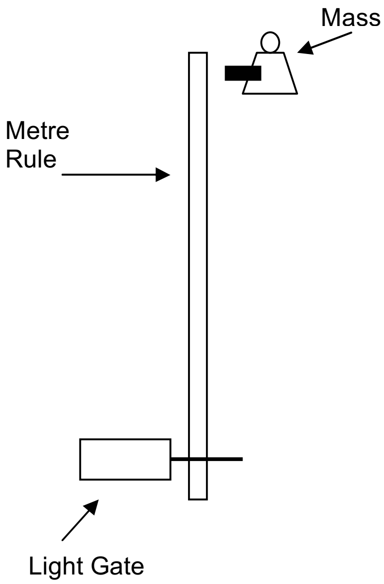
AS Physics Coursework – Making Sense of Data

An experiment was carried out in which the velocity of a falling mass was measured using a light gate:



A 0.5 kg tapered hexagonal section block with a ring on top was dropped from rest, at a variety of distances, and its velocity measured as it passed through a light gate. The mass had 20mm wide metal strip attached at its centre using blue tack, which was used to break the beam of the light gate – thus making the total mass of the falling object 0.516kg.

The mass was dropped 3 times from each height in order to highlight any anomalous results and allowing investigation of accuracy - and therefore reliability. Before being released it has gravitational potential energy, which is transformed largely into kinetic energy upon release. I plan to explore this further.

The results obtained also allow the calculation of acceleration, which, as the object is in freefall, should be equal to that of gravity.

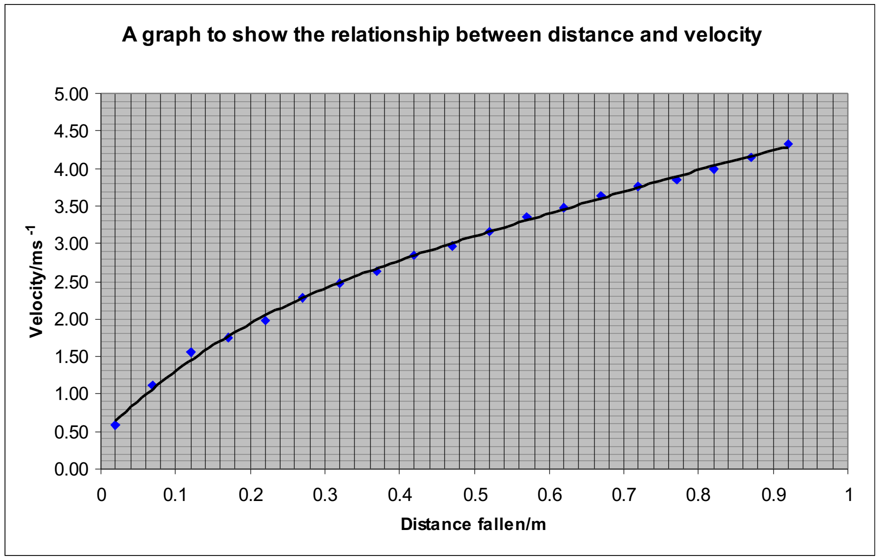
The results are shown in the table below:

Height Above Light Gate (mm)	Velocity #1 (m/s)	Velocity #2 (m/s)	Velocity #3 (m/s)
20	0.61	0.62	0.51
70	1.12	1.11	1.10
120	1.52	1.62	1.50
170	1.76	1.72	1.79
220	1.93	2.03	1.99
270	2.26	2.28	2.30
320	2.45	2.50	2.46
370	2.62	2.67	2.63
420	2.84	2.80	2.89
470	2.96	2.97	2.99
520	3.18	3.13	3.20
570	3.30	3.44	3.34
620	3.53	3.53	3.40
670	3.62	3.64	3.67
720	3.84	3.62	3.83
770	3.86	3.84	3.83
820	4.03	3.97	3.99
870	4.18	4.12	4.14
920	4.36	4.41	4.20

Provided with these results I have initially decided to look at any relationship between the actual figures collected, with the plan of calculating and exploring further data later.

I am therefore looking at the relationship between the distance the object fell, and its velocity as it passed through the light gate. An average of the velocities measured in each experiment has been calculated and the height at which the weight was dropped has been multiplied by 1000 to convert it to metres. I have created a graph of these values.

