Physics coursework: data analysis

ASSIGN BUSTER

The experiment consisted of recording the results of a small toy car being allowed to roll down a ramp and then leave the end of the ramp by continuing straight off the drop from the end of the desk. I measured the ramp's length, the height of the ramp, and the distance it covered horizontally. I also measured the mass of the car. It was necessary to measure these things so that I can perform calculations later. All of the information I gathered can be seen in the diagram below.

To get the results, I will attach ticker tape to the back of the car, so the car will pull the ticker tape through the machine as it moves, and therefore create a dot on the piece of ticker tape every 0. 2 seconds. When I come to analyse this, I will obviously not use every point, I will use probably every one point in five

Predictions

I think that the car is going to gradually accelerate as it goes down the ramp, therefore gradually gaining speed as it goes down. Then the car will accelerate even more as it drops off the end of the ramp and the friction from the ramp will no longer be present. Although there will still be air resistance, the friction from the ramp will be gone, and only friction from the air and from the ticker tape will be present. If we were to assume no resistance, the car's acceleration would go up to about 9. 8ms-2 (although this value for gravity is not exact, gravity varies so much in different areas of the Earth that it is hard to get an exact value, 9. 8 is judged to be close enough). So the acceleration time graph will probably look like the one below:

You may wonder why the acceleration will only go up to 9. 8, or close to, when the car goes off the end of the ramp, after all, gravity was acting upon the car before this time wasn't it?

The acceleration will only go up to gravity – drag when there is no force acting upon the car in a vertically upwards direction.

Ie, the forces on the car will be as follows:

All these predictions assume that

" F = ma"

which is Newton's second law of motion.

We can see that, when the car is on the ramp, there is a force from the ramp stopping the car from going directly downwards; however, gravity is still affecting the car. Nevertheless, the gravity can only act directly downwards on the car, not parallel to the slope, so most of the acceleration due to gravity is cancelled out by the drag.

We can easily work out how much gravity will effect the car as it goes down the slope as we have the horizontal length and the vertical height and can therefore work out the angle the ramp is at. If we take the sin of the angle and multiply it by the mass of the car multiplied by the acceleration due to gravity, we get the total force acting down the ramp due to gravity. From this we can get the acceleration of the car down the ramp by dividing by the mass. Now we know this, we can actually find out how long the car would spend on the ramp, and how long it will take to fall to the ground using suvat equations. However, this all still assumes no drag or friction of any kind, which is obviously impossible, but it will tell us how much friction and drag there is present.

To find the acceleration on the ramp we must first find the angle it is at.

To find the angle ? we must use trigonometry.

We know:

Tan ? = 0. 320/1. 608

So Tan-1 (0. 320/1. 608) = ?

Therefore ? = 11. 255ï¿½

To find the acceleration on the car due to gravity we do sin? x the normal acceleration due to gravity.

So:

Acceleration = sin 11. 255 x 9. 8

Acceleration = 1. 9m/s (2 sf)

We can also find out how long the car would spend on the ramp, and the time that it would take to hit the ground after leaving the ramp. We know the length of the ramp, and we know the acceleration and initial speed of the car, so we can work out how long the car would take to go down the ramp, and fall to the ground below.

We work out the length of the ramp using Pythagoras’ Theorem:

Length2 = 0. 3202 +1. 6082

Length = V(0. 3202 +1. 6082)

Length = 1. 639m

To find the time the car spends on the ramp, we use the equation s = ut + 1/2 at2

So, if there were no friction, the car would take 1. 3 seconds to get to the end of the ramp. We can also find out how long the car will take to fall to the ground after it has left the end of the ramp. And we can use a similar method for this, however there is the added complication that the car already has a velocity when it leaves the end of the ramp, and even more complicated, it is not heading in a horizontal direction. So first we must find its velocity, split it into the horizontal and vertical components, and then find from there what speed it will be heading down at when it leaves the ramp.

