Writing a good lab report

Revised August 28, 2005

The Notebook: Write what section number (say 4.1.1) of the lab write-up you are working on! Record your original measurements (with units) in your lab book. Include your estimates of uncertainty and their justification for the measured quantities (it might be more uncertain than the finest you can read the instrument!). All your work should be in the lab notebook - including any mistakes or duplicate measurements. Your lab notebook records what exactly you did, including any false steps. Errors should be neatly crossed out and a note should be recorded in the lab book indicating the nature of the mistake. This is the method used by practicing scientists for the recording of their experimental measurements. Write in pen—no pencils or erasers in lab. Write legibly; it can't be graded if it can't be read.

Analysis of results with Kaleidagraph and Excel:

Calculate derived quantities from the original data and uncertainties
Plot data with correct labeling and uncertainties (error bars)
Class info in upper right corner, a descriptive title, labeled axes with units, etc.
Titles should distinguish graphs from each other.
Check that your results make sense: smooth graphs; consistency in tables
Find best fit lines, curves, and fit results as needed

Testing for statistical consistency: learn to use formulae in Taylor

a. Use uncertainties to compare two results (calculate the t value)
b. Use uncertainties to compare a result with an expected value (calculate the t value)

Lab reports

The goal is to clearly communicate your analysis and results. You do not have to do everything in Word: by hand is fine, provided it can be read. Or you can do text in Word, but write in equations and sample calculations to save time. Your report will consist of: the report proper (written or typed); pages from your lab notebook (the duplicate sheets or the photocopies)l and printouts of spreadsheets or graphs.
In the upper right hand corner of the first page put:

Your name
Your partner's name
PHY191 section xxx (your section's number)
Experiment #

DO NOT make your grader hunt for things! Follow the section order of the lab write-up. Staple things in an order so the report can be read. Notebook pages and figures should be near where they are referred to in the text. Use the order: report text for a section, then notebook pages, then figures, then spreadsheets, then back to text for the next section; it won't be perfect, but the idea is to make it as easy to follow as possible. Section numbers from the lab write-up for answers to questions are critical; it is good to add them to printouts as well. If there's more than one figure in a section, to refer to them in the text you could either assign figure numbers (Fig 6 and 7) or call them something like Fig 5.4.3 A and 5.4.3 B.

For each part of experiment, in the order given by the lab manual, your report should have

1. Formulae and a sample calculation for each calculation type
    a. In words, why did you choose this formula (e.g. "independent random errors")
    b. The sample calculation is required
2. Use summary tables to organize results (often, a spreadsheet printout) . These really help you to focus on the final results.
    a. Give a summary table for each part of lab
    b. Use an overall summary at the end if comparing results across parts

For example:

	δx(cm)	L(cm)	W(cm)	H(cm)	Mass(g)	V(cm^3)	Density g/cm^3	Material	Expected Density
Ruler	.1	1.5	2.0	1.3	100.0±.1	3.9±.4	2.5±.3	Aluminum	2.7
Caliper	.01	1.47	2.03	1.31	100.0±.1	3.92±.04	2.61±.07		

3. Note whether results differed from your predictions; why?

At the end of your report, include the final discussion of the experiment
Answer the questions asked in the lab manual
Make quantitative compatibility comparisons where relevant
(for multiple measurements or experiment vs. theory)
What do you conclude based on the above comparisons?
What did you learn about physics from this lab? About procedure?
Do a critique of your group's performance:
what went well, what went wrong, why
Give the muddiest point(s) of the lab:
Give specifics! not "this was bogus" but "the readings didn't cover standard deviation but it was needed in part 4b"
suggest an improvement to the techniques, the lab manual, or Taylor

A Sample Report

Below is a good example of a lab report for 191 on an experiment we aren't doing. It is not perfect, but should give you a feeling for what a good lab report might look like. The "Objectives" section isn't usually needed. Here it replaces a lab write-up, to help you read the report. Notice:

Equations and sample calculations
Lab book pages, tables, and graphs inserted as needed in the text
Good labeling and referencing of tables and figures

I would have liked clearer comparisons of the measured values and expectations, along the lines of:

Page 7 or 9 We expect $g = 9.804$, and measure $9.780 \pm .019$ cm/s^2. Our measurement of g is consistent with expectations since the t value of the discrepancy is $t = -.024/.019 = -1.3$ standard deviations, less than 2 standard deviations from the expected result.

Page 13 *as the text says, it's compatible with 0; better would have been:* Then the coefficient is $-.021 \pm .017$ J/kg s, which, though it is nonzero, is also statistically consistent with zero ($t = -1.2$)

Page 14 *Ideally the student would have had time to perform the fits with a custom function, in which case the uncertainty in the parameter would have been available. Then they might have written:*
Here is a table with the various parameters of the quadratic fits, and their sums. The sum of each is expected to be zero. The uncertainties on the sum of the terms come from:

$$\delta(a + b) = \sqrt{ (\delta a)^2 + (\delta b)^2} \text{ and } t = (a + b - 0) / \delta(a + b)$$

Term	PE/m	KE/m	sum	error(sum)	t
constant	0	0.015	0.015	0.02	0.7
Linear	-2.06	2.18	0.12	0.07	1.7
quadratic	-47.86	47.52	-0.34	0.13	-2.6

The constant and linear terms are consistent with zero, but the quadratic term is not, because $|t| > 2$.

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(Jim Linnemann)
PHY 191 Sec. 8
Experiment 2

Energy of a Free-Falling Body

Objectives:

1) To observe the changes of the potential energy (PE), the kinetic energy (KE), and the total energy (TE), of a free-falling body.
2) To verify, graphically, that the TE remains constant in time.
3) To compare the theoretical predictions for the time dependence of the potential energy and the kinetic energy, with the experimental results.