Distance fallen /m	Average Velocity/ ms^{-1}
0.02	0.58
0.07	1.11
0.12	1.55
0.17	1.76
0.22	1.98
0.27	2.28
0.32	2.47
0.37	2.64
0.42	2.84
0.47	2.97
0.52	3.17
0.57	3.36
0.62	3.49
0.67	3.64
0.72	3.76
0.77	3.84
0.82	4.00
0.87	4.15
0.92	4.32



I added a curved line of best fit to the graph, showing positive correlation between the distance fallen and the velocity of the object as it passed through the light gate. The line is curved until about 0.3 metres but then becomes more linear, which would be expected if acceleration due to gravity is constant – as a straight line shows constant acceleration. The velocity values from smaller distances appear to be anomalous, suggesting some error involved in the experiment. This could be because any errors in height make up a larger proportion of the overall distance the mass had fallen when dropped from lower heights.

Due to the fact that the object seems to be moving with a constant acceleration I have next decided to explore this value acceleration of the falling mass due to gravity. I believe this figure will be most accurately obtained through graphical methods by working out the gradient of a line of best fit, as fluctuations/slightly anomalous points (and therefore error) have been reduced over the large range. I plan to use two different graphs whose gradient is equal to acceleration in order to verify the answer.

The simplest graph where the gradient is equal to acceleration is a velocity-time graph. I therefore must calculate time from the results by using the equation:

Speed=distance/time

rearranged to:

Time= speed/distance

However this formula requires the use of the average velocity throughout the whole fall, change in velocity divided by 2:

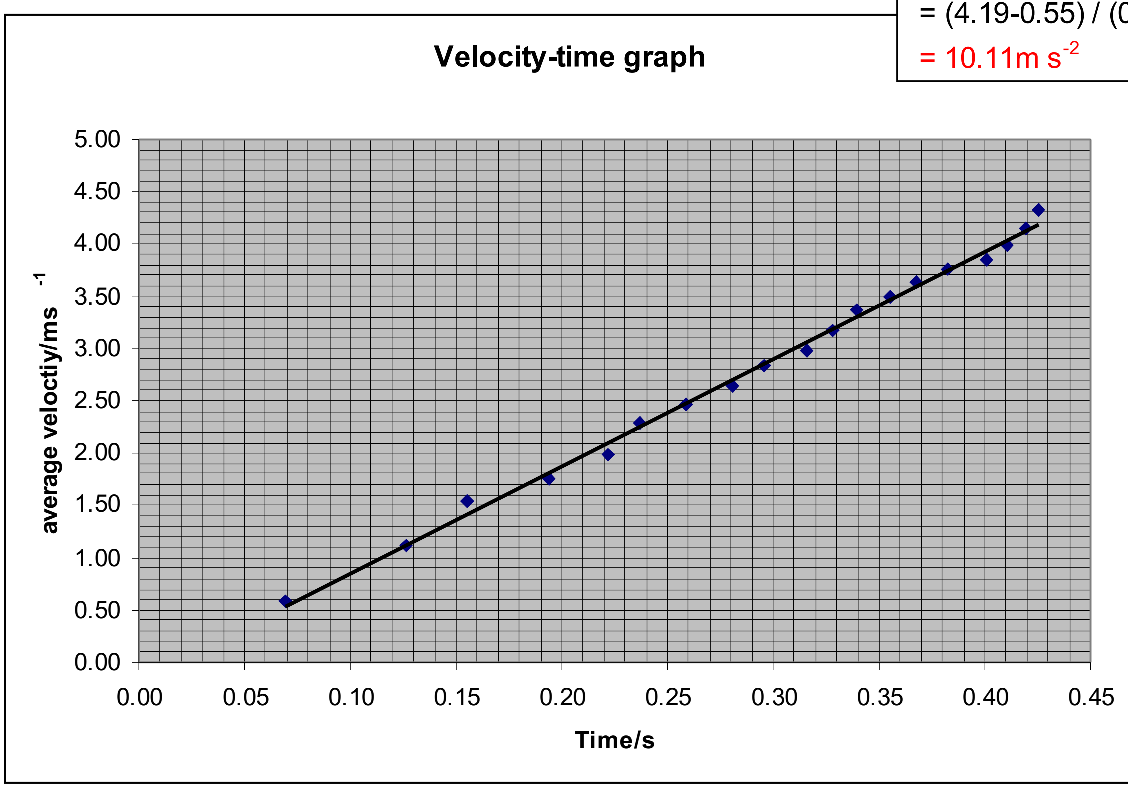
(u+v)/2

u=initial velocity
v=final velocity

u=0 as the object started from rest, so the average velocity of the whole fall is equal to v/2