To find the velocity we use v = u + at.

v = 0 +1. 9 x 1. 3

this gives us v = 2. 47 ms-1

However, we must remember that this velocity is heading towards the floor at 11. 255ï¿½. Therefore to find the vertical velocity, assuming down in positive, we do

Velocity down = Speed x sin 11. 255

V vertically = -0. 48 ms-1

Velocity horizontally = Speed x cos 11. 255

V horizontally = 2. 24 ms-1

We find when the car hits the floor using s = ut + 1/2 at2 again. This time we use the height as 0. 850 as that is the height of the desk, and we have an initial velocity of 0. 48 m/s and an acceleration of 9. 8 m/s/s. This makes the equation more complicated as we will have to solve a quadratic equation this time, and we cannot take out a factor of t.

If we know the time, we can also find the horizontal distance the car should travel off the end of the ramp before the car hits the ground. However, the assumptions we have made throughout these calculations will probably have multiplied up to mean that the result is probably out by a great amount.

s = ut + 1/2 at2 can be used again, however, as there is no acceleration or deceleration in the horizontal direction all we need to do is calculate the initial speed as the car leaves the ramp multiplied by the time. The time is 0. 37 and the initial velocity is 2. 24 ms-1.

so s = 2. 24 x 0. 37

and s = 0. 83

We can conclude from this that the car should travel 0. 83 m past the end of the ramp before it hits the ground, we will be able to compare this to the actual answer later.

However, velocity, time, acceleration and distance are not the only things which we need to consider. We must also look at the motion of the car in terms of energy. This will provide us with another way of finding the theoretical speed of the car at any stage, and will also tell us the total energy exerted during the car's movement down the ramp, and onto the floor. We already know that there are large resistances coming into play, so now we can find out the amount of wasted energy produced, i. e. energy, which does not cause the movement of the car.

We can use 2 equations involving energy, these are E(Potential) = mgh, and E(Kinetic) = 1/2mv2. Where m is the mass, h is the height and g is the strength of gravity. v is the velocity

As we know the height that the car is starting at, and we can assume that the height it finishes at is zero (as the potential energy equation can be used to find energy exerted with a change of height), we can calculate all the energy converted from potential in the car's journey to the floor.

The Raw Data

To produce the graphs, I will use the measurements taken from the ticker tape. The ticker-tape is marked with dots every 0. 02 seconds, and when measuring these, I recorded every 5th point, so every one of my results is a measurement 0. 1 seconds from the last piece of data. If I had recorded every single point I would have had about 150 pieces of data, as the car took just under 3 seconds to complete its journey.

Once I had these pieces of data, I decided to plot them in a table in chronological order with the distance from the last point, and the cumulative distance along side. Using these pieces of data, I could form a very accurate picture of the data, as I had 10 results for every second of travel (assuming the ticker to be accurate).

Error Bounds

The fact that all the data comes from the same source means that the results are quite prone to error. We had to derive the acceleration and the velocity of the car at each point using all the same data, and this means that any original errors are magnified throughout the calculation process. The original results were recorded using a ruler with an accuracy of 0. 5 mm, or rather 0. 0005m, so the distances all have error bounds of 0. 0005m. This value does not seem very significant at first glance, but this error is magnified by the calculation process. The maximum original error is taken away from the actually value, then we apply the same rules, divide by the time, and then use the same rule we previously used to calculate the acceleration.

This means that the 0. 0005 m out in the distance error is magnified up to 0. 05 ms-1 in the velocity error and then, magnified right up to 0. 5 ms-2 in the acceleration error, a factor of 100 times. This means we must put error bars on the graphs to show this, and we must seriously consider these errors during calculation and observation of the graphs. These bars have been placed on all the graphs, even though on the first two graphs they are barely visible. To counter the problem of error bounds, we could reduce the number of decimal places that the results are left to, however, because all the results would be incorrect by the same margin, it is not such a problem, and any results which appear too anomalous can be ignored when drawing lines of best fit.

The Table of Results

On the page below the table of results can be seen, however, first I feel it is necessary to explain the columns in the table.