PART 1

In this part we want to test the conservation of the TE of a free-falling object. In the Behr apparatus, an object is released from a given height. Falling down, it marks periodically a tape, with period $\tau=1/60\ s$. The latter quantity is given with negligible error. We ignore the first and the last marks on the tape, because they are affected by the systematic errors connected to the motion beginning and the motion end. Therefore, the second mark on the tape corresponds to the 0th point in Tab.1. We assign the instant $t=0\ s$ to the 0th point, so that the nth point corresponds to $t=n/60\ s$. We measure the distance of the nth point from the zero-tick of a meter stick, and denote it by y_n. The error on y_n is $\delta y=0.0008\ m$, as explained in the lab book.

Equations Used

The instantaneous velocity at the nth mark is

$$V_n = \frac{y_{n+1} - y_n}{2\tau} \qquad \left(ex: \ V_1 = \frac{1.29 \cdot 10^{-2} - 10^{-4}}{2 \cdot \frac{1}{60}} \frac{m}{s} = 3.84 \cdot 10^{-1} \frac{m}{s} \right)$$

The corresponding error is

$$\delta V_n = \frac{2\delta y}{2\tau} = \frac{\delta y}{\tau} = \frac{8.0 \cdot 10^{-4}\ m}{\frac{1}{60}\ s} = 4.80 \cdot 10^{-2} \frac{m}{s}$$

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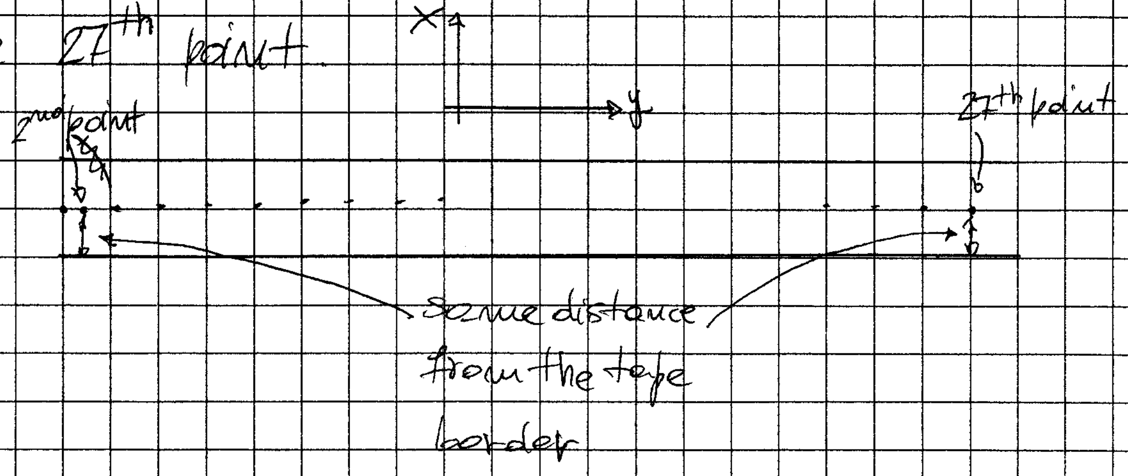
Experiment: CONSERVATION OF ENERGY

- After we run the Behr free fall apparatus, following the directions given in the "Experimental Procedure" section, we measure the position of each point, taking the second point to be $y=0$, and ignoring the last point. We ignore the first and last points because they are affected by systematic errors. We find that the points do not fall on a straight line, probably due to the tape oscillation. In order to solve this inconvenient, we measure the distance of the second point from the tape border, and look for a far away point which is at the same distance from the border: this happens for the 27th point.



Then we place a meter stick (which we suppose to be reaso-

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Experiment: CONSERVATION OF ENERGY

nably straight) on the tape, in such a way that it is tangent to the 2nd and the 27th point. We assume that the oscillations are purely transversal, that is, along the x-direction, in such a way that they do not affect our measurements in a sensible way. Measuring the thickness of the ticks with a caliper, we find that they are ≃ 0.54 ÷ 0.60 mm thick. Therefore we assign an error, in the y measurement, of 1.6 mm, that is, $\Delta y = 0.8$ mm (in $y \pm \Delta y$). The values are reported below.

#	y (mm)	#	y (mm)	#	y (mm) $- y(27)$
2	0.1	15	275.8	28	72.4
3	5.3	16	315.9	29	148.2
4	12.9	17	358.5	30	226.3
5	22.6	18	404.5	31	307.0
6	36.3	19	452.9	32	391.6
7	51.4	20	504.0	33	477.0
8	70.1	21	557.8		
9	91.5	22	614.0		
10	115.4	23	673.4		
11	141.9	24	735.4		
12	171.1	25	799.8		
13	203.4	26	867.3		
14	237.9	27	937.9		

Name: KOSHAN TOADI **Date:** 9/20/2004

Experiment: CONSERVATION OF ENERGY

The points after the 27th ~~have been measured~~ are measured by repositioning the meter stick, with the zero at the 27th point.

- We create a table with KaleidaGraph. The table is shown in the lab report, where we also include the details of how the various quantities have been calculated.