Average Velocity/ms^{-1}	Average velocity of whole fall/ms^{-1}	Time/s
0.58	0.29	0.07
1.11	0.56	0.13
1.55	0.77	0.16
1.76	0.88	0.19
1.98	0.99	0.22
2.28	1.14	0.24
2.47	1.24	0.26
2.64	1.32	0.28
2.84	1.42	0.30
2.97	1.49	0.32
3.17	1.59	0.33
3.36	1.68	0.34
3.49	1.74	0.36
3.64	1.82	0.37
3.76	1.88	0.38
3.84	1.92	0.40
4.00	2.00	0.41
4.15	2.07	0.42
4.32	2.16	0.43

Gradient=□y/□x
= (4.19-0.55) / (0.43-0.07)
= 10.11m s^{-2}



The kinematic equation: $s = ut+½at^2$ can also be used to calculate acceleration. Again, u=0 due to the fact that the object starts from rest, this simplifies the equation to:

$$s = ½at^2$$

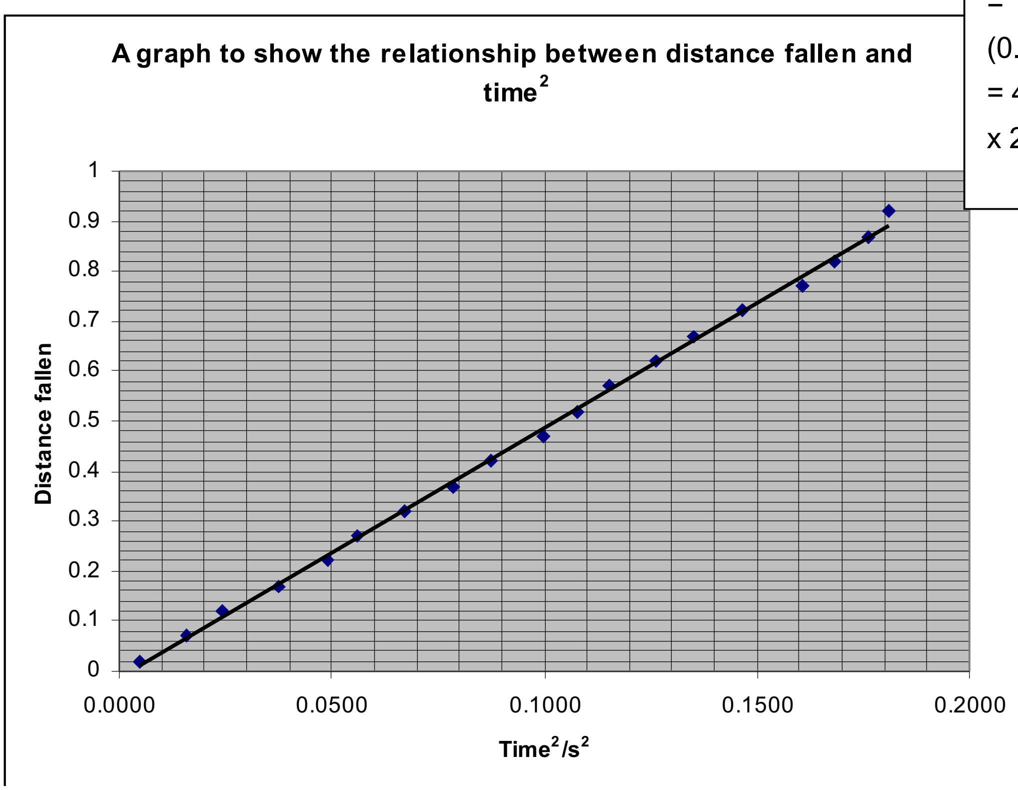
This is a function of y=mx+c therefore acceleration is equal to twice the gradient, when time squared (x-axis) is plotted against distance (y-axis).

