, calculate the resultant vector for change in velocity. **[3 marks]**

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9. From an observer, city A is 030° and 540km away, and city 17 is 135° and 710km away. Using vector subtraction, calculate the bearing and distance of city 17 from city A.

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10. A cyclist must first slow down before making a turn. A cyclist was travelling at 12m/s on a straight road, and slows down to 8m/s before turning 90°, with final velocity of 10m/s.
    a. Calculate the change in velocity for just the turn itself. **[2 marks]**

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    b. Calculate the change in velocity for the entire event, including the initial slowdown. **[2 marks]**

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    c. From your answer in (a), add to it the vector for initially slowing down from 12m/s to 8m/s. Compare this result to your answer in (b) and explain why it is the same. **[2 marks]**

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End of homework