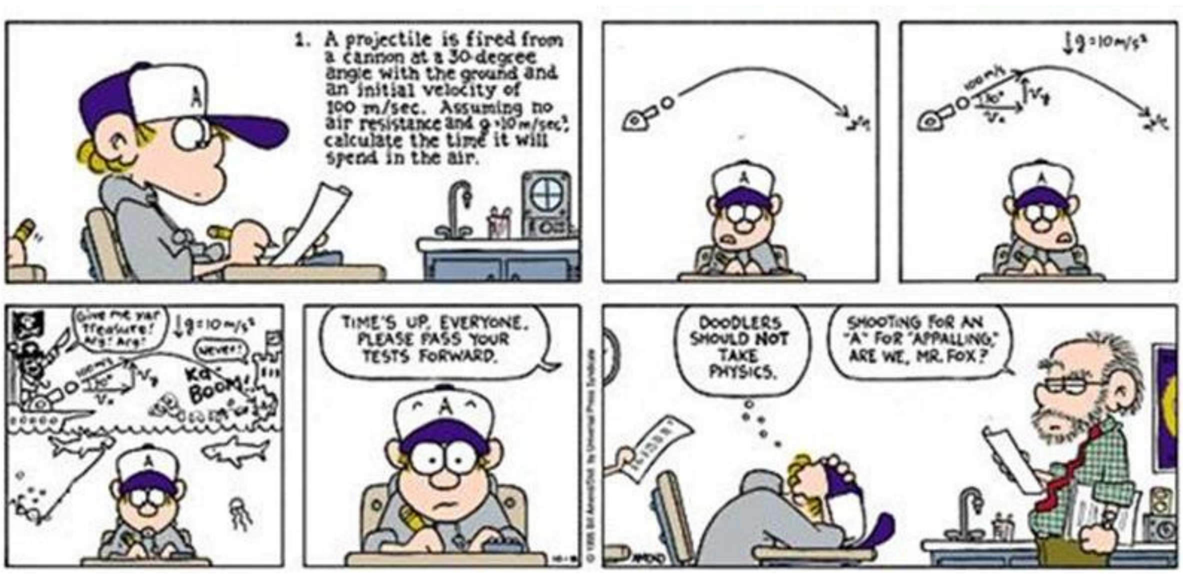
SALTUS GRAMMAR SCHOOL

AP Physics I



Unit 1 – Kinematics

Name: ....

Date: ....

Summary

Kinematics is the study of motion. Specifically, just the mathematical description of the motion without considering what causes the motion. The latter study is known as dynamics. The father of kinematics was Galileo Galilei, and this formed the foundations that Isaac Newton built the science of dynamics upon. At AP level we concern ourselves purely with motion that is undergoing uniform acceleration. To consider anything further requires the use of calculus, which is not covered in this course.

Topics

1.1 Common Measurements

1.3 Problem Solving

1.4 The Kinematic Variables

1.5 The Equations of Motion

1.2 Vectors and Scalars

1.6 Projectiles

There are four detailed labs to be performed during this topic and several pages of homework assignments. Additionally, I have included some sample AP problems at the end of the topic.

While I have included spaces for you to make notes, answer questions and solve problems, it is expected that you make additional notes, comments and aide memoirs in any available space and annotate diagrams and equations as you desire. This will assist in future study endeavours as annotating texts etc is a valuable study skill.

Paul Wright

Updated: 30 September 2015

1.1 Common Measurements

Objectives:

- To revise the importance of units
- To be able to convert from one unit to another where necessary
- To be able to rearrange an equation to find the units of a variable

Our goal of understanding the physical world through theory and experiments always leads to measurements and numbers. To ensure that we can communicate our ideas we need a common group of standards so that numbers relating to such quantities as length and time can be compared and understood the world over.

Systeme International (SI or Metric)

In 1960 the collective scientific community agreed upon a 'base' or 'foundation' set of seven units to use. The units for length, mass, time, temperature and current are the metre, kilogram, second, Kelvin and ampere respectively are the most commonly used.

Derived units

In many situations we wish to express a physical quantity in terms of a derived unit, this often aids our understanding and communication of a concept or idea. It is much easier to imagine the concept of energy in terms of Joules rather than a collection of kilograms, metres and seconds. Every derived unit can ultimately be expressed as a base unit.

Example 1

Find the base unit for Energy (Joule).

Example 2

Find the base unit for Force (Newton).

Example 3

Find the base unit for Power (Watt).

Example 4

Find the base unit for Intensity (Watts per square metre).

Dimensional analysis
All formulas include quantities that have some units. On each side of an equation the units should be identical with regard to their dimensions. The symbols for mass, length and time are M, L and T respectively. On the whole, I find it easier to work with the units themselves rather than the dimensions.

Example 5
What are the dimensions of force?

Prefixes
When stating answers it is often common to use a prefix rather than standard form.

Prefix	**Symbol**	**Value**
Giga	G	1×10^9
Mega	M	1×10^6
Kilo	K	1×10^3
Milli	m	1×10^{-3}
Micro	μ	1×10^{-6}
Nano	n	1×10^{-9}

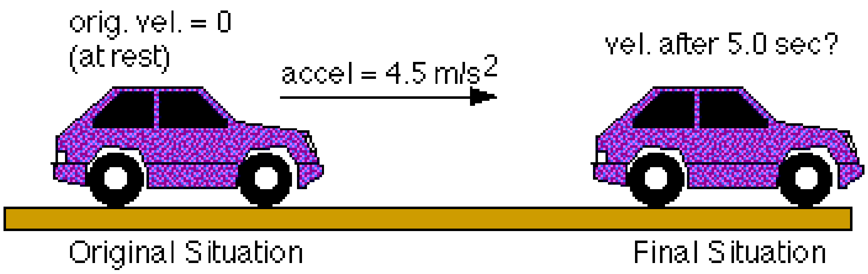
1.2 Problem Solving

Objectives:

- To understand the importance of visualising the problem before starting to try to solve it
- To be able to draw an accurate, labelled diagram
- To be able to convert units before attempting to solve a problem.

Problem solving is probably the single most important skill to work on throughout this course. At IGCSE level the problems are straightforward in that they only require the use of one equation or concept. At higher level physics the problems often require multiple equations and concepts to solve them. Usually once you have figured out HOW to solve the problem, the actual act of using the equations and algebra is easy. There are many techniques that are good for helping with this and time and practice are essential. One of the key ones that I find useful (and most others too!) is to draw a carefully labelled diagram or graph of the scenario – ensuring that you know what is going on! This often gives you the clue on how to attack the problem. It also helps you to decide whether your final answer is in the right ball park or not. For kinematics problems, a commonly used technique is to list the known and unknown variables in a standard format.

An example of a carefully labelled diagram:

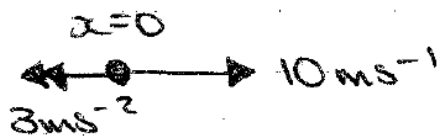


An example of listing the variables:

$u = 10\ ms^{-1}$

$a = -3\ ms^{-2}$

$x = 0m.$



Example 9

A bike accelerates from rest to a speed of 35 km/hr over a distance of 60 m.

Example 10
The Earth orbits the Sun at a distance of 150 million km. What is the speed that the Earth is moving?

Example 11
A rocket is launched to a height of 1000m over a time of 45 seconds. What is the final velocity of the rocket?

Example 12
A plane flying at 120 km/hr lands and comes to rest over a distance of 800 m. Calculate the deceleration.

1.3 The Kinematic Variables

Objectives:

- To know the five variables that describe motion
- To fully appreciate their physical meaning
- To be able to measure all of these variables experimentally

There are five variables that are used to describe motion:

Variable	Symbol	Units	Comments
Initial velocity			
Final velocity			
Displacement			
Acceleration			
Time			

LAB: Measuring the Kinematic Variables

Aim: To use dataloggers and lightgates to measure the key kinematic variables.

Method:

1. Set up a ramp at a slight angle and roll a trolley down it. It should steadily accelerate. Set it up that so that the trolley always starts from the same location.
2. Set up two light gates a measured distance, x, apart (say 1.0 m).
3. As the trolley's interrupt card goes through the lightgates they record the speed that it is going. The initial speed, v_0, and the final speed, v.
4. Set up the datalogger to also record the time taken from the first lightgate to the second lightgate. This is the time variable, t.
5. The acceleration can also be measured by replacing the single interrupt card with a double interrupt card, you will need to reprogram the datalogger to measure the acceleration, a.
6. You have now measured all 5 of the key kinematic variables!
7. To finish – check the average value of the acceleration matches the theoretical value using:

$$a = (v - v_0)/t$$

Initial velocity (m/s)	**Final velocity (m/s)**	**Time taken (s)**	**Calculated acceleration (m/s^2)**

Mean measured acceleration = ……………………. m/s^2

1.4 The Equations of Motion

Objectives:

- To know (learn!) the 3 main equations of motion
- To be able to use the equations of motion to solve kinematics problems in one-dimension.
- To be able to demonstrate their accuracy in a practical experiment.