When rearranged acceleration is therefore:

$a=2(s/t^2)$

Distance fallen /m	Time/s	$Time^2/s^2$
0.02	0.07	0.0048
0.07	0.13	0.0159
0.12	0.16	0.0241
0.17	0.19	0.0375
0.22	0.22	0.0492
0.27	0.24	0.0561
0.32	0.26	0.0671
0.37	0.28	0.0786
0.42	0.30	0.0873
0.47	0.32	0.0999
0.52	0.33	0.1076
0.57	0.34	0.1151
0.62	0.36	0.1265
0.67	0.37	0.1353
0.72	0.38	0.1464
0.77	0.40	0.1606
0.82	0.41	0.1684
0.87	0.42	0.1761
0.92	0.43	0.1811

Gradient=□y/□x
= (0.89-0.01) / (0.1181-0.0048)
= 4.99
x 2 =9.98m s^{-2}



These results comply with the AS Advancing Physics book, which suggests that the acceleration of an object in freefall is about $10m/s^{-2}$, however the actual figure for acceleration of all freefalling objects on Earth is $9.81m/s^{-2}$ so there is a small amount of error within the data, also indicated by the slight difference in the two calculated acceleration values.

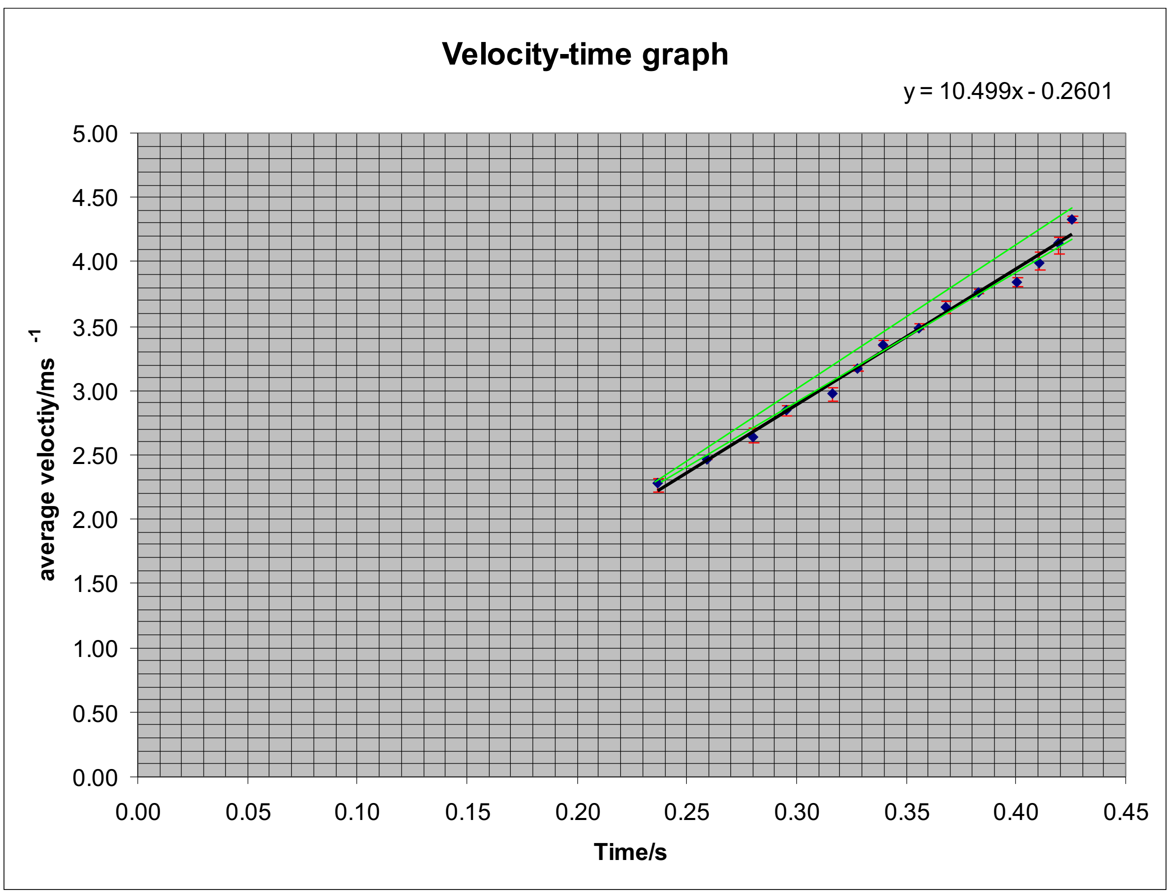
I have decided to look a little more closely at the error involved in my calculations. I believe the main source of error in the actual experiment is likely to be caused by the metal strip used to break the beam of the light gate. Due to the extra 16g on one side of the block, its centre of mass has changed, possibly making it fall at a slight angle. It is likely that this effect would be exaggerated the higher the distance fallen meaning, as the metal strip is pointing increasingly further down, effectively an object of greater and greater width is breaking the beam as it goes diagonally through the strip of metal. This would resul t in the beam being broken for relatively longer and the measured velocity being slightly less. Also the beam is being broken when the tota l mass has not travelled as far, which, in relation to the very first graph would also mean the velocity could be les s.