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	t(s)	y(m)	v(m/s)	PE/m(J/kg)	KE/m(J/kg)	TE/m(J/kg)	TE/m Res.(J/kg)	TE/m Chauvenet
0	0.0000	0.00010000		0.050884				
1	0.016667	0.0053000	0.38400	0.0000	0.073728	0.073728	-0.0027846	-0.092662
2	0.033333	0.012900	0.51900	-0.074369	0.13468	0.060311	0.010778	0.35867
3	0.050000	0.022600	0.70200	-0.16929	0.24640	0.077115	-0.0058784	-0.19561
4	0.066667	0.036300	0.86400	-0.30335	0.37325	0.069901	0.0014820	0.049315
5	0.083333	0.051400	1.0140	-0.45111	0.51410	0.062991	0.0085378	0.28411
6	0.10000	0.070100	1.2030	-0.63409	0.72360	0.089511	-0.017835	-0.59350
7	0.11667	0.091500	1.3590	-0.84350	0.92344	0.079939	-0.0081173	-0.27012
8	0.13333	0.11540	1.5120	-1.0774	1.1431	0.065699	0.0062687	0.20860
9	0.15000	0.14190	1.6710	-1.3367	1.3961	0.059435	0.012679	0.42193
10	0.16667	0.17110	1.8450	-1.6224	1.7020	0.079593	-0.0073324	-0.24400
11	0.18333	0.20340	2.0040	-1.9385	2.0080	0.069520	0.0028869	0.096068
12	0.20000	0.23790	2.1720	-2.2761	2.3588	0.082708	-0.010154	-0.33790
13	0.21667	0.27580	2.3400	-2.6470	2.7378	0.090849	-0.018149	-0.60396
14	0.23333	0.31590	2.4810	-3.0393	3.0777	0.038335	0.034511	1.1484
15	0.25000	0.35850	2.6580	-3.4562	3.5325	0.076279	-0.0032860	-0.10935
16	0.26667	0.40450	2.8320	-3.9063	4.0101	0.10378	-0.030641	-1.0196
17	0.28333	0.45290	2.9850	-4.3799	4.4551	0.075167	-0.0018818	-0.062619
18	0.30000	0.50400	3.1470	-4.8800	4.9518	0.071826	0.0016063	0.053452
19	0.31667	0.55780	3.3000	-5.4064	5.4450	0.038566	0.035012	1.1651
20	0.33333	0.61400	3.4680	-5.9564	6.0135	0.057138	0.016586	0.55193
21	0.35000	0.67340	3.6420	-6.5376	6.6321	0.094456	-0.020585	-0.68500
22	0.36667	0.73540	3.7920	-7.1443	7.1896	0.045311	0.028706	0.95524
23	0.38333	0.79980	3.9570	-7.7745	7.8289	0.054425	0.019739	0.65685
24	0.40000	0.86730	4.1430	-8.4350	8.5822	0.14721	-0.072900	-2.4259
25	0.41667	0.93790	4.2900	-9.1259	9.2021	0.076186	-0.0017298	-0.057561
26	0.43333	1.0103	4.4460	-9.8343	9.8835	0.049130	0.025472	0.84764
27	0.45000	1.0861	4.6170	-10.576	10.658	0.082285	-0.0075358	-0.25077
28	0.46667	1.1642	4.7640	-11.340	11.348	0.0075483	0.067347	2.2411
29	0.48333	1.2449	4.9590	-12.130	12.296	0.16586	-0.090817	-3.0221
30	0.50000	1.3295	5.1000	-12.958	13.005	0.047173	0.028016	0.93227
31	0.51667	1.4149		-13.794				
32								
33							-0.090817	-3.0221
34							0.067347	2.2411

Table 1

	t(s)	y(m)	v(m/s)	PE/m(J/kg)	KE/m(J/kg)	TE/m(J/kg)	TE/m Res.(J/kg)	TE/m Chauvenet
35							-1.4901e-08	-4.9586e-07
36							30.000	998.30
37							-4.9671e-10	-1.6529e-08
38							-0.00012391	-0.0041235
39							0.029546	0.98319
40							0.030051	1.00000
41							0.00090306	0.030051
42							0.0054865	0.18257
43							-0.93075	-30.972
44							2.3822	79.271

Table 1

(cont.)

The relationship between position and time, and between velocity and time, in a free falling object, are

$$y(t) = y_0 + V_0 t + \frac{1}{2} g t^2$$

$$v(t) = v_0 + g t$$

where, v_0 is the velocity at the instant *t=0*, and *g* is the gravitational acceleration. In Fig.1 we plot velocity vs. time. A linear fit gives the value of *g*. The error is given by the formulas reported in Taylor, Chapt.8:

$$\delta v_0 = \sqrt{\frac{N-1}{N-2} \sigma^2 \left(\sum_{m=1}^{N} t_m^2\right) / \Delta} \quad , \quad \delta g = \sqrt{\frac{N(N-1)}{N-2} \frac{\sigma^2}{\Delta}}$$

σ = standard deviation of the residuals = $8.295 \cdot 10^{-3} \frac{m}{s}$

N = # of measurement = 23

$$\Delta = N\left(\sum_{m=1}^{N} t_m^2\right) - \left(\sum_{m=1}^{N} t_m\right)^2 = 4.644$$

We obtain:

$$g = (9.780 \pm 0.019)\ m/s^2$$

We calculate the potential energy per unit mass, *PEₙ/m* , at each point *n*. The formula is

$$PE_m/m = -g(y_m - y_0) \quad \left(ex: \ PE_{20}/\underset{\substack{\uparrow \\ \text{mass}}}{m} = -9.78 \frac{m}{s^2} (0.614 - 10^{-4}) m \right.$$
$$\left. = -5.956 \frac{J}{kg} \right)$$

The error associated to, *PEₙ/m* is

$$\delta \frac{PE_m}{m} = \delta g (y_m - y_0) + g \cdot 2 \delta y \left(ex: \ \delta \frac{PE_{20}}{m} = \ldots\ldots \right)$$