Total time elapsed: The time in seconds is the total cumulative time in seconds so far. So the total amount of time that has passed since the car started to move down the ramp.

Distance from previous point: This is the distance that the car had travelled from the previous point on the tape. So the distance travelled in the last 0. 1 seconds.

Cumulative Distance: This is the total distance travelled so far by the car starting from t = 0 up to the present time.

Instantaneous Velocity: This is calculated by dividing the distance from the previous point by the difference in time from that point, which in this case is always 0. 1 seconds.

Instantaneous Acceleration: This is the change in velocity during the previous time interval, calculated by dividing the current velocity minus the previous velocity, by the time difference between the two velocities, which again, is always 0. 1 seconds.

This information is also shown in the table below.

time in seconds

distance from previous time’s distance in meters

cumulative distance in meters

instantaneous velocity in meters/second

instantaneous acceleration

= previous value + 0. 1

= current cumulative – last cumulative

= previous value + distance from last value

= distance for last 0. 1 seconds / 0. 1

= (current instantaneous velocity – last instantaneous velocity) / 0. 1

Total time elapsed

(secs)

Instantaneous distance (m)

(ï¿½0. 0005m)

Cumulative distance (m)

(ï¿½0. 0005m)

Instantaneous velocity (ms-1)

(ï¿½0. 005 ms-1)

Instantaneous acceleration

(ï¿½0. 05ms-2)

0. 00

0. 000

0. 000

0. 00

0. 10

0. 008

0. 008

0. 08

0. 80

0. 20

0. 018

0. 026

0. 18

1. 00

0. 30

0. 027

0. 053

0. 27

0. 90

0. 40

0. 035

0. 088

0. 35

0. 80

0. 50

0. 043

0. 131

0. 43

0. 80

0. 60

0. 052

0. 183

0. 52

0. 90

0. 70

0. 057

0. 240

0. 57

0. 50

0. 80

0. 064

0. 304

0. 64

0. 70

0. 90

0. 070

0. 374

0. 70

0. 60

1. 00

0. 076

0. 450

0. 76

0. 60

1. 10

0. 081

0. 531

0. 81

0. 50

1. 20

0. 083

0. 614

0. 83

0. 20

1. 30

0. 090

0. 704

0. 90

0. 70

1. 40

0. 092

0. 796

0. 92

0. 20

1. 50

0. 095

0. 891

0. 95

0. 30

1. 60

0. 097

0. 988

0. 97

0. 20

1. 70

0. 099

1. 087

0. 99

0. 20

1. 80

0. 102

1. 189

1. 02

0. 30

1. 90

0. 103

1. 292

1. 03

0. 10

2. 00

0. 105

1. 397

1. 05

0. 20

2. 10

0. 107

1. 504

1. 07

0. 20

2. 20

0. 110

1. 614

1. 10

0. 30

2. 30

0. 117

1. 731

1. 17

0. 70

2. 40

0. 141

1. 872

1. 41

2. 40

2. 50

0. 208

2. 080

2. 08

6. 70

2. 60

0. 293

2. 373

2. 93

8. 50

2. 70

0. 300

2. 673

3. 00

0. 70

Interpretation

We can start to observe and understamd the ideas and predictions discussed earlier when we look at the sources of data gathered, the table and the graphs, and we can really start to put together an accurate picture of the car’s motions down the ramp, and free-falling to the ground. I hope to explain and demonstrate what was happening in the paragraphs below.

The dimensions we have already, those of the height of the desk, the distance the car travels, the height and length of the ramp itself can be compared to the data in the tables. These can be seen again in the diagram below:

Earlier we calculated, using trigonometry, Pythagoras’ Theorum, and various suvat equations, the various distances that we would expect the car to travel. Now we will be able to look back at these values, and using the fixed dimensions of the ramp and desk, be able to compare the actual values to the estimations that we made earlier.

The graphs all show different things. The first graph, the distance against time graph is the graph that is plotted directly from the measurements made. The second graph is a velocity time graph, this shows the gradient of the distance time graph. The final graph is the acceleration time graph and that shows the gradient of the distance time graph. Overall, the second graph is the differential of the first and in turn, the third graph is the differential of the second, or the double differential of the first.