Another source of error could potentially come from the way the metal strip is attached. It is not impossible that, being attached with blu -tack, it could have moved from its perpendicular position relative to the block. If it pointed down, this could compound the above problem and decrease measured velocity. If it was pointing up, the reverse effect could be true. Of course, due to human inconsistency, the mass may not be dropped in the same way each time which could contribute further error to the dat a.

The initial error in measured values can be seen in the results with differing repeat values of velocity. It is these values which have been used in every calculations and errors would therefore be compounded. I have therefore added range bars to the velocity-time graph using the table below to show the maximum and minimum values for velocity recorded around the average.

Average velocity – minimum recorded velocity (m/s)	Maximum velocity – average recorded velocity (m/s)
0.07	0.04
0.01	0.01
0.05	0.07
0.04	0.03
0.05	0.05
0.02	0.02
0.02	0.03
0.02	0.03
0.04	0.05
0.01	0.02
0.04	0.03
0.06	0.08
0.09	0.04
0.02	0.03
0.14	0.08
0.01	0.02
0.03	0.03
0.03	0.03

0.12	0.09



The velocity-time graph has been re-drawn showing the data which was taken when the object was dropped from 0.3m and higher – i.e. the results which were established to have less error attached from the very first graph (velocity-distance fallen) when a constant acceleration could be seen. This, as shown by the equation of the line, gives a gradient and value for the acceleration due to gravity as 10. 5m s^{-2}.

The range bars have been joined to give straight lines showing the most extreme differences in gradient that the maximum and minimum recorded velocity values provide – the minimum velocity for the first piece of data has been joined to the maximum of the last (or penultimate as it was judged to give a line with a more representative gradient), and vice versa. The difference between the gradients of each of these lines is the error associated with my calculated figure of acceleration.

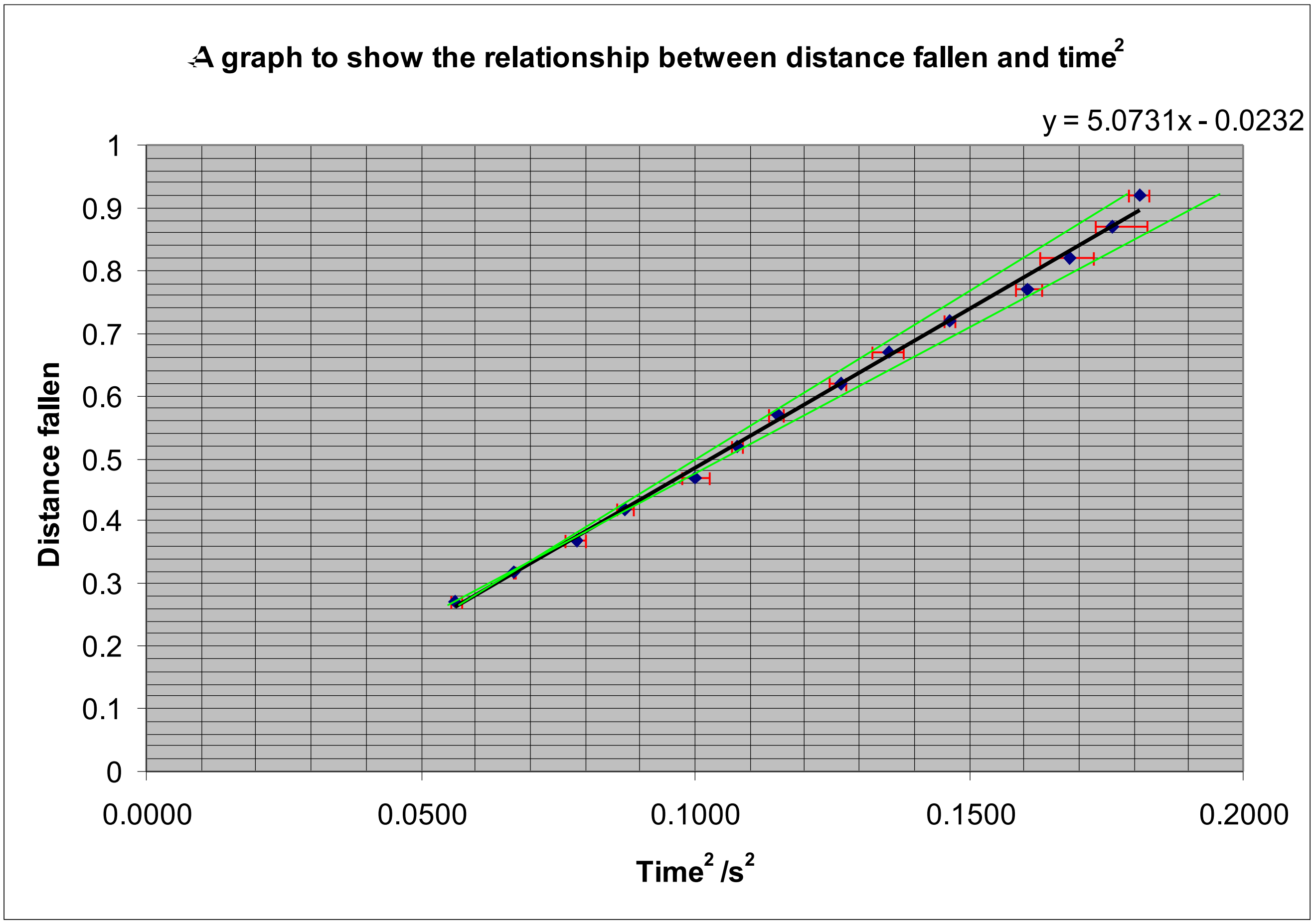
(4.41 – 2.26) / (0.43 – 0.24) = 11.32 m s^{-2}