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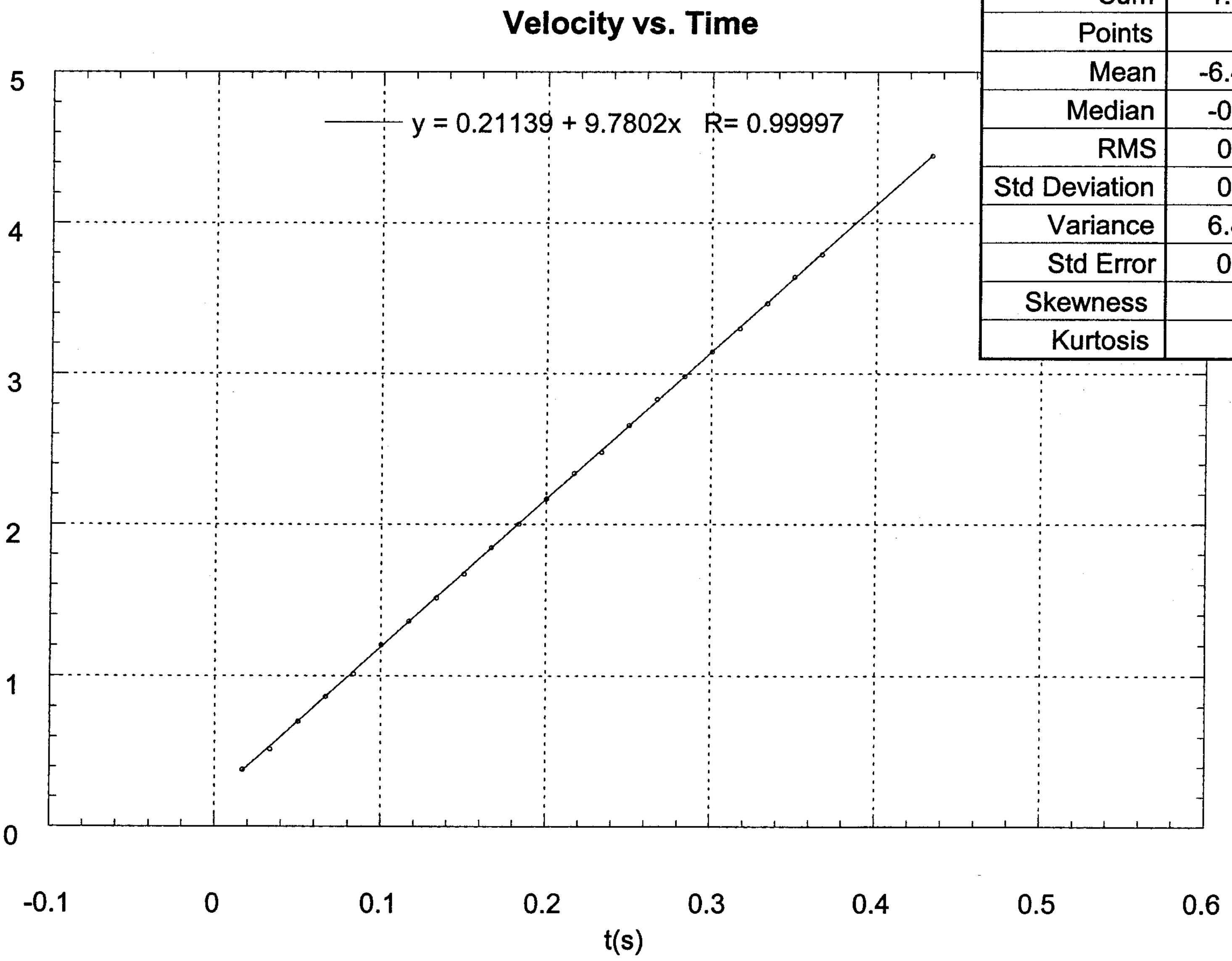
Figure 1



	v Res.(m/s)
Minimum	-0.013586044
Maximum	0.018400311
Sum	-1.4901161e-07
Points	23
Mean	-6.4787657e-09
Median	-0.0015451908
RMS	0.0081123583
Std Deviation	0.0082946812
Variance	6.8801737e-05
Std Error	0.0017295606
Skewness	0.34539494
Kurtosis	-0.45711055

Then we calculate the kinetic energy per unit mass, KE_n/m at each point n:

$$\frac{KE_n}{m} = \frac{1}{2} v_n^2 \quad \left(ex. \ \frac{KE_{10}}{m} = \frac{1}{2} \cdot (1.711 \cdot 10^{-1})^2 \frac{m^2}{s^2} = -1.622 \, J \right)$$

The error is

$$\delta \frac{KE_n}{m} = \frac{1}{2} \cdot 2 v_n \delta v_n = v_n \delta v_n = \frac{v_n}{\tau} \delta y \quad \left(ex.: \frac{\delta KE_{10}}{m} = \ldots\ldots \right)$$

Finally, we calculate the total energy per unit mass, TE_n/m at each point n, which is given by

$$TE_n/m = PE_n/m + KE_n/m \quad \left(ex.: \frac{TE_{30}}{m} = -12.130 \, J + 12.296 \, J = 1.659 \cdot 10^{-1} \, J \right)$$

with the experimental error

$$\delta \frac{TE_n}{m} = \delta \frac{PE_n}{m} + \delta \frac{KE_n}{m} \quad \left(ex.: \delta \frac{TE_{30}}{m} = \ldots\ldots \right)$$

Results

All of these quantities are reported in Tab.1. In Fig. ~~1~~ 2 we show the plot of *TE/m* vs. time. Based on the Chauvenet criterion, we reject the 24th, the 28th and the 29th points, which are sensibly different from the other ones. We also discard the 0th point, since its velocity is unknown: it cannot be zero, because we ignored the first mark on the tape. As a consequence, also the total energy is not zero, as it is clear from Fig.~~1~~2 The new data, after the wrong numbers have been rejected, are shown in Tab.2. Note that we can assign a velocity to an even lower number of points. The value we get for g is smaller than what we expect ($g=9.804 \ m/s^2$). A possible explanation for this discrepancy lies in the apparatus oscillations during the free fall. All the quantities in Tab.2 have been calculated based on the obtained value of g. In Fig.2 we show the new *TE/m* vs. time plot, with the statistic of the residuals. The constant term, in the linear fit, gives the initial *TE/m*. Its error is