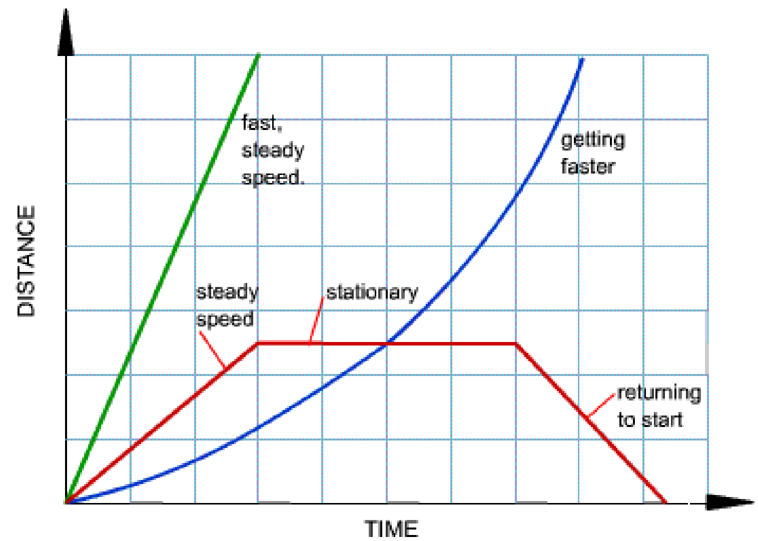
There are four equations that link these 5 kinematic variables, but before we launch into these, let us revisit the concept of representing motion graphically. The most useful graphs are the velocity-time graphs.

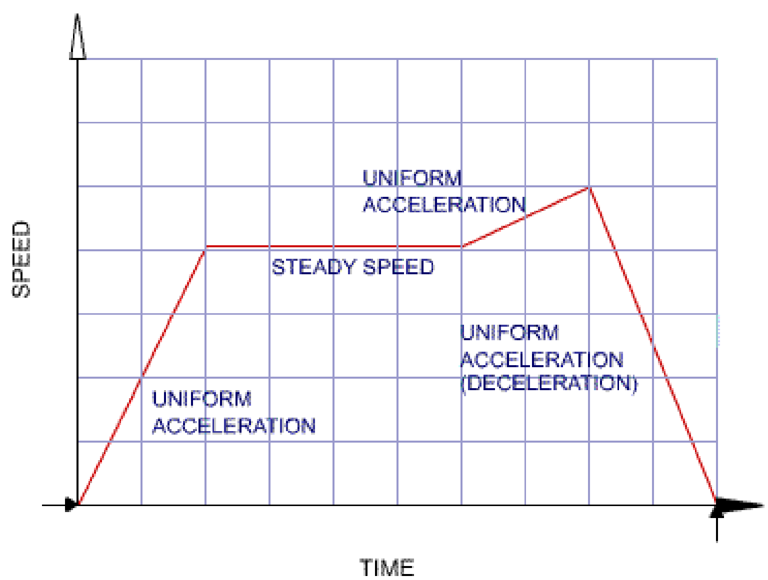
The two key things to remember are that:

1. The gradient represents the rate of change of velocity – i.e. the acceleration
2. The area under the graph represents the displacement travelled by the object.

Calculus aside: The gradient is the derivative of the velocity, which equals the acceleration and the area under the graph is the integral of the velocity.

Distance-time graphs are also occasionally used, but somewhat less useful. The gradient represents the rate of change of distance, so is equal to the speed.

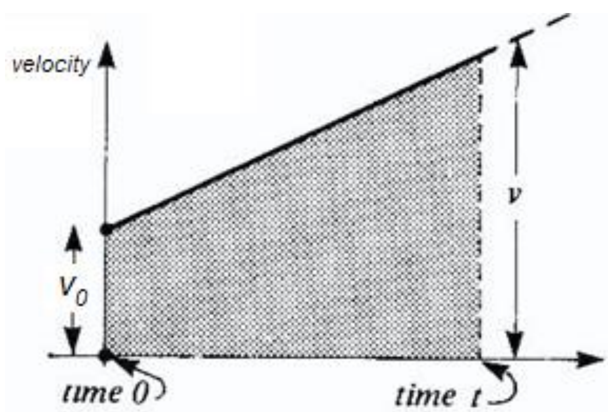




Example 13
Draw distance, displacement, speed and velocity graphs for a ball falling and bouncing without loss of energy.

The Equations of Motion

There are 4 basic equations that link the five kinematic variables that you investigated in the experiment, although generally you will only really use three of them. As long as you know any three of the variables, the other two can always be found. You do not need to remember how the equations are derived, but it is helpful to be convinced!



The diagram above shows a body in motion with constant acceleration. Its velocity changes in a regular way from v_0 to v, in a time t – it is a straight-line (linear) graph.

The average velocity can be calculated using the starting and finishing points of the graph:

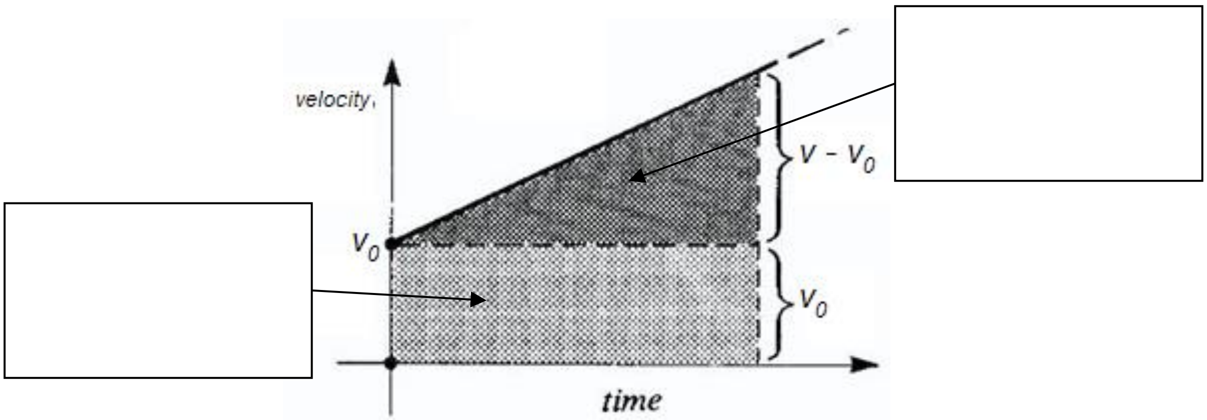
$$average\_velocity = \left(\frac{v + v_0}{2}\right)$$

An equation for the rate of change of velocity (acceleration) can be derived from the gradient of the graph:

$$a = \frac{(v - v_0)}{t} \qquad (1)$$

Which, can be rearranged as:

$$v = v_0 + at$$



The total displacement of a body moving in a straight line with constant acceleration can be found from the area under the graph.

$$x = v_0 t + \tfrac{1}{2}(v - v_0)\,t$$

But as $(v - v_0) = a\,t$

We have:

$$x = v_0 t + \tfrac{1}{2} a t^2 \qquad (2)$$

Each equation on the previous page contains the variable of time. By substituting one into another we can derive an expression for the motion that is independent of this variable, hence:

$$v^2 = v_0^{\,2} + 2ax \qquad (3)$$

Derive the above equation:

The final equation is based on the average velocity of the object and the simplest equation in physics (and most misused one!)

$$\textit{Average velocity} = x/t$$

$$(v - v_0)/2 = x/t$$

so

$$x = \tfrac{1}{2}\,(v_0 + v)\,t \qquad (4)$$

This equation is rarely used in real problems so isn't terribly useful. The first one should have been remembered from IGCSE and is the definition of acceleration, so should be easy! The other two are worth learning by rote - so take the time!

The three important equations of motion:

Example 14

A stone is dropped from the top of a building and takes 2.5 s to hit the ground. Assuming that it is dropped from rest and that the acceleration due to gravity is 9.8 m/s^2 calculate the height of the building.

Example 15

A failing student is fired into the air by cannon. Neglecting air resistance, what would the initial velocity have to be for the student to reach a height of 50 m?

Example 16

A particle is moving in a straight line with a constant acceleration of -6.0 m/s^2. As it passes a point, A, its velocity is 20 m/s. What is its speed 10 s after passing A?

Example 17
A boy racer SGY student (just passed their test, out in his parents car) crashes into a brick wall whilst speeding in the early hours of the morning. The car hits the wall at 45 mph and is brought to rest in 0.2 s before rebounding. What is the average acceleration on the vehicle and hence the student during the crash and how loud was the radio at the time of impact? (note: 1 mph = 1.66 km/hr)

LAB: Using the Kinematic Equations

Aim: to use the dataloggers to verify the three equations of motion.

Set up a ramp with a gentle gradient – in such a way that a trolley released from near the top accelerates at a moderate rate down the slope. It is critical that the experiments are consistent.

Experiment 1 – just measuring the final velocity.
Set up a light gate near the bottom to record the final velocity, v. Repeat the measurement three times to achieve an accurate value. You know: v_0, x and v. Calculate a.

Experiment 2 – measuring the velocities and the time.

Set up the two light gates to record the initial velocity, v_0, and the final velocity, v, as well as the time, t, between them. You know: v_0, v and t. Calculate a.

Experiment 3 – measuring the time.

Set up two light gates up so that the time from the start to the finish, t, can be recorded by the data logger. Repeat three times. You know x, t and v_0. Calculate a.

Experiment 4 – measuring acceleration directly

Repeat the experiment one more time but with a double interrupt card on the trolley and the data logger set up to record the trolley's acceleration. Repeat three times. The value of the average acceleration, a, should be close to that calculated above….