(4.2 – 2.3) / (0.43 – 0.24) = 10 m s^{-2}

11.32 – 10 = acceleration due to gravity ±1.32m s^{-2}.
= 10.5 ±1.32m s^{-2}.

The same principal was applied to the distance - time^2 graph. The minimum and maximum time² values were calculated by dividing the distance by the maximum and minimum average velocities of the whole fall respectively. As this error range is associated with time, the variable along the x-axis, a line of best fit through each of the maximum and minimum ranges was drawn to show the difference in gradient s as before.

Maximum time²	Minimum time²	Maximum - average time² (s²)	Average - minimum time² (s²)
0.000	0.000	0.00140	0.00059
0.000	0.000	0.00029	0.00028
0.000	0.001	0.00152	0.00213
0.000	0.001	0.00161	0.00138
0.000	0.002	0.00276	0.00224
0.000	0.003	0.00100	0.00097
0.000	0.005	0.00110	0.00160
0.000	0.006	0.00120	0.00176
0.000	0.008	0.00272	0.00280
0.000	0.010	0.00090	0.00111
0.000	0.012	0.00277	0.00201
0.000	0.013	0.00422	0.00529
0.000	0.016	0.00653	0.00309
0.000	0.018	0.00175	0.00196
0.000	0.021	0.01182	0.00579
0.000	0.026	0.00112	0.00138
0.000	0.028	0.00227	0.00277
0.000	0.031	0.00229	0.00280
0.000	0.033	0.01079	0.00705



Gradient of average =5.1 x2 = 10.2 s^{-2}.
Extreme gradient values:
(0.178-0.057) / 0.6 = 4.96
x2 = 9.92 m s^{-2}

(0.174-0.055) / 0.65 = 5.46
x2 10.92 m s^{-2}

10.92 – 9.92 = acceleration due to gravity ±1 m s^{-2}
= 10.2 ±1m s^{-2}.