	t(s)	y(m)	v(m/s)	v Res.(m/s)	PE/m(J/kg)	PE/m Res.(J/kg)	PE/m Err.(J/kg)	KE/m(J/kg)	KE/m Res.(J/kg)	KE/m Err.(J/kg)
0	0.0000	0.00010000			0.0000	-0.00093944	0.0078260			
1	0.016667	0.0053000	0.38400	-0.0096031	-0.050857	0.0020530	0.0079243	0.073728	-0.0083408	0.018432
2	0.033333	0.012900	0.51900	0.018400	-0.12519	0.0020272	0.0080679	0.13468	0.0066895	0.024912
3	0.050000	0.022600	0.70200	-0.0015963	-0.22005	-0.0039509	0.0082511	0.24640	-0.0026504	0.033696
4	0.066667	0.036300	0.86400	-0.00059289	-0.35404	0.0027009	0.0085100	0.37325	-0.00071609	0.041472
5	0.083333	0.051400	1.0140	0.012410	-0.50172	-0.0034456	0.0087953	0.51410	0.013613	0.048672
6	0.10000	0.070100	1.2030	-0.013586	-0.68461	-0.0012947	0.0091486	0.72360	-0.014316	0.057744
7	0.11667	0.091500	1.3590	-0.0065826	-0.89391	0.00068784	0.0095529	0.92344	-0.0061752	0.065232
8	0.13333	0.11540	1.5120	0.0034208	-1.1277	0.00063002	0.010004	1.1431	0.0085688	0.072576
9	0.15000	0.14190	1.6710	0.0074241	-1.3868	-0.00048995	0.010505	1.3961	0.016294	0.080208
10	0.16667	0.17110	1.8450	-0.0035725	-1.6724	-0.0016938	0.011057	1.7020	-0.0024251	0.088560
11	0.18333	0.20340	2.0040	0.00043106	-1.9883	0.00059342	0.011667	2.0080	0.0051510	0.096192
12	0.20000	0.23790	2.1720	-0.0045657	-2.3257	-0.0022616	0.012319	2.3588	-0.0056627	0.10426
13	0.21667	0.27580	2.3400	-0.0095623	-2.6964	0.0016451	0.013035	2.7378	-0.018302	0.11232
14	0.23333	0.31590	2.4810	0.012441	-3.0886	0.00057745	0.013792	3.0777	0.034586	0.11909
15	0.25000	0.35850	2.6580	-0.0015554	-3.5052	-0.0025301	0.014597	3.5325	-0.0010495	0.12758
16	0.26667	0.40450	2.8320	-0.012552	-3.9551	0.00087118	0.015466	4.0101	-0.033114	0.13594
17	0.28333	0.45290	2.9850	-0.0025487	-4.4285	0.0010028	0.016381	4.4551	-0.0061502	0.14328
18	0.30000	0.50400	3.1470	-0.0015452	-4.9282	0.0010495	0.017346	4.9518	-0.0044799	0.15106
19	0.31667	0.55780	3.3000	0.0084581	-5.4544	0.0010133	0.018363	5.4450	0.027086	0.15840
20	0.33333	0.61400	3.4680	0.0034616	-6.0041	-0.0020428	0.019424	6.0135	0.0097346	0.16646
21	0.35000	0.67340	3.6420	-0.0075352	-6.5850	-0.00045967	0.020547	6.6321	-0.031277	0.17482
22	0.36667	0.73540	3.7920	0.0054684	-7.1914	-0.00027657	0.021718	7.1896	0.015131	0.18202
23	0.38333	0.79980			-7.8212	-0.0031114	0.022935			
24										
25	0.41667	0.93790			-9.1719	0.0027027	0.025544			
26	0.43333	1.0103	4.4460	0.0034819	-9.8800	-0.0014467	0.026912	9.8835	0.0011234	0.21341
27	0.45000	1.0861			-10.621	0.00074577	0.028344			
28										
29										
30	0.50000	1.3295			-13.002	0.0048599	0.032942			
31	0.51667	1.4149			-13.837	-0.0050192	0.034556			

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Table 2

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	TE/m(J/kg)	TE/m Res.(J/kg)
0		
1	0.022871	0.0017434
2	0.0094939	0.014775
3	0.026348	-0.0024242
4	0.019205	0.0043729
5	0.012374	0.010858
6	0.038990	-0.016104
7	0.029530	-0.0069891
8	0.015415	0.0067806
9	0.0092883	0.012562
10	0.029598	-0.0080939
11	0.019693	0.0014654
12	0.033060	-0.012247
13	0.041399	-0.020931
14	-0.010907	0.031029
15	0.027258	-0.0074816
16	0.054999	-0.035568
17	0.026638	-0.0075521
18	0.023562	-0.0048220
19	-0.0094180	0.027812
20	0.0094466	0.0086022
21	0.047073	-0.029370
22	-0.0017490	0.019107
23		
24		
25		
26	0.0035000	0.012475
27		
28		
29		
30		
31		

Table 2

(cont.)