Motion while the Car is on the Ramp

We can easily obtain the time at which the car leaves the end of the ramp because we know how long the ramp is, and using the table of results, we can find where the ticker tapes' dots reach that length. The length of the ramp is 1. 64 m (to 3sf) which we calculated earlier by Pythagoras' Theorum. The car has travelled 1. 64 m when the time is just over 2. 2 seconds. When we look back, this figure seems remarkably large, as the figure we acquired earlier was only 1. 3 seconds (to 2sf) and we can start to see the forces which must be against the car's motion down the ramp to cause it to almost take double the time that it would assuming no resistance to motion.

When we look at the time on the graphs, the time 2. 2 seconds is when we can see that the car starts to accelerate much more, and to confirm this, the velocity also begins to increase. This was expected because the car is obviously going to be more affected by gravity when it leaves the ramp and starts to freefall.

The actual motion of the car is now quite easy to describe. By looking at the graphs we can see that while on the ramp ($0 < t < 2.2$) the car is accelerating, which is expected. As it continues along the ramp, the car's acceleration decreases to quite close to zero and the car's velocity hits the highest speed on the ramp at about 1. 1 ms-1. This can be seen on the graph as the gradient of the velocity graph appears to decrease all the time, and it is even more obvious on the acceleration time graph where the car's acceleration can be seen to be decreasing throughout its journey.

Motion while the Car is in Freefall

This is where the analysis of the graphs and tables becomes more complicated. Because of the nature of the points, it is hard to tell when the car actually finishes this part of the motion, in fact, according to the graphs and tables, the car never stops accelerating. For the moment, I am going to make the assumption that the car stops just after the final result in the tables. The reason for my making this assumption is that I know the car did stop, and that the car must have stopped within 0. 08 seconds of the end of the results, however, these results were missed in the sampling because they were the last 4, or possibly less results. The time I am going to assume the car stopped at is 2. 74, as this is the middle value, and therefore the answer that would give us the least inaccuracy given either the top or bottom possible values.

This section is also more complicated because of what we assume about the ticker tape. We assume that the ticker tape will follow the path of the car exactly, when actually, the ticker tape is much more likely to take a straighter path while the car takes its parabolic path, this can be seen in the diagram to the left.

We can see that when the car lands, the ticker tape will be stretched the shortest distance while the car will have taken a much longer route on the parabola. This means we can actually find when the car should hit the floor, and we do not need to make any assumptions about missed results.

This calculation provides us with the knowledge we need to find out where the car actually stopped, or rather, to get a much better idea of where the car actually stopped. By looking in the tables where the value is 0. 911 m + 1. 639 m. So, where the value of the cumulative distance is 2. 55 m (to 3sf), the car will hit the floor for the first time. It turns out that this is actually before the final result that we have, and that if we had continued to assume that the car had landed after the last point, we would have been assuming something which was incorrect.

Now we can look at the graphs to give ourselves an even better estimate. If we draw a line across where the distance will equal 2. 55m, we can find an even more accurate time for the time the car lands, and you can see I have done this on the graph. This gives us a value for the landing time of 2. 65 seconds

The Last Point

You may have noticed that so far I have not explained why there is an extra point at the end of the graph. This point will be present because, at the end of the drop, the car does bounce. And it would appear that this point is after the bounce, and is the point when the car has lost most of its velocity, and then speeds up again coming down from the bounce. Either this, or possibly the car may just still be accelerating for one more 0. 1 of a second before it slows down to a halt.

What we would really have expected here was a huge deceleration as the car hits the ground and loses all its velocity, however this is not the case, and so we must try and make the best guess as to what happens here. Although the aforementioned motions are possible, neither is certainly correct, and the result may be completely wrong because of it being some form of anomaly. I will try to explain some possibilities for this in an evaluation further towards the end of the report.