Data:

Trial	**Velocity (m/s)**
Mean	

Trial	**Initial velocity (m/s)**	**Final velocity (m/s)**	**Time (s)**
Mean			

Trial	**Velocity (m/s)**
Mean	

Trial	**acceleration (m/s^2)**
Mean	

Discussion:

Graphing Motion Example (AP B 1982)

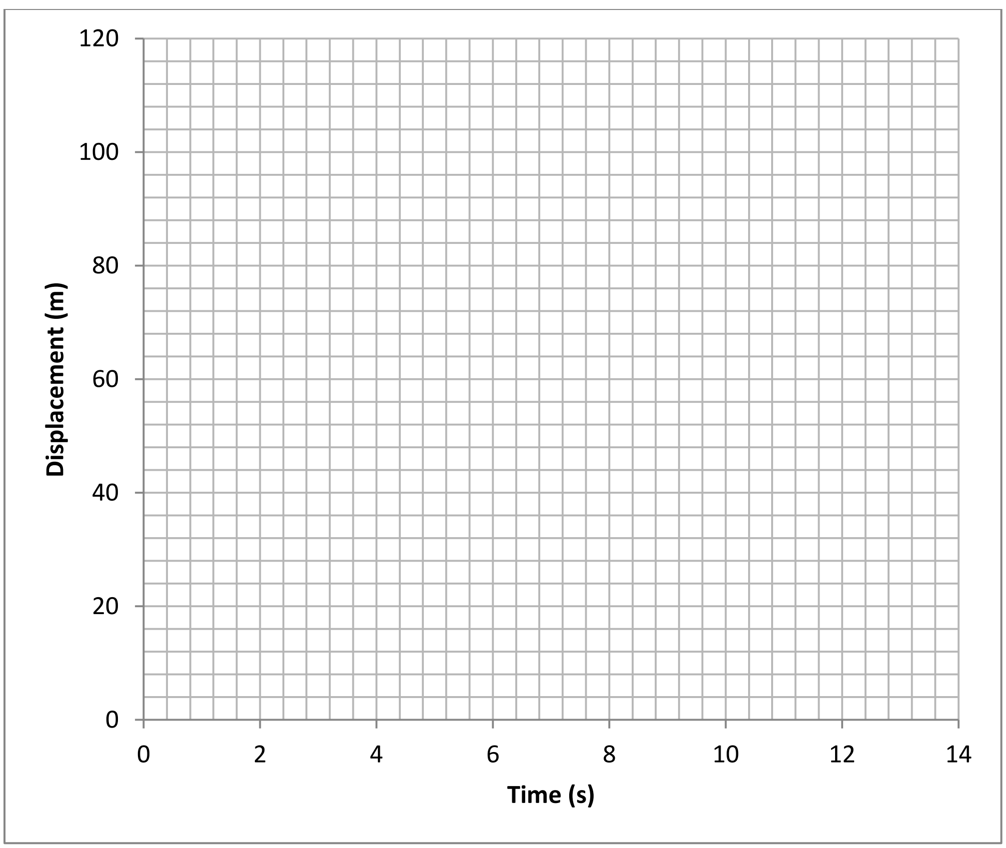
The first 10 m of a 100 m race are covered in 2 s by a sprinter who starts from rest and accelerates at a constant rate. The remaining 90 m are run at a constant velocity.

a) Determine the sprinter's acceleration during the first 2 s.

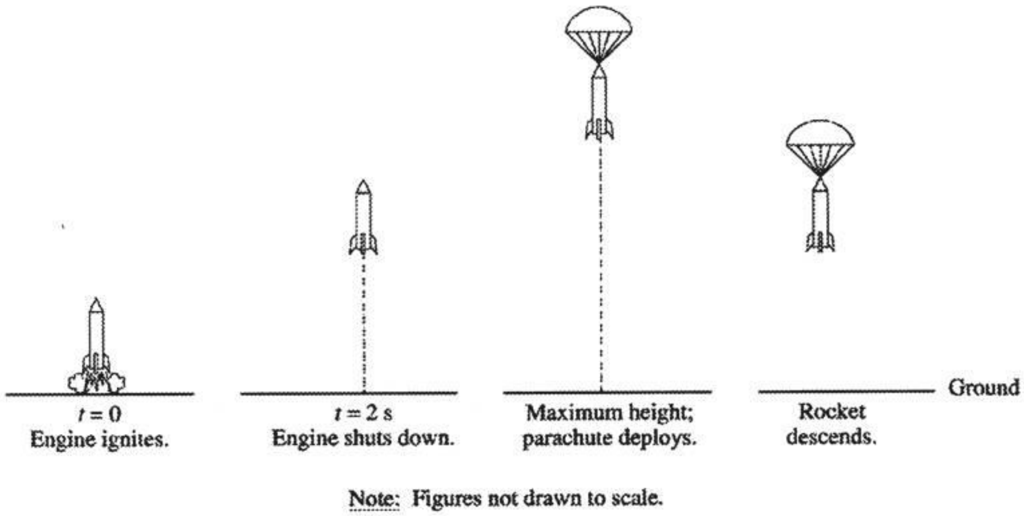
b) Determine the sprinter's velocity after the first 2 s.

c) Determine the total time to run the full 100 m.

d) Draw the displacement-time graph of the sprinter.



Multiple-step Problem (AP B 2002 – modified)



A model rocket is launched vertically with an engine that is ignited at time t = 0, as shown above. The engine provides an upward acceleration of 30 m/s^2 for 2.0 s. Upon reaching its maximum height, the rocket deploys a parachute, and then descends vertically to the ground.

a. Determine the speed of the rocket after the 2 s firing of the engine.

b. What maximum height will the rocket reach? (this is a two-step problem)

c. At what time after t = 0 will the maximum height be reached? (again, a two-step problem)

e) The rocket takes 20 s to fall back to the ground. What is its average speed?

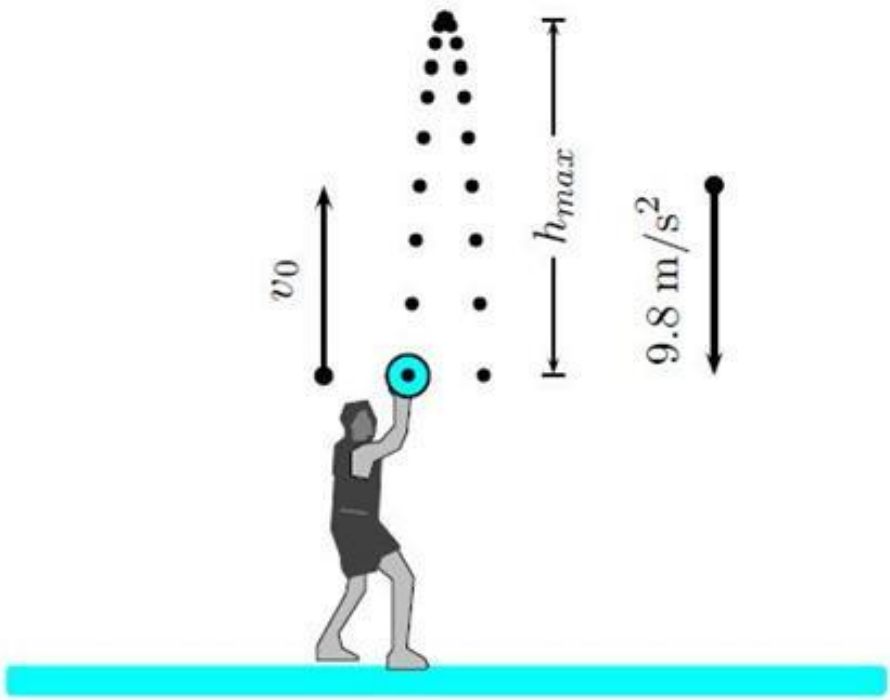
1.5 Free Fall

Objectives:

- To know that the acceleration due to gravity is always downwards and has a value of 9.81 m/s^2.
- To be able to solve problems involving *g*, whether the object is moving upwards and/or downwards.

One of the most important situations involving constant acceleration is the motion of an object free-falling under the influence of gravity. Galileo famously demonstrated that in the absence of air resistance, all object fall at the same rate – accelerating towards the ground at an acceleration of 9.81 m/s^2. Objects falling down obviously accelerate! But it harder to describe what happens as it is thrown upwards…. It still ACCELERATES but this time, the acceleration acts against the motion, slowing it down and then re-accelerating it downwards.

KEY IDEA: the acceleration due to gravity ALWAYS acts DOWNWARDS – no matter what the motion of the object is doing!



Question: Sketch a velocity-time graph of this motion

Example **

A ball is thrown directly upwards with a velocity of 30 m/s.

1. Is the speed of the ball at the apex of its flight?
2. How long will it be before the ball hits the ground?
3. What is the distance travelled by the ball?
4. What is the greatest displacement of the ball?
5. What is the total displacement of the ball?

LAB: Measuring the Acceleration due to Gravity, *g*

Aim: To use one of three methods to measure the acceleration due to gravity, g.

Method A – measuring the time of flight

1. Set up the fast timer with the ball bearing launcher and trap door.
2. Ensure that system is working correctly, the timer should start when the ball is released and stop when the ball hits the trap door switch at the bottom.
3. Carefully measure the height between the release and the trapdoor, and perform the experiment three times to achieve an accurate average time of flight.
4. Repeat the measurements for a range of heights. You know the variables: v_0, x, and t.
5. Use the equation $x = v_0t + \frac{1}{2} at^2$ to determine the mean acceleration. Compare with the official value of $g = 9.81$ m/s^2.
6. Extension: plotting a graph of height against time squared should produce a straight line with a gradient = $g/2$.

Method B – measuring the final velocity

1. Set up a tube on clamp stands such that a 10.0 cm metal cylinder can fall through it – place a cushion on the floor to protect it. Set up a light gate at the bottom of the tube to measure the final velocity, v.
2. Measure the length of the tube, x. You now know the variables: v_0, x, and v.
3. Use the equation $v^2 = v_0^2 + 2ax$ to determine the acceleration due to gravity.
4. Repeat for a range of different lengths of tube.
5. Plotting a graph of velocity squared against length should yield a straight line with a gradient = $2g$.

Method C – ticker timer

1. Attach a length of ticker tape to a 100 g mass.
2. Set up the ticker time on a clamp stand upon a stool.
3. Holding the mass below the ticker time, start the timer running and release the mass.
4. To measure the acceleration, it is possible to determine the initial and final velocities by measuring between two sets of dots on the tape, knowing that the time interval between adjacent dots = 1/60 second (speed = distance between adjacent dots x 60). Counting the intervals between your two velocities will give you the time taken to accelerate (1/60 x number of spaces)
5. Repeat for a range of heights.