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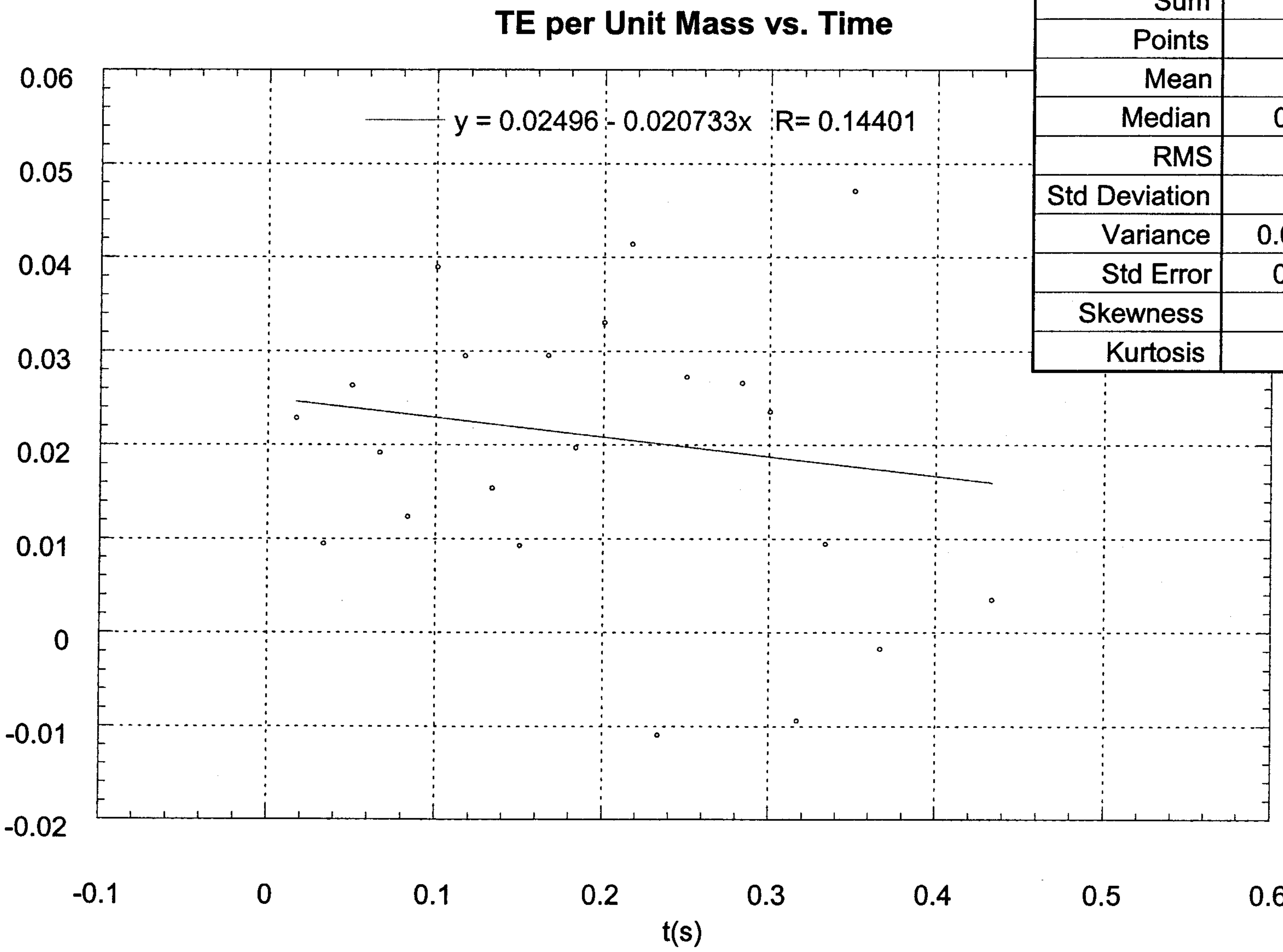
Figure 2



	TE/m Res.(J/kg)
Minimum	-0.035568327
Maximum	0.031028835
Sum	0
Points	23
Mean	0
Median	0.0014654323
RMS	0.016321382
Std Deviation	0.0166882
Variance	0.00027849603
Std Error	0.0034797303
Skewness	-0.19529332
Kurtosis	-0.29367177

The linear coefficient gives the TE average rate of change. Its error is

$$\delta \text{rate} = \sqrt{\frac{N(N-1)}{N-2} \frac{\sigma^2}{\Delta}} \quad , \quad \sigma = 1.669 \cdot 10^{-2} \frac{J}{Kg\, s}$$

We summarize the results for this part in the table below. We observe that the rate of change is compatible with zero, but a negative value is more likely. This energy loss is probably due to the friction acting on the falling body. We also observe a clear oscillatory pattern. These oscillations are mainly along the tape x-axis, as we assumed in the lab book. They affect the speed measurement, because one has to take into account the total distance between the two points, not only their vertical displacement. Therefore, a more accurate measure would require one column for the x-position, in addition to the column for the y-position of Tab.2.

g(m/s^2)	Err.(m/s^2)	TE/m(t=0)(10^-2 J/kg)	Err.(10^-2 J/kg)	Rate (10^-2 J/kg*s)	Err.(10^-2 J/kg*s)
9.78	0.019	2.5	1.2	-2.1	4

PART II

In this part we compare the theoretical prediction for the PE and the KE as functions of time, with the experimental curves.

Equations Used

Inserting the equations for *y(t)* and *v(t)* in the formulas for the *PE* and the *KE*, we obtain

$$\frac{PE}{m} = -g\left(y(t) - y_0\right) = -g\left(V_0 t + \frac{1}{2} g t^2\right) = -gV_0 t - \frac{1}{2} g^2 t^2$$

$$\frac{KE}{m} = \frac{1}{2} v^2 = \frac{1}{2}\left(V_0 + g t\right)^2 = \frac{1}{2} V_0^2 + gV_0 t + \frac{1}{2} g^2 t^2$$

NOTE : THE ABS. VALUE
OF THE LINEAR AND QUADRATIC
COEFFICIENTS ARE IDENTICAL

Results

The PE/m vs. time, and the KE/m vs. time plots are in Fig.3 and Fig.4, respectively, with the statistic of the residuals. The absolute values of the linear and quadratic terms, from the PE and the KE fits, do not coincide. The main reason for this, once again, is the oscillations of the apparatus, which affect the speed measurements, mainly because we ignored the x-displacements. They also affect the y-position measurements, since an oscillation is never purely transverse. However, the single fits for PE/m and KE/m are excellent, as the correlation coefficients show.

Questions for Preliminary Discussion

1) Discuss the time $PE=TE$ and the time $KE=TE$ for an object in free fall. What happens at these points? That is, what are the position, speed, and acceleration of the object at these points?

The condition $PE=TE$ corresponds to $KE=0$: this happens at the beginning of the motion, right after the object is released. At that instant the speed is zero, and the acceleration is g. The condition $KE=TE$ corresponds to $PE=0$: this happens at the end of the motion, right before the object touches the ground. At that instant the speed has its maximum value, $v_{max}=2TE/m$, and the acceleration is of course still g.

2) A student says that the TE of a body is $2.3\ J$. A different student says that the TE of the same object is $532.2\ J$. What do you think is the reason of this discrepancy?

