Guidelines for a Physics Lab Reports

A laboratory report has three main functions:

(1) To provide a record of the experiments and raw data included in the report,
(2) To provide sufficient information to reproduce or extend the data, and
(3) To analyze the data, present conclusions and make recommendations based on the experimental work.

General Comments:

The single most important requirement for a laboratory report is clarity. Imagine that your audience is one of your classmates who missed that experiment.

If you are using a word processor for your lab report, then use the spelling and grammar checkers. The grammar check can be annoying because often technical sentences are wordy and complex, but it will help you avoid using too many passive sentences. In general, passive sentences are less understandable. However, grammar check will not assess clarity, and it will ignore simple errors. (I do not doubt there are still mistakes in this document I have run it through spelling and grammar checks.)

Many technical writers prefer to write sentences with passive verbs. A simple example: "The spring constant k was found from the slope to be 3.02 N/m." If you run this sentence through the grammar check, it will tell you that "was found" is a verb in the passive voice. To change this to an active voice you could write: "The spring constant k is the slope, 3.02 N/m." Not every sentence has to be in an active voice. What you want is a report that is readable.

Lab Report Structure:

I. **Cover Sheet:** This page has the course number and assigned lab section, the title of the experiment, your name, your lab partner's names, the date that the lab was performed and your TA's name.

II. **Abstract:** The purpose of an abstract in a scientific paper is to help a reader decide if your paper is of interest to him/her. (This section is the executive summary in a corporation or government report; it is often the only section that a manager reads.)

The abstract should be able to stand by itself, and <u>it should be brief</u>. Generally, it consists of three parts which answer these questions:

- What did you do? – A statement of the purpose of the experiment, a concise description of the experiment and physics principles investigated.
- What were your results? – Highlight the most significant results of the experiment.
- What do these results tell you? – Depending on the type of experiment, this is conclusions and implications of the results or it may be lessons learned form the experiment.

Write the abstract after all the other sections are completed. (You need to know everything in the report before you can write a summary of it.)

III. **Data Sheets:** For each experiment, the lab manual has one or more data sheets for recording raw data, as well as, intermediate and final data values. These are not for doodling, but for recording your data. Record the data neatly in pen. If your data values are so sloppily recorded that you have to recopy them, then the accuracy of the data is questionable. This fact will be reflected in your laboratory performance score. If there is a mistake, then draw a single line through that value. <u>*"White-Out" and similar covering agents are expressly forbidden.*</u>

The values that you record on your data sheet must have:

- Units (such as kg for kilograms)
- Reasonable uncertainty estimates for given instruments and procedures