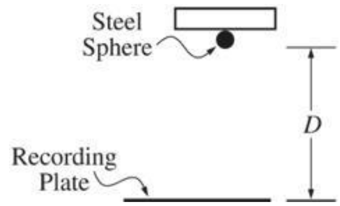
Method D – VideoPhysics App on iPad

1. Set up a metre ruler against a wall and mount an iPad so that it can clearly see the ruler.
2. Drop a squash ball (or similar) and record the motion using the VideoPhysics app.
3. Use the scale and origin function to calibrate the distance travelled between the frames.
4. Analyse the graph – what value should the gradient be?

Lab notes:

Data and Analysis:

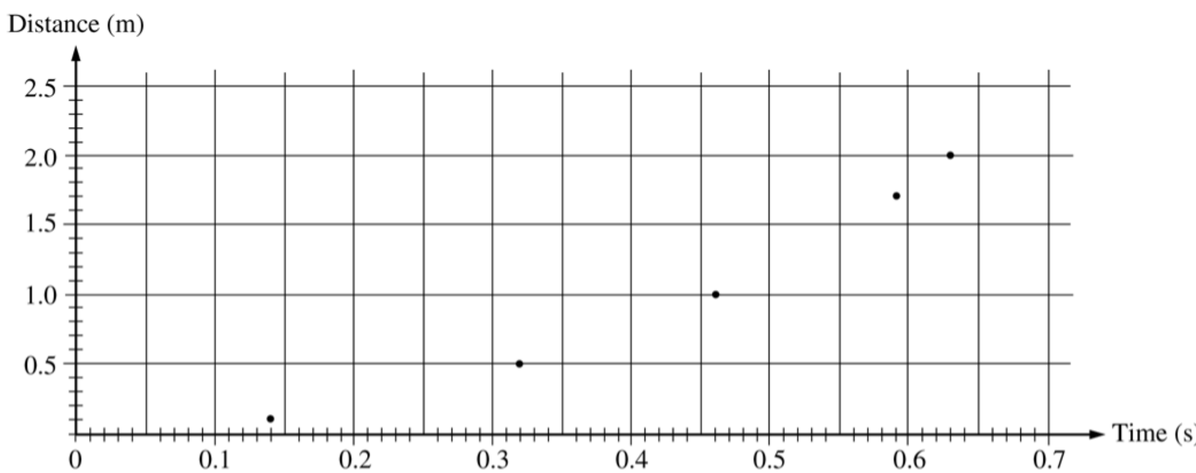
2006Bb1. Experimental Question (linearising data)



A student wishing to determine experimentally the acceleration g due to gravity has an apparatus that holds a small steel sphere above a recording plate, as shown above. When the sphere is released, a timer automatically begins recording the time of fall. The timer automatically stops when the sphere strikes the recording plate.

The student measures the time of fall for different values of the distance D shown above and records the data in the table below. These data points are also plotted on the graph.

Distance of Fall (m)	0.10	0.50	1.00	1.70	2.00
Time of Fall (s)	0.14	0.32	0.46	0.59	0.63

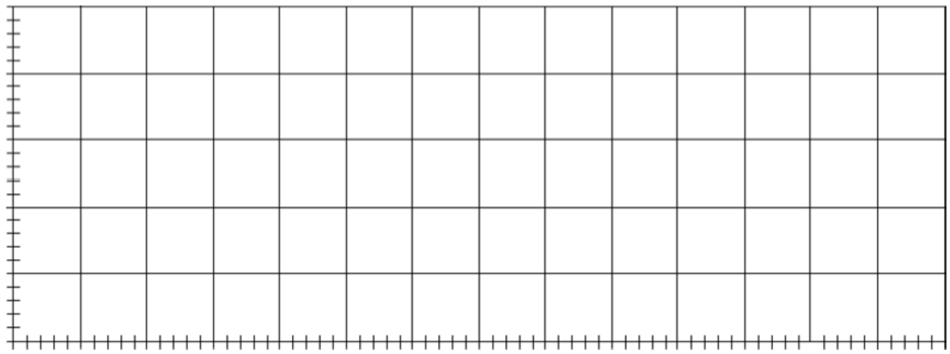


(a) On the grid above, sketch the smooth curve that best represents the student's data

The student can use these data for distance D and time t to produce a second graph from which the acceleration g due to gravity can be determined.

(b) If only the variables D and t are used, what quantities should the student graph in order to produce a linear relationship between the two quantities?

(c) On the grid below, plot the data points for the quantities you have identified in part (b), and sketch the best straight-line fit to the points. Label your axes and show the scale that you have chosen for the graph.



(d) Using the slope of your graph in part (c), calculate the acceleration *g* due to gravity in this experiment.

(e) State one way in which the student could improve the accuracy of the results if the experiment were to be performed again. Explain why this would improve the accuracy.

1.6 Vectors and Scalars

Objectives:

- To know the difference between a vector and a scalar
- To know which variables are vectors and which are scalars
- To be able to add two vectors together

All physical quantities such as force and speed are either vectors or scalars. A vector quantity such as force has a physical size and direction. A force can act in different directions and hence is a vector quantity. A scalar quantity just has a physical size; hence speed, energy and time, which are all independent of direction, are scalar quantities. You must be able to identify all physical quantities as either vectors or scalars. Here is a helpful hint; if a quantity can have a negative value it is a vector.

Distance and Displacement

Distance can be defined as the total length travelled by an object; it has a physical size only and is therefore a scalar quantity. Displacement can be defined as the distance travelled from an objects starting point, it has a physical size and a direction and is a vector quantity. Imagine leaving this room walking to a shop and returning. The total distance travelled during this journey would steadily increase to a maximum of a few hundred metres when you arrived back in your seat. Your displacement would also initially increase whilst changing direction as you move, however as soon as you start to journey back your displacement would start to decrease until it reached zero when you returned to your seat.

Speed and Velocity

Speed can be defined as the 'rate of change' of distance.

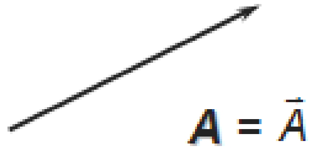
The term 'rate of change' tells us how quickly a quantity is changing; it is essentially the gradient of a quantity and usually means 'divide by time'. Speed only has a physical size and is therefore a scalar quantity.

Velocity can be defined as the rate of change of displacement.

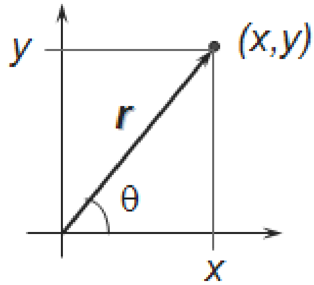
Velocity is a vector quantity as it has a physical size and a direction. Imagine two cars passing each other at 60 mph. Both cars have identical speeds but opposite velocities as the cars are moving in opposite directions.

Vector addition and subtraction

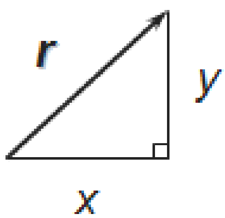
The two most common ways of showing that a quantity is a vector is boldface F or and arrow over the top of the quantity



If two vector quantities have the same direction we can simply add or subtract the magnitude of the two quantities to find the resultant. However, in most instances there is a difference in angle, we will use a simple coordinate system to represent each vector.



The magnitude of the vector r can simply be found from x and y using Pythagoras' theorem. The horizontal and vertical components of any vector can be found using basic trigonometry.



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

Example 6
Using a graphical method find the resultant magnitude of two vectors at right angles to each other if the magnitudes are 15 N and 25 N respectively. Compare with the Pythagoras approach.

Example 7

Find the magnitude and direction of two right angled vectors of sizes 4 N (horizontal) and 8 N (vertical).

Example 8

A force acts with 15 N at an angle of 30° from the horizontal. A second force acts in the opposite direction with a force of 25 N at an angle of 45° from the horizontal. Calculate the magnitude and direction of the resultant of the two forces.

1.7 Projectile Motion

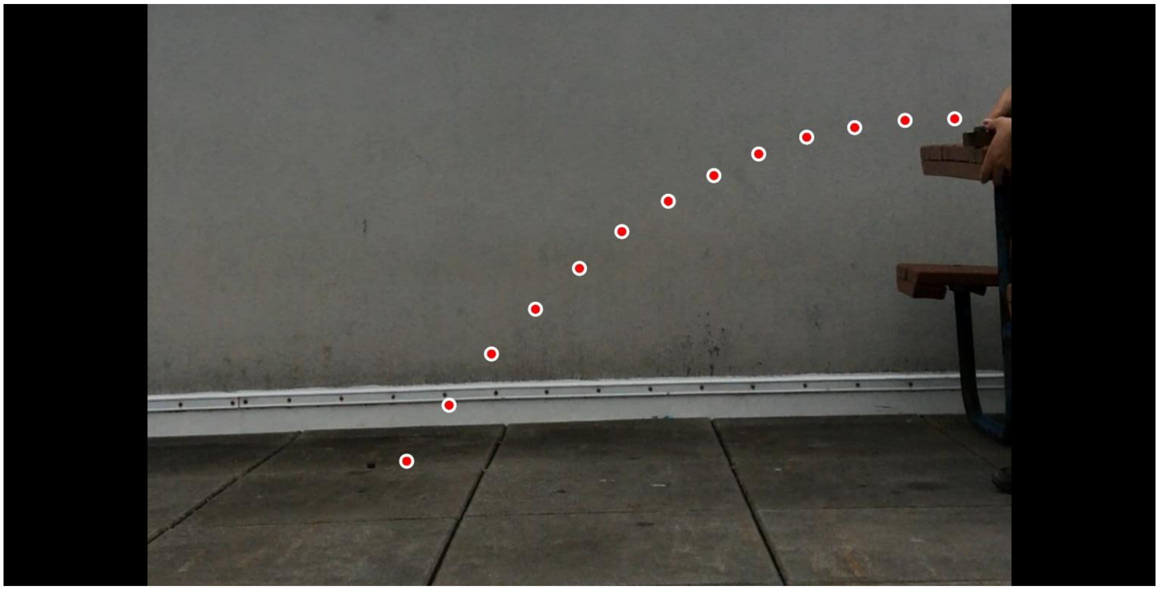
Objectives:

- To know that the time-of-flight for a projectile is the same as it would be if the object had no horizontal motion
- To be able to break motion at an angle into two perpendicular components
- To be able to use the above and trigonometry to solve simple projectile problems.