The TE of an object is defined only up to a constant, which is arbitrary. For example, if we decide that the PE at the top of the free-fall motion is zero, then $TE=0$. In the same way, if we decide that the PE at the bottom of the free-fall motion is zero, then $TE=(1/2)m\ v_{max}^2$.

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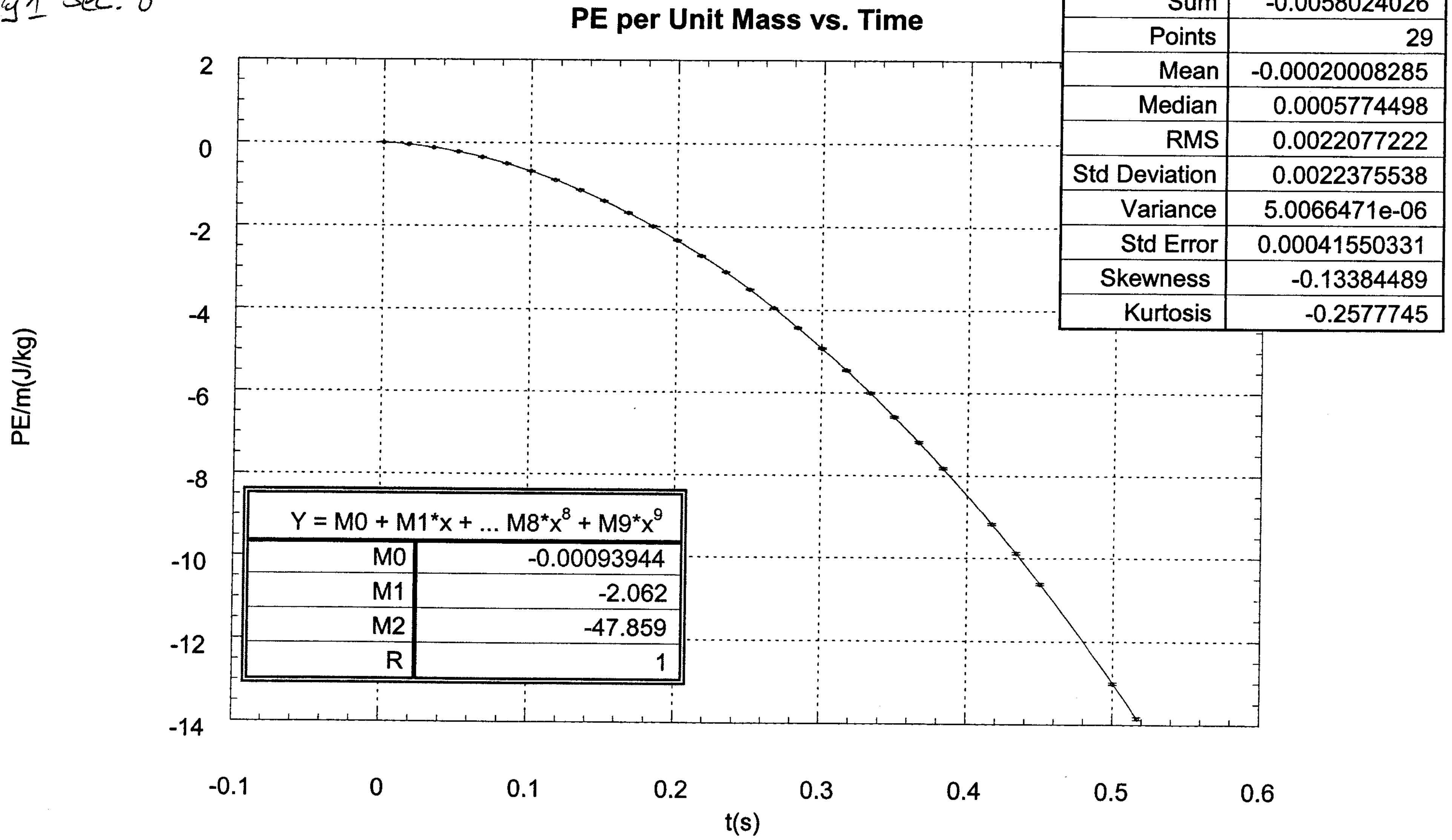
Figure 3



PE per Unit Mass vs. Time

	PE/m Res.(J/kg)
Minimum	-0.0050191879
Maximum	0.0048599243
Sum	-0.0058024026
Points	29
Mean	-0.00020008285
Median	0.0005774498
RMS	0.0022077222
Std Deviation	0.0022375538
Variance	5.0066471e-06
Std Error	0.00041550331
Skewness	-0.13384489
Kurtosis	-0.2577745