Analysing the Overall Motion

It is now time that we look back over the calculations we did earlier, and find how accurate the predictions were, and consider the overall motion compared to the figures we obtained earlier. We will be able to compare times, velocities, accelerations, distances, and energies, and I am going to start with the times.

Firstly, we can compare the accelerations. The theoretical acceleration, taking into consider no resistance force, was 1. 9 ms-2 (2 sf), however, if you look at the acceleration down the slope for the real car, it is a lot less that this. (I have taken the average because the earlier equations assumed constant acceleration.) The fact that the acceleration decreases from about 0. 9 right down about 0. 1 or 0. 2 shows that the resistance from either the slope or the ticker tape must be increasing. And, as the slope’s surface was almost the same roughness all the way down, it is more likely that the ticker tape was pulling back the car as it moved further down the slope. Overall, the average acceleration on the slope was 0. 5 ms-2, a whole 1. 4 ms-2 lower than I expected, and this means that the average resistance force can be calculated.

This shows how much resistance is present on the ramp, but we can work out how efficient the system is as a whole, including both the time on the ramp, and the time the car spent falling. We know the final velocity, and how much energy was changed from potential, now we can find out how much of the energy was actually used in moving the car, and not wasted in heat, sound, and other wasted energy.

This supports what has been said above, but shows that the car has a more efficient end of its journey that at the beginning. The system up to the end of the ramp was only 27% efficient whereas when over the whole distance was actually 38% efficient, and the only change is the resistance of the ramp being lost when the car enters freefall. The ramp is clearly more resistant that I had assumed earlier, but still probably not as much hinderance to the motion of the car than the ticker tape was.

Another thing we can look at is the freefall motion itself. We know that there was no acceleration on the motion of the car in the horizontal direction when the car came off the end of the ramp, the only way the car could decelerate was to lose its velocity by air resistance and by the drag from the ticker tape.

Overall, it is obvious that the predictions were wrong, and for obvious reasons. In the suvat equations we used earlier, the first major fault was that in the actual experiment, the acceleration was not constant, the one necessary factor for the suvat equations to work. The reason the acceleration wasn’t constant was because there was a constantly increasing force upon the car. And the reason for this was that the ticker tape was getting longer and becoming more of a mass for the car to pull down.

Another reason for the resistance to be present, even if it did not increase by very much throughout the experiment was that the car was suffering from the friction of the ramp, something that would seriously affect the car due to it having such a small mass. It was clear that this was a significant factor, because as soon as the car left the ramp, the efficiency of the motion of the car went up to a much higher value.

Evaluation

It is necessary to evaluate the experiment, as it was by no means a perfect model of motion down a ramp, and freefalling to the ground. There were certainly some places where the experiment was lacking in accuracy and where we could have improved, and there were also some accuracy lacking areas which we couldn’t improve either without significantly better equipment, or not at all.

The first area to highlight is the car. This was the place where most of the inaccuracies were caused. The car certainly had friction occurring in the wheels of the car, and with the surface it was going down. However, this is one of the places where it is impossible to completely solve the problem. We could have found a better car with better bearings in the wheels and more therefore less friction, causing less wasted energy through sound and heat. But a frictionless car is impossible, and therefore it is impossible to completely solve this problem.

The other problem with the car was that for the experiment, it did not actually go exactly in a straight line, however, we could have solved this problem with another car. The problem was that the wheels of the car themselves were not exactly in a straight line, and it would certainly have been possible to find a car with better wheels, and this too would have helped to get more accurate answers.

The ticker-tape raises some questions too, as I explained earlier, the ticker-tape almost certainly did not follow the path of the car as it was being dragged. It would be much more likely that the car took a parabolic route off the end of the ramp, and the ticker-tape took a much more direct route, and although I have taken that the straight route is correct, it is hard to be sure that the ticker-tape did behave as I think it did.

To get even more accurate results, there is perhaps one more thing I could have done, I could easily have measured the dots on the ticker tape every 2, 3, or even 4 dots. This would have made the results much easier to interpret, even if it would increase the number that I would need to plot and analyse.