We can use the equations of motion to describe motion in more than one dimension – at AP level we limit ourselves to one or two dimensions. The motion of a projectile is common used – it was one of the first things analysed long ago as it was useful to predict the range of cannonballs in warfare!

In the absence of air resistance, a projectile follows a parabolic trajectory for the following reasons:

- The projectile accelerates downwards due to the pull of gravity
- The projectile moves at a constant velocity in the horizontal direction.



Above is a screenshot from VideoPhysics of an experiment carried out by the class of 2017.

1. Draw vertical lines at each dot to show that the horizontal motion is at a constant speed.
2. Draw horizontal lines across to show that the ball is accelerating downwards.

So if we take the horizontal and vertical components and treat them separately we can solve what looks like a complicated problem with relative ease. The key is that the time of flight in the vertical and the horizontal MUST be the same – it IS the same particle after all and Galileo worked out the motion of free fall.

Question: What is the key variable for all two-dimensional motion and why?

Demonstration: Describe the experiment with the two ball bearings and explain what it is demonstrates.

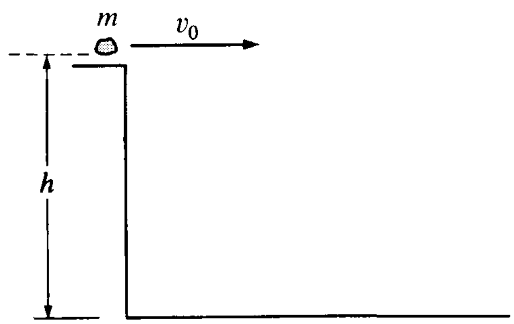
Example***

An aeroplane moving horizontally at 150 m/s releases a bomb at a height of 3500 m. The bomb falls to the ground and hits the intended target.

a) How long does it take for the bomb to reach the ground?

b) What was the horizontal distance of the plane from the target when the bomb was released?

Example ***



A rock of mass *m* is thrown horizontally off a building from a height *h*, as shown above. The speed of the rock as it leaves the thrower's hand at the edge of the building is v_0.

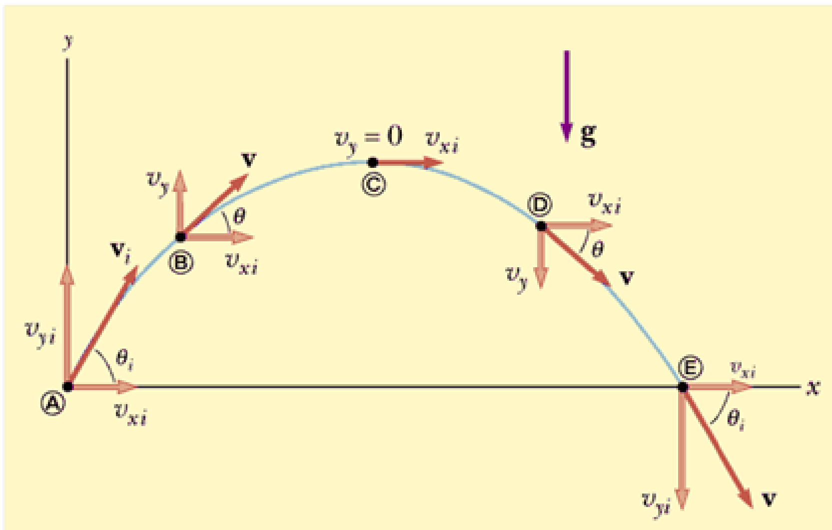
a) What is the rock's initial vertical velocity?

b) How long does it take the rock to hit the ground?

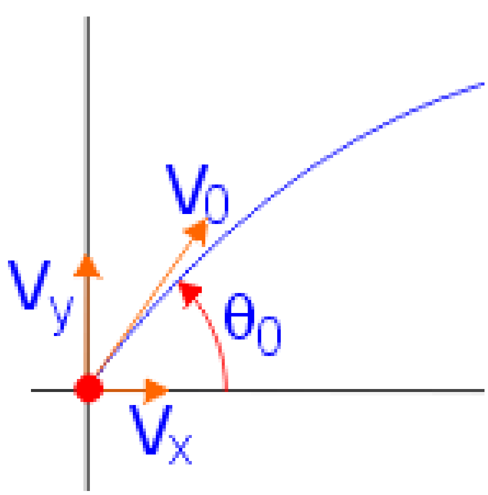
c) How far does the rock travel in this time?

d) What would happen if the rock was thrown off a taller building?

So what happens if we throw something up at an ANGLE? Now we move into the realm of requiring trigonometry! The first stage must always be to work out the vertical and horizontal components of the launch velocity. After that the basic concept remains the same: vertical motion undergoes acceleration due to gravity and the horizontal motion remains at a constant value.

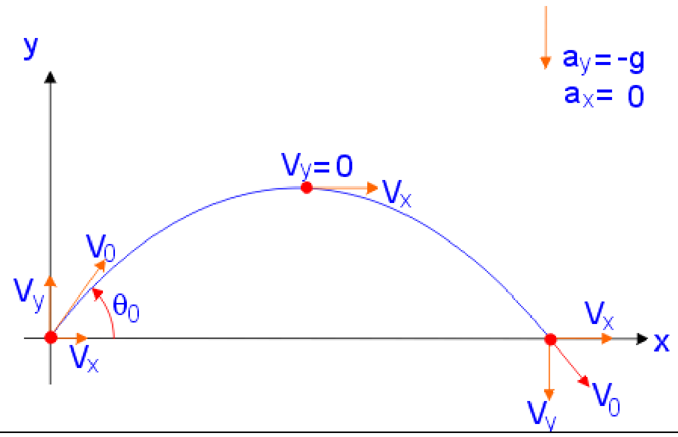


To calculate the components of the initial velocity:



Example 18

A ball is thrown upwards at an angle of 60° to the horizontal with a velocity of 15 m/s. Calculate the maximum height of the ball, the time taken to hit the ground, and the horizontal distance from the starting point when it reaches the ground.

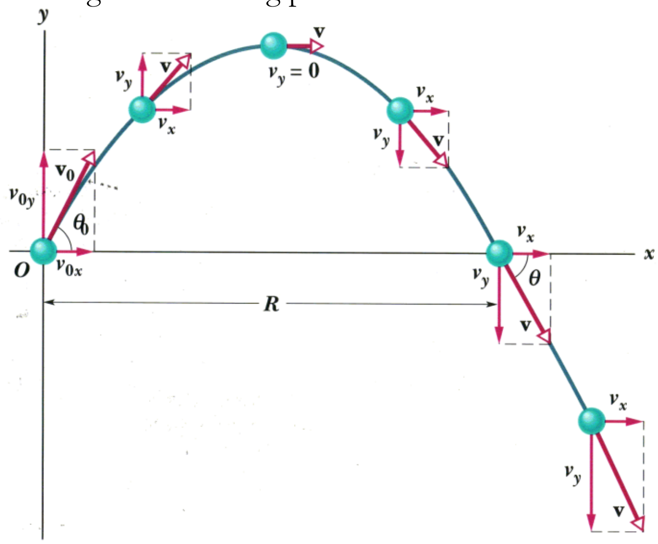


Upwards initial velocity =

Horizontal initial velocity =

Example 19

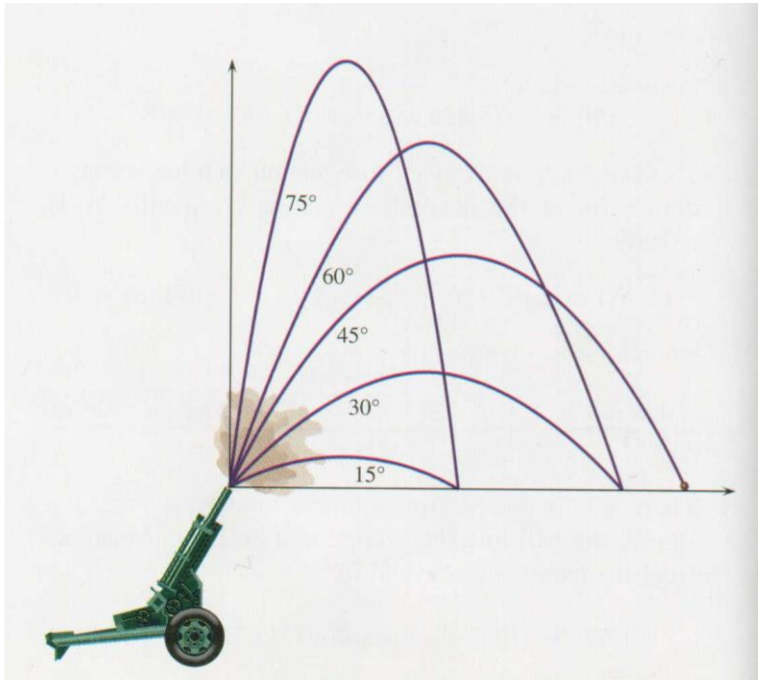
A ball is thrown from the top of a building with a velocity of 20 m/s and at an angle of 30° from the horizontal. If the launch point is 30 metres above the ground what is the horizontal distance from the building to the landing point.