$Y = M0 + M1*x + \ldots M8*x^8 + M9*x^9$

M0	-0.00093944
M1	-2.062
M2	-47.859
R	1

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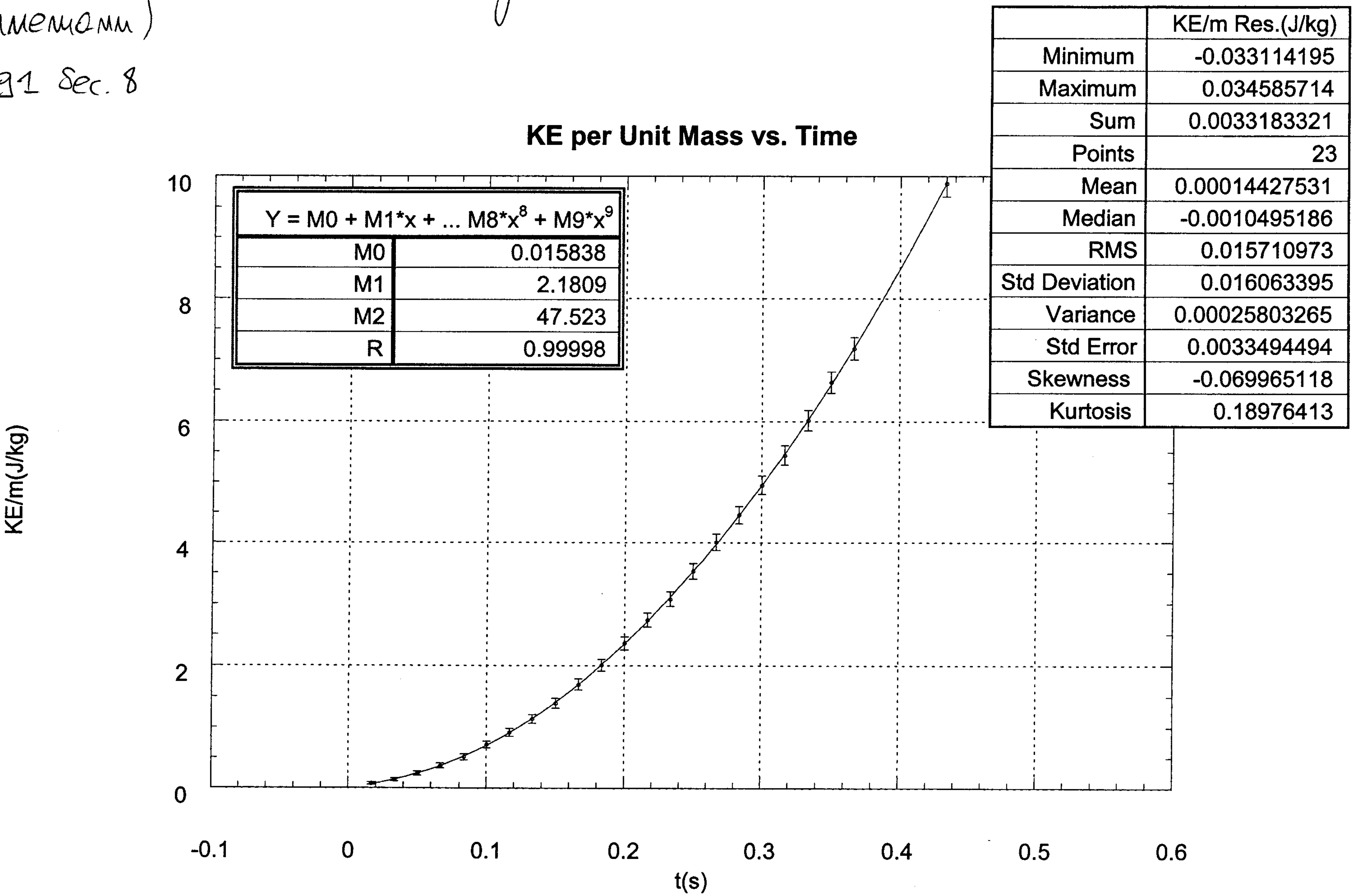
Figure 4



$Y = M0 + M1*x + \ldots M8*x^8 + M9*x^9$	
M0	0.015838
M1	2.1809
M2	47.523
R	0.99998

	KE/m Res.(J/kg)
Minimum	-0.033114195
Maximum	0.034585714
Sum	0.0033183321
Points	23
Mean	0.00014427531
Median	-0.0010495186
RMS	0.015710973
Std Deviation	0.016063395
Variance	0.00025803265
Std Error	0.0033494494
Skewness	-0.069965118
Kurtosis	0.18976413

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Questions to be Discussed

1) Does *TE/mass* depend linearly on *t*? If not, what kind of time dependence does it show?

The plot *TE/mass* vs. *t* is shown in Fig.2. We observe that the dots form, approximately, a sinusoid whose middle point falls down roughly linearly. The reason for this behavior is in the systematic error due to the apparatus oscillation, which we (mistakenly) neglected.

2) Does the fit curves for *PE/mass* and *KE/mass* fall within the experimental uncertainties?

The curves, for *KE/mass,* and, especially, for *PE/mass* are very accurate: there is no point, in each plot, that does not contain the curve. We were careful not to overestimate the error, and tried to be as accurate and precise as possible in determining the mark positions on the tape. In this way we reduced the only source of casual error to the minimum, since the time intervals are extremely accurate.

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Conclusions

In the first part of this experiment we tested the conservation of the TE for a free-falling body. First, we found the gravitational acceleration, by linearly fitting the velocity vs. time plot. The obtained value of *g*, $g=9.78\ m/s^2$, was slightly below its known value,

$g=9.80\ m/s^2$. (The reasons for this discrepancy have been discussed in the Exp.2 Lab Report.) Then, we calculated the TE, and plotted it vs. time. Our results show that some energy is lost during the motion, most likely because of frictional forces acting in the Behr apparatus. Also, we found that the motion was affected by oscillations, which propagated up to the measured values of the PE, the KE, and the TE. Based on these observations, we believe that the experiment can be improved by: (1) Trying to keep the apparatus stable. (2) Measuring also the x-component of the motion, and including it in the formulas for the KE and the TE. (3) Reducing the apparatus friction, by using a specific lubricant.

In the second part of the experiment, we compared the theoretical predictions for the PE and the KE of the falling body (per unit mass), with the data fits. The absolute values of the coefficients, in the quadratic fits, should be the same, for both *PE/m* and *KE/m*. Our results show some discrepancy (we did not calculate the error), which are probably due to the systematic sources of error discussed above: oscillation of the apparatus, and frictional forces. Our suggestions, summarized in the points (1)-(3) of the last paragraph, should improve also this part of the experiment. However, the quadratic fits are excellent, for both *PE/m* and *KE/m,* with coefficients of correlation very close to unity: this means that casual errors have been reduced to a very high level of accuracy. Thus the systematic errors are mainly responsible for the large uncertainties in the TE and its rate of change, (as the oscillatory pattern of Fig.2 clearly shows) , and the discrepancies between the coefficients of the *PE/m* and *KE/m* fits.