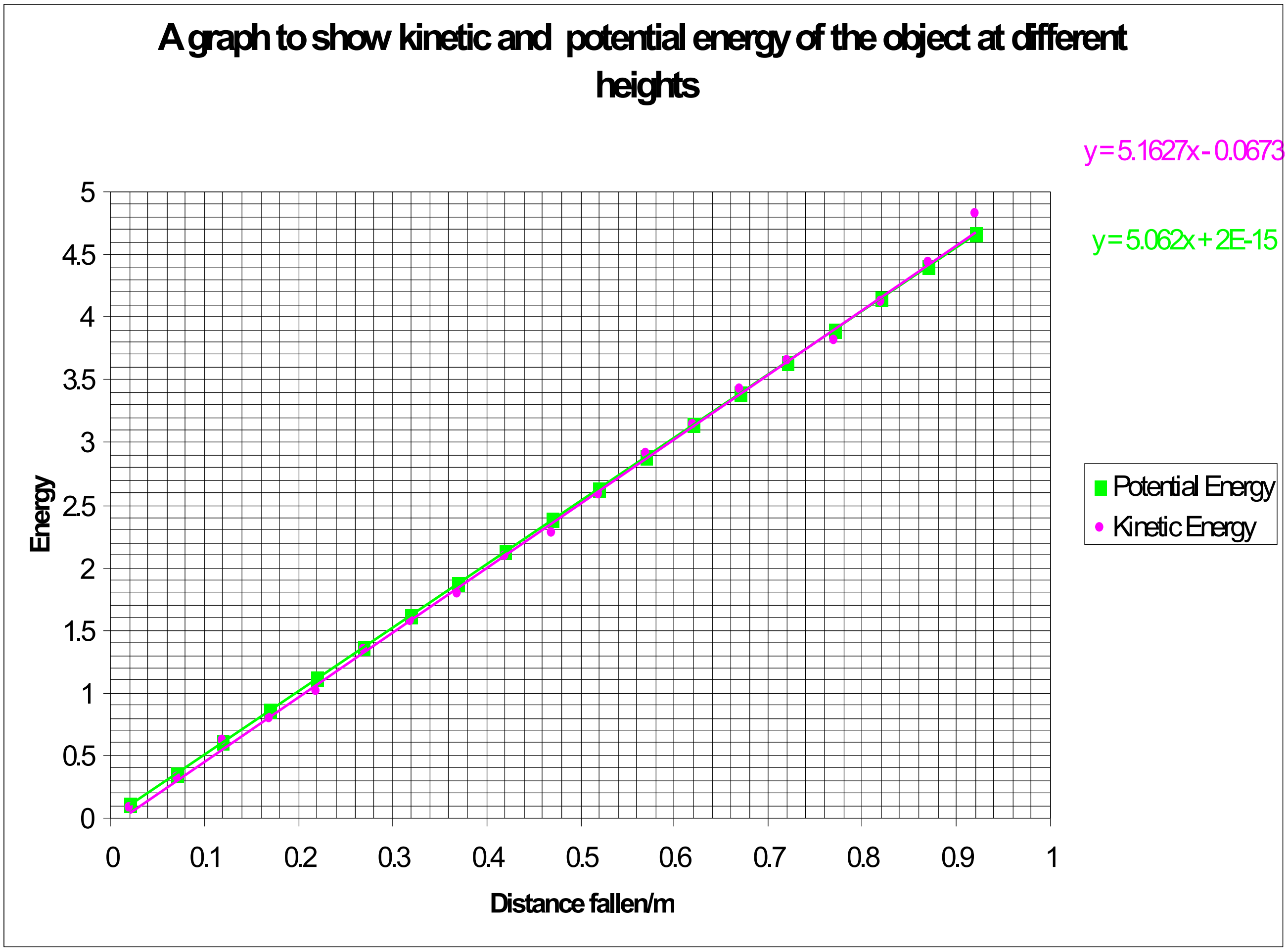
Each graph has given a slightly different value for acceleration due to gravit y, and also a difference in error - rounding is probably a factor in this. Both however, are within acceptable range of 9.8ms^{-2} as the correct value for acceleration due to gravity lies within the ±error.

By using the actual value for acceleration due to gravity (eradicating error from previous calculations), 9.81m/s^{-2}, I aim to prove conservation of energy by looking at the potent ial energy before the mass has been dropped from a certain height and the kinetic energy of the mass as it is falling. These two figures should be equal if all energy is conserved and simply transferred from potential to kinetic. The formulas below will be used:

Potential Energy = mass x acceleration due to gravity x height object was dropped