Example 20

A home run is hit in such a way that the baseball just clears a wall 21 m high, located 130 m from the home plate. The ball is hit at an angle of 35° to the horizontal, and air resistance is negligible. Find (a) the initial velocity of the ball, (b) the time it takes the ball to reach the wall, and (c) the velocity components and the speed of the ball when it reaches the wall. (Assume that the ball is hit at a height of 1.0 m above the ground.)

Different angle – same range



Using the PhET simulation and your knowledge of physics – discuss the above diagram.

Additional notes:

LAB – Predicting the Range of a Ball Bearing.

Aim: To use the kinematics of projectiles to predict the range that a ball bearing launched horizontally from a bench will be.

Method:

1. Set up the spring launcher in a secure manner that will allow a ball bearing to be launched off the table horizontally. Catch the ball so that it does not hit the floor.
2. Set up a light gate and data logger at the point where the ball bearing leaves the table. Be sure to set the "length of the interrupt card" to be equal to the diameter of the ball bearing and that the diameter of the ball bearing cuts the light beam exactly.
3. Test at least 3 – 5 runs to ensure that a) the bearing is leaving the table at a consistent speed and b) you can obtain a meaningful average speed.
4. Use the kinematics equations of motion to predict the range of your ball bearing.
5. Make a large "pizza base" out of plasticine/playdoh and place on the floor where you think that the ball will land.
6. Test at least three times!
7. Analyse your results. What is the percentage error?
8. BONUS: use the video physics app to analyse the motion – especially the vertical acceleration!

Lab notes, data and analysis

LAB – Predicting the Range of a Ball Bearing Fired at an Angle!

Aim: To use the kinematics of projectiles to predict the range that a ball bearing launched at an angle from a bench will be.

Method:

1. Set up the launcher in a secure manner that will allow a ball bearing to be launched off the table at an angle of roughly 30°. Catch the ball so that it does not hit the floor.
2. Set up a light gate and data logger at the point where the ball bearing leaves the launcher. Be sure to set the "length of the interrupt card" to be equal to the diameter of the ball bearing and that the diameter of the ball bearing cuts the light beam exactly. Measure the angle.
3. Test at least 3 – 5 runs to ensure that a) the bearing is leaving the table at a consistent speed and b) you can obtain a meaningful average speed.
4. Use the kinematics equations of motion to predict the range of your ball bearing.
5. Make a large "pizza base" out of plasticine/playdoh and place on the floor where you think that the ball will land.
6. Test at least three times!
7. Analyse your results.
8. BONUS: use the video physics app to determine the vertical acceleration!

Lab notes, data and analysis

Assignment 1.1 - Converting to S.I. Units

A fundamental skill for this course is converting non-standard units such as mm^2 to S.I. units such as m^2. There are two main ways to correct these mistakes:

1. At the start of each problem list all the physical quantities you know in their given units and then immediately convert them to S.I. units.
2. When substituting numerical values into equations include the units in your substitutions, this should trigger your mind into remembering the conversions when calculating your answer.

To focus your minds upon this subject you will need to answer the questions on this sheet.

Conversions	**Prefixes**
1 cm = 1×10^{-2} m.	Giga 1×10^{9}.
1 cm^2 = 1×10^{-4} m^2.	Mega 1×10^{6}.
1 cm^3 = 1×10^{-6} m^3.	Kilo 1×10^{3}.
1 mm = 1×10^{-3} m.	Milli 1×10^{-3}.
1 mm^2 = 1×10^{-6} m^2.	Micro 1×10^{-6}.
1 mm^3 = 1×10^{-9} m^3.	Nano 1×10^{-9}.
1 g = 1×10^{-3} kg.	

Convert the following values to standard form quoting your answers to 3 s.f. with S.I. units.

1. 4.21 mm		11. 38.6 cm	
2. 21.7 mm		12. 12500 cm	
3. 137000 mm		13. 3.143 cm^2	
4. 50 mi/hr		14. 42.0 cm^2	
5. 37.4 mm^2		15. 5327491 cm^2	
6. 1230 mm^2		16. 2.47 cm^3	
7. 1.49 mm^3		17. 26.45 cm^3	
8. 140 km/hr		18. 35 km/hr	
9. 185 mm^3		19. 38 mg	
10. 9.981 cm		20. 2.94 μg	

Assignment 1.2 - Equations of Motion

$$\boldsymbol{v = v_0 + at}$$

$$\boldsymbol{x = \tfrac{1}{2}(v_0 + v)\,t}$$

$$\boldsymbol{x = v_0 t + \tfrac{1}{2}at^2}$$

$$\boldsymbol{v^2 = v_0^2 + 2ax}$$

The formulae in bold type are those that will be included on the formula sheets available in all examinations.

1. Calculate v given that $v_0 = 2$ ms^{-1}, $a = 10$ ms^{-2} and $t = 6$ s.
2. Calculate v_0 given that $v = 20$ ms^{-1}, $a = 2$ ms^{-2} and $t = 4$ s.
3. Calculate t given that $v = 100$ ms^{-1}, $v_0 = 20$ ms^{-1} and $a = 2.5$ ms^{-2}.
4. Calculate a given that $v = 2.5$ ms^{-1}, $v_0 = 0.5$ ms^{-1} and $t = 10$ s.
5. Calculate x given that $v_0 = 10$ ms^{-1}, $v = 60$ ms^{-1} and $t = 10$ s.
6. Calculate t given that $v_0 = 0$ ms^{-1}, $v = 3$ ms^{-1} and $x = 15$ m.
7. Calculate v_0 given that $x = 210$ m, $v = 110$ ms^{-1} and $t = 3$ s.
8. Calculate v given that $x = 1000$ m, $v_0 = 40$ ms^{-1} and $t = 10$ s.
9. Calculate x given that $v_0 = 2$ ms^{-1}, $a = 10$ ms^{-2} and $t = 4$ s.
10. Calculate t given that $x = 22.5$ m, $v_0 = 0$ ms^{-1} and $a = 5$ ms^{-2}.
11. Calculate a given that $x = 5$ m, $v_0 = 2$ ms^{-1} and $t = 2$ s.
12. Calculate v_0 given that $x = 500$ m, $t = 10$ s and $a = 10$ ms^{-2}.

Assignment 1.3 - Equations of Motion Problems

Read through examples 2.4 and 2.5 on page 37 of College Physics. For each of the problems there will be marks awarded for a detailed and labelled diagram. Ensure that working is clearly shown.

1. In 1865, Jules Verne proposed sending men to the Moon by firing a space capsule from a 220-metre-long cannon with final speed of 10.97 km/s. What would have been the unrealistically large acceleration experienced by the space travelers during their launch? Compare your answer to *g*.

2. A speedboat increases its speed uniformly from 20 m/s to 30 m/s in a distance of 200 m. Find (a) the magnitude of its acceleration and (b) the time it takes the boat to travel the 200-m distance.

3. A truck on a straight road starts from rest and accelerates at 2.0 ms^{-2} until it reaches a speed of 20 m/s. Then the brakes are applied, stopping the truck in a uniform manner in an additional 5.0 s. (a) How long is the truck in motion? (b) What is the average velocity of the truck during the motion described?

Read through example 2.7 on page 40.

4. A jet plane lands with a speed of 100 m/s and can accelerate at a maximum rate of -5.0 ms^{-2} as it comes to rest. (a) From the instant the plane touches the ground, what is the minimum time needed before it can come to rest? (b) Can this plane land on a small tropical island airport where the runway is 0.800 km long?

Read through example 2.9 on page 43.

Read through example 2.10 on page 44.

CHALLENGING QUESTIONS:

5. Two students are on a balcony 19.6 m above the street. One student throws a ball vertically downward at 14.7 m/s; at the same instant, the other student throws a ball vertically upwards with the same speed. The second ball just misses the balcony on the way back down. (a) What is the difference in the two balls' time in the air? (b) What is the velocity of each ball as it strikes the ground? (c) How far apart are the balls 0.800 s after they are thrown?

6. A ball is thrown upward from the ground with an initial velocity of 25 m/s; at the same instant, another ball is dropped from a building 15 m high. After how long will the balls be at the same height?

Assignment 1.4 - Harder Kinematics Problems

1. Create a table of results for an object accelerating at 10 ms^{-2} for 10 s taking a reading at one-second intervals, your table should include a column for velocity and a column for distance. Plot distance against time and velocity against time graphs for the motion of the object.

2. A particle, which is moving in a straight line with constant acceleration 2 ms^{-2}, is initially at rest. Find the distance covered by the particle in the third second of its motion.

3. A particle moving in a straight line with a constant retardation of 3 ms^{-2} has an initial velocity of 10 ms^{-1}. Find after what time it returns to its starting position.

4. A particle, which is moving in a straight line with constant acceleration, covers distances of 10 m and 15 m in two successive seconds. Find the acceleration.

5. A stone is fired vertically upwards from a catapult and lands 5 seconds later. What was the initial velocity of the stone? For how long was the stone at a height of 20 m or more?

6. A hot air balloon is 21 m above the ground and is rising at a rate of 8 ms^{-1} when a sandbag is dropped from the balloon how long does it take the sandbag to reach the ground?

7. A particle is projected vertically upwards at 30 ms^{-1}. Calculate (a) how long it takes to reach its maximum height, (b) the two times at which it is 40 m above the point of projection, (c) the two times it is moving at 15 ms^{-1}.

8. A stone is thrown vertically upwards at 10 m s^{-1} from a bridge, which is 15 m above a river. (a) What is the speed of the stone as it hits the river? (b) With what speed would it hit the river if it was thrown downwards with a velocity of 10 ms^{-1}.

