

## Spreadsheet Assignment

*Motion of an object moving through a fluid*



*AS-level Physics  
Sixth Form Centre*

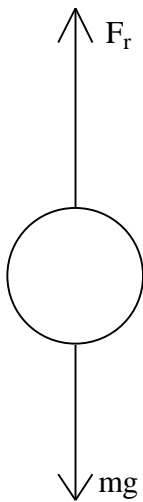
## Motion of an object moving through a fluid.

The equations of motion that we have used are only valid for motion in a straight line and where the force acting on the object is constant. If either of these two conditions is not true we can no longer use our linear equations of motion we have to use others or find suitable approximations. Most common day physical examples are situations where the force is not constant but changes with time and position.

For motion in 2D we have been able to split the motion into two parts and looked at vertical and horizontal components. Later we will look at circular motion and simple harmonic motion where we have to use different equations of motion.

In the problem that you are going to consider we are going to look at motion that still is in a straight line but one where frictional forces are no longer negligible. In these situations it is hard to write down a formula that tells us where an object will be after a given time (like  $s = ut + \frac{1}{2} at^2$ ). Instead we are going to use a spreadsheet to produce a speed-time graph and another graph of position against time that will enable us to discuss the motion of the object.

We can attempt to model the frictional force in several different ways, with our results we can then investigate experimentally which model is closer to the truth.



An object falling downwards under the effect of gravity will experience the force  $mg$  acting downwards and an upward force  $F_r$  caused by the resistive effect of the frictional force.

The resultant force acting on the object is  
 $mg - F_r$  acting downwards.

By Newton's second law this resultant force will equal  $ma$   
 Hence  $mg - F_r = ma$

The resulting instantaneous acceleration ( $a$ ) is  
 $a = g - F_r/m$

Our problem is to model how the resistive force behaves. We may suggest that the resistive force is larger the faster the object moves.

A simple model is to assume that the frictional force ( $F_r$ ) is directly proportional to the speed of the object ( $v$ ) and from this we can write  $F_r = kv$ . The constant,  $k$  is often called the drag coefficient.

The acceleration at a particular instant will therefore be given by  $a = g - kv/m$ .

Note that the acceleration changes with speed and we cannot use the equations of linear motion as such. It means that given an object's speed and position we cannot use  $v = u + at$  to find out its speed *several seconds later*.

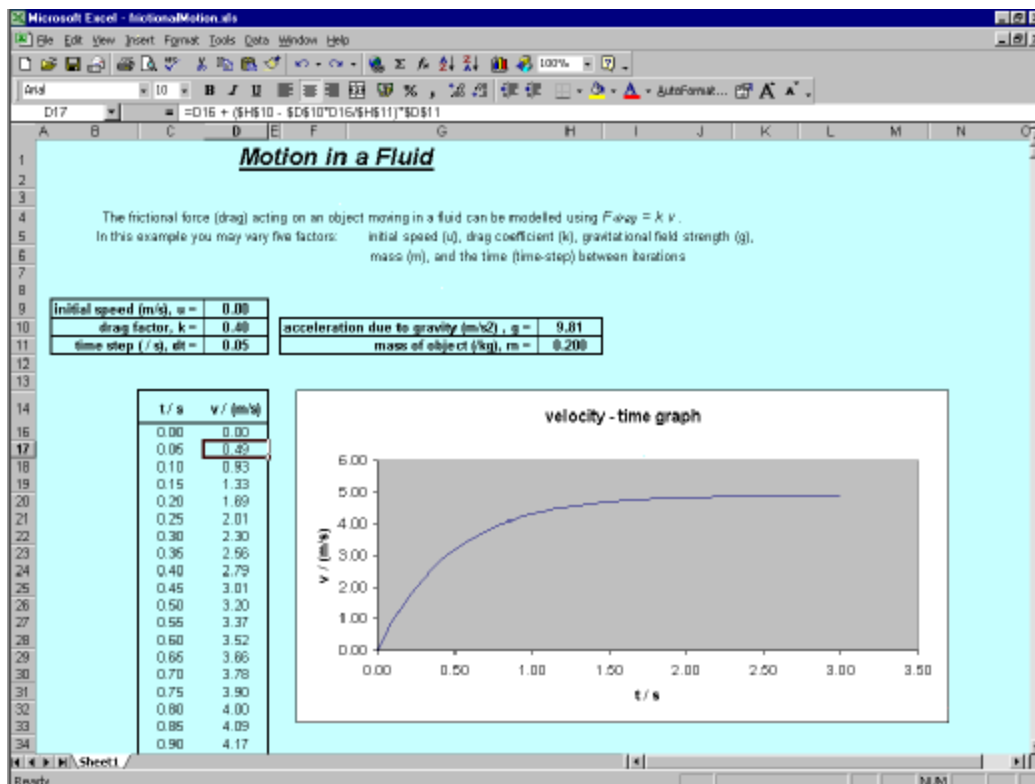
What we can do is to calculate the object's speed and position after a very short time over which the speed has hardly changed and the acceleration has been almost constant. Once we know its new position and speed we can continually make more calculations so that we can know where it will be after another very brief time.