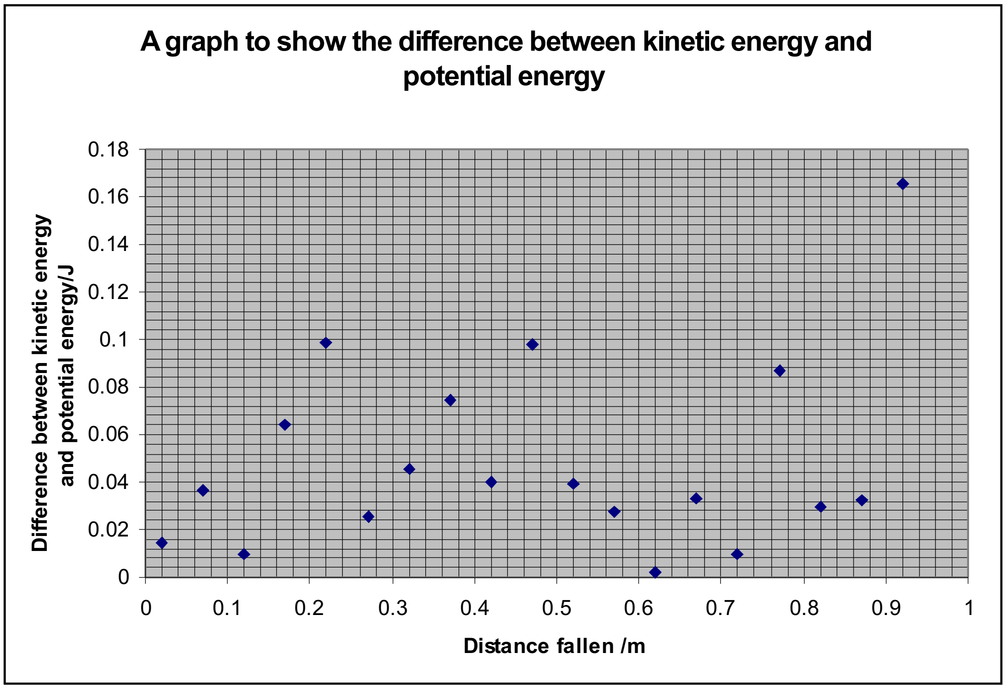
Kinetic Energy = ½ mass x velocity^2

mass/g	gravity/ms-2		
0.516	9.81		
	Distance fallen (m)	Potential Energy/ J	Kinetic Energy/J
	0.02	0.1012392	0.0867912
	0.07	0.3543372	0.3178818
	0.12	0.6074352	0.617181867
	0.17	0.8605332	0.796156467
	0.22	1.1136312	1.014871667
	0.27	1.3667292	1.3411872
	0.32	1.6198272	1.5740322
	0.37	1.8729252	1.7981568
	0.42	2.1260232	2.085812467
	0.47	2.3791212	2.280903467
	0.52	2.6322192	2.5926162
	0.57	2.8853172	2.9127168
	0.62	3.1384152	3.136465867
	0.67	3.3915132	3.424660467
	0.72	3.6446112	3.653970867
	0.77	3.8977092	3.810972467
	0.82	4.1508072	4.121122867
	0.87	4.4039052	4.436269867
	0.92	4.6570032	4.822332467



The graph shows that both energy forms increase in direct proportion to the distance fallen. The gradients are almost exactly equal (equations of lines shown in corresponding colour) proving the conservation of energy. However there is a 0.1007 difference in gradient and the lines can just be seen to be unequal - particularly towards the lower end of the graph. I am therefore going to investigate whether there is any relationship between the distance fallen and the difference between energy forms, to see wh ere the kinetic energy was lost – most likely as heat from friction.

Distance fallen (m)	Difference between kinetic energy and potential energy/ J
0.02	0.0144
0.07	0.0365
0.12	0.00975
0.17	0.0644
0.22	0.0988
0.27	0.0255
0.32	0.0458
0.37	0.0748
0.42	0.0402
0.47	0.0982
0.52	0.0396
0.57	0.0274
0.62	0.00195
0.67	0.0331
0.72	0.00936
0.77	0.0867
0.82	0.02969
0.87	0.0324
0.92	0.165



There seems to be little correlation between the difference in potential and kinetic energy and the distance the object fell from. I would have perhaps expected there to be greater difference as the height increased, due to the fact that the speed of a falling object has been proved to increase with the height it has dropped from – increasing the effect of air resistance and therefore friction, creating heat. Although due to the scale of this experiment, it would be probable that any effect of this nature is very difficult to see.

In summary, I have calculated the acceleration due to gravity of a falling object and consequently recognised the error involved, before going on to prove the conservation of energy by calculating the potential and kinetic energy of the falling mass.