9. A bus travelling steadily at 30 ms^{-1} along a straight road passes a car, which 5 s later, begins to move with a uniform acceleration of 2 ms^{-2} in the same direction as the bus. (a) How long does it take the car to acquire the same speed as the bus? (b) How far has the car travelled when it is level with the bus?

Assignment 1.5 – Projectile Problems

1. A peregrine falcon is the fastest bird, flying at a speed of 200 miles per hour. Nature has adapted the bird to reach such a speed by placing baffles in its nose to prevent air from rushing in and slowing it down. Also, the bird's eyes adjust their focus faster than the eyes of any other creature, so the flacon can focus quickly on its prey. Assume that a peregrine falcon is moving horizontally at its top speed at a height of 100 m above the ground when it brings its wings into its sides and begins to drop in free fall. How far will the bird fall vertically while traveling horizontally a distance of 100 m?

2. A tennis player standing 12.6 m from the net hits the ball at 3.00° above the horizontal. To clear the net, the ball must rise at least 0.330 m. If the ball just clears the net at the apex of its trajectory, how fast was the ball moving when it left the racquet?

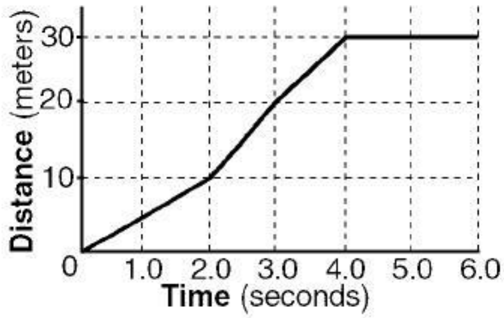
3. A brick is thrown upward from the top of a building at an angle of 25° to the horizontal and with an initial seed of 15 m/s. If the brick is in flight for 3.0 s, how tall is the building?

4. A fireman 50.0 m away from a burning building directs a stream of water from a ground-level fire hose at an angle of 30.0° above the horizontal. If the speed of the stream as it leaves the hose is 40.0 m/s, at what height will the stream of water strike the building?

5. A medium level bomber traveling horizontally at 200 m s^{-1} at an altitude of 6000 m would like to drop a bomb onto a target. How far in front of the target must the bomb be dropped for it to land on target.

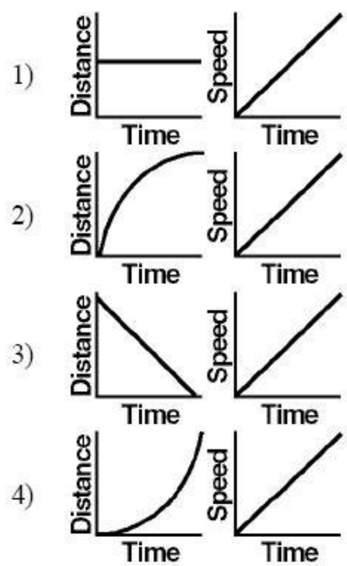
Assignment 1.7 - Graphing Motion Quiz

1. The distance-time graph below represents the position of an object moving in a straight line. What is the speed of the object during the time interval t = 2.0 seconds to t = 4.0 seconds?



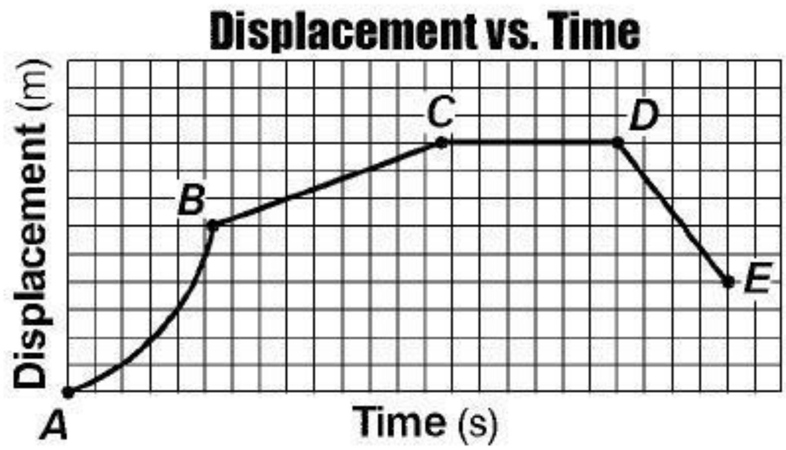
A. 10. m/s
B. 5.0 m/s
C. 0.0 m/s
D. 7.5 m/s

2. Which pair of graphs represents the same motion?



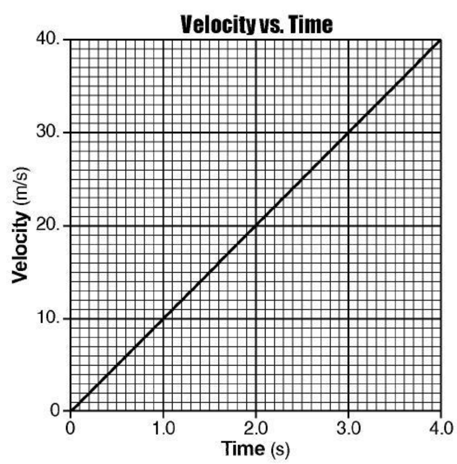
A. 1
B. 2
C. 3
D. 4

3. The displacement-time graph below represents the motion of a cart initially moving forward along a straight line. During which interval is the cart moving forward at constant speed.



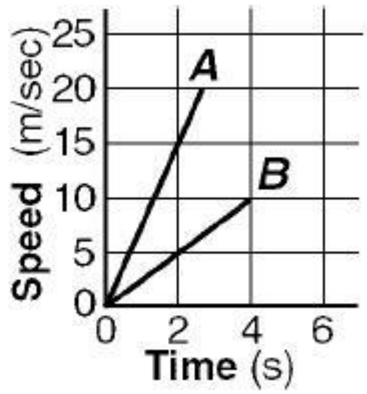
A. AB
B. CD
C. BC
D. DE

4. The graph below shows the velocity of a race car moving along a straight line as a function of time. What is the magnitude of the displacement of the car from t = 2.0 seconds to t = 4.0 seconds?



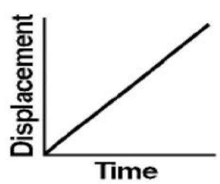
A. 80. m
B. 20. m
C. 60. m
D. 40. m

5. The graph below shows the relationship between speed and time for two objects, A and B. Compared with the acceleration of object B, the acceleration of object A is:



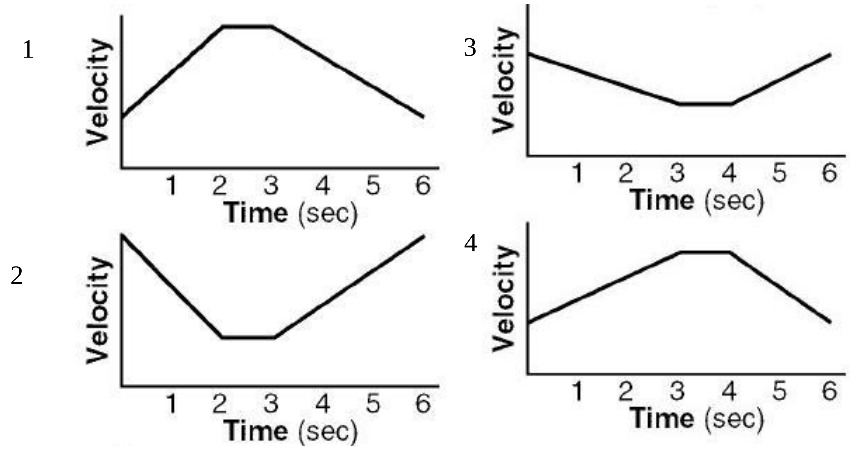
A. three times as great
B. the same
C. one-third as great
D. twice as great

6. The graph below represents the motion of an object. According to the graph, as time increases, the velocity of the object



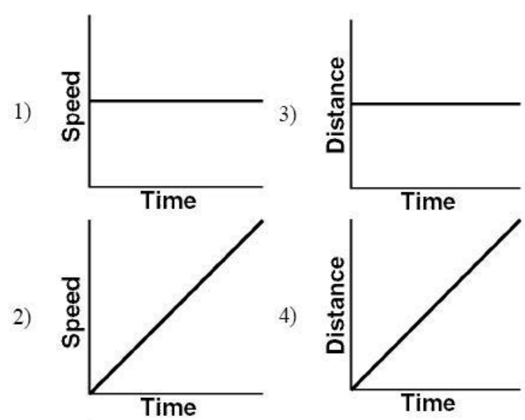
A. increases
B. decreases
C. remains the same

7. Which graph best represents the relationship between velocity and time for an object which accelerates uniformly for 2 seconds, then moves at a constant velocity for 1 second, and finally decelerates for 3 seconds?