A spreadsheet is very useful in doing hundreds of these calculations without any effort from us. What we make the spreadsheet do is as follows:

If we know the initial speed is  $u$ , its speed ( $v$ ) just a little later will be given by  $v = u + at$ . This will only be approximately correct but the smaller the value of  $t$ , the better will be our estimate for  $v$ .

Now  $v = u + (g - ku/m)t$  so all we need do is plug in our values of  $u$ ,  $g$ ,  $k$ ,  $m$  and  $t$  and our work is done. We then repeat the procedure a hundred times to see where it will be say a second later.

The diagram below is taken from frictionalMotion.xls which can be found on the CD and on the web-site.



Notice that the cell highlighted is D17. It represents the speed of the object 0.05 s after the object has begun to fall.

The formula used to calculate the value in the cell D17 uses the following

- D16 The initial value of the velocity (u) for the period of time being considered
- \$H\$10 The acceleration due to gravity (g). Note the use of the \$ signs these are used to ensure that when we drag down the cursor the contents of cell H10 are always used (this is called an absolute reference).
- \$D\$10 The drag factor(k). Also an absolute reference.
- \$H\$11 The mass (m) of the object.
- \$D\$11 The time interval (t) over which we calculate.

Note when we change the values of any of the above cells all the values change and the graph changes too.

Your assignment is to investigate and to extend this spreadsheet. (Please include your name in one of the cells.)

1. Produce a third column that allows you to determine the position (s) of the particle. Use the formula  $s = \frac{1}{2} (u + v)t$  to find the extra distance travelled.
2. Produce a second graph that is a position-time graph.
3. Produce a third graph with velocity (on the y-axis) and position (on the x-axis).
4. What determines how far an object moves before it reaches its terminal speed? Is the distance proportional to the initial speed of the object? Provide evidence.
5. Another model uses  $F_r = k v^2$  as its formula for the resistive motion of a particle through a fluid. Adapt the spreadsheet and obtain velocity-time and position-time graphs for the motion of an object falling through the fluid.
6. Compare the two models using identical objects falling with the same initial velocities. Provide copies of the graphs along with your comments.
7. How would you determine experimentally which of the two formulae for  $F_r$  more closely represents the motion of small spheres moving through glycerine .
8. Using the model you produced in part 5 deduce a reasonable value for k for a human being freefalling through air given that the terminal speed is around  $80 \text{ km h}^{-1}$ , their mass is 75 kg and g is  $9.8 \text{ m s}^{-2}$  . Does it matter what the initial speed was?
9. Comment on the benefits of using a spreadsheet for this work compared to calculating and drawing the graphs by hand.