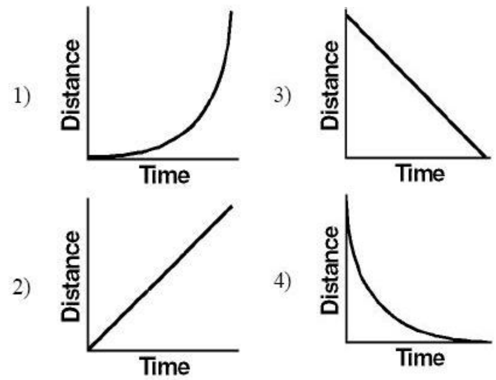
A. 1
B. 2
C. 3
D. 4

8. Which graph best represents the motion of an object initially at rest and accelerating uniformly?



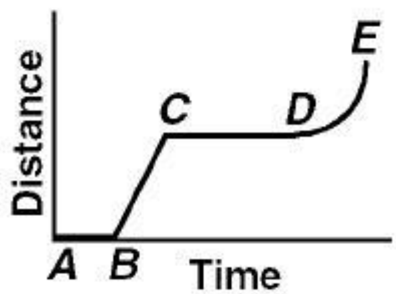
A. 1
B. 2
C. 3
D. 4

9. Which graph best represents the motion of an object whose speed is increasing?



A. 1
B. 2
C. 3
D. 4

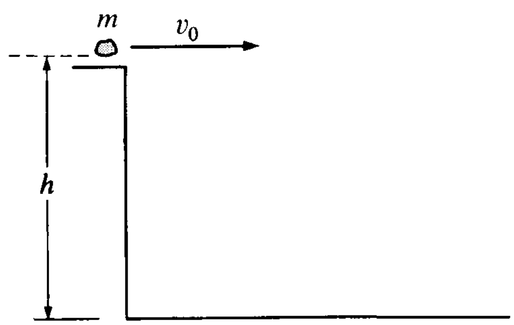
10. The graph below represents the relationship between distance and time for an object in motion. During which interval is the speed of the object changing?



A. CD
B. AB
C. BC
D. DE

AP STYLE QUESTIONS

Kinematics does not tend to be used on its own in the AP exam, but rather as part of a general question on Mechanics, Fluids or Electromagnetism… Therefore these questions are just to give some idea of the level that is required.

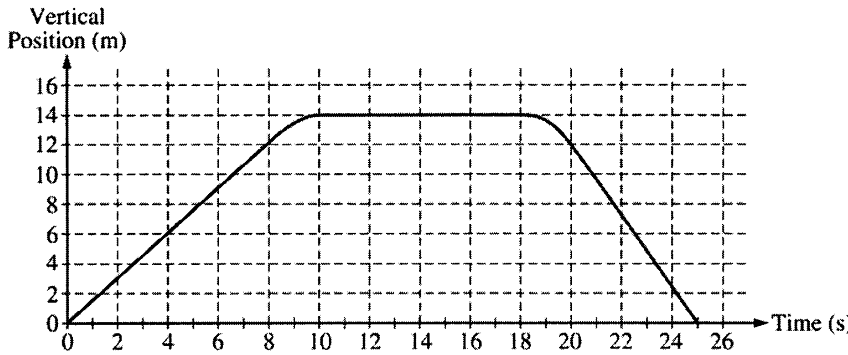


A rock of mass *m* is thrown horizontally off a building from a height *h*, as shown above. The speed of the rock as it leaves the thrower's hand at the edge of the building is v_0.

How much time does it take the rock to travel from the edge of the building to the ground?

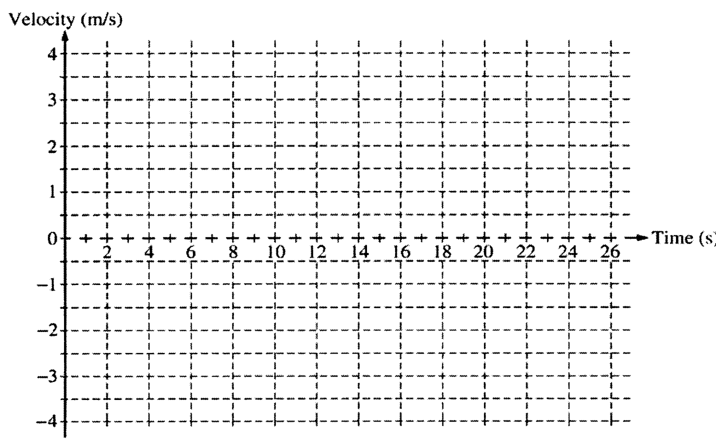
a. $\sqrt{hv_o}$ b. $\frac{h}{v_0}$ c. $\frac{hv_0}{g}$ d. $\frac{2h}{g}$ e. $\sqrt{2h/g}$

2005B1 (modified)



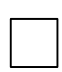
The vertical position of an elevator as a function of time is shown above.

a) On the grid below, graph the velocity of the elevator as a function of time.



b) i. Calculate the average acceleration for the time period t = 8 s to t = 10 s.

ii. On the box below that represents the elevator, draw a vector to represent the direction of this average acceleration.



A world-class runner can complete a 100 m dash in about 10 s. Past studies have shown that runners in such a race accelerate uniformly for a time *t* and then run at constant speed for the remainder of the race. A world-class runner is visiting your physics class. You are to develop a procedure that will allow you to determine the uniform acceleration *a* and an approximate value of *t* for the runner in a 100 m dash. By necessity your experiment will be done on a straight track and include your whole class of eleven students.

(a) By checking the line next to each appropriate item in the list below, select the equipment, other than the runner and the track, that your class will need to do the experiment.

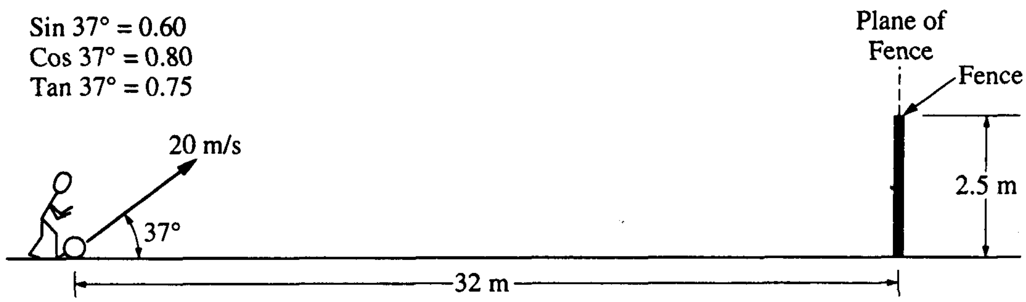
____Stopwatches ____Tape measures ____ Rulers ____ Masking tape

____Metersticks ____ Starter's pistol ____ String ____ Chalk

(b) Outline the procedure that you would use to determine *a* and *t*, including a labeled diagram of the experimental setup. Use symbols to identify carefully what measurements you would make and include in your procedure how you would use each piece of the equipment you checked in part (a).

(c) Outline the process of data analysis, including how you will identify the portion of the race that has uniform acceleration, and how you would calculate the uniform acceleration.

FR 2



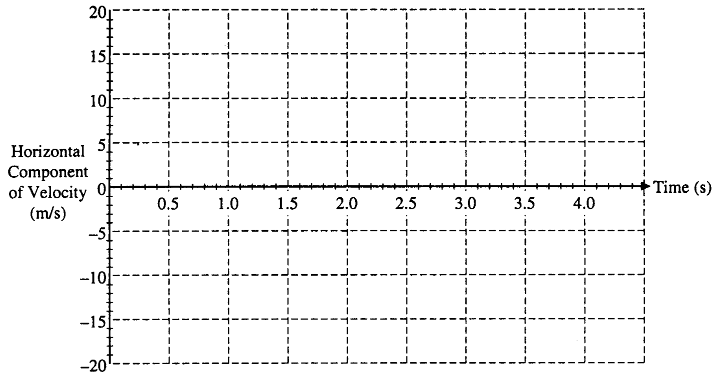
Note: Diagram not drawn to scale.

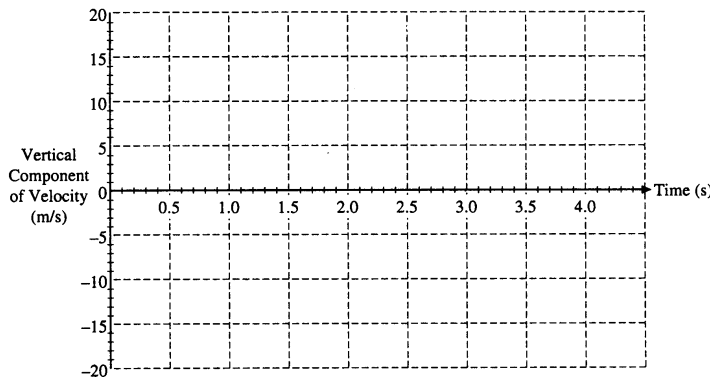
A ball of mass 0.5 kilogram, initially at rest, is kicked directly toward a fence from a point 32 meters away, as shown above. The velocity of the ball as it leaves the kicker's foot is 20 meters per second at an angle of 37° above the horizontal. The top of the fence is 2.5 meters high. The ball hits nothing while in flight and air resistance is negligible.

a. Determine the time it takes for the ball to reach the plane of the fence.

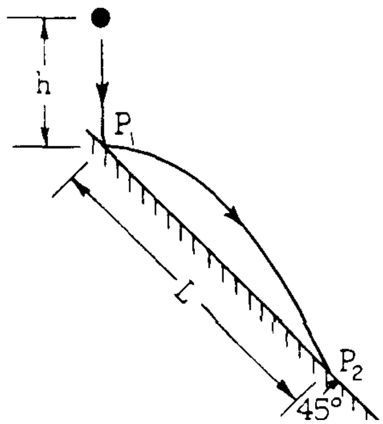
b. Will the ball hit the fence? If so, how far below the top of the fence will it hit? If not, how far above the top of the fence will it pass?

c. On the axes below, sketch the horizontal and vertical components of the velocity of the ball as functions of time until the ball reaches the plane of the fence.





FR 3 (difficult!)



A ball of mass m is released from rest at a distance h above a frictionless plane inclined at an angle of 45° to the horizontal as shown above. The ball bounces horizontally off the plane at point P_1 with the same speed with which it struck the plane and strikes the plane again at point P_2. In terms of *g* and *h* determine each of the following quantities:

a. The speed of the ball just after it first bounces off the plane at P_1.

b. The time the ball is in flight between points P_1 and P_2.

c. The distance *L* along the plane from P_1 to P_2.

d. The speed of the ball just before it strikes the plane at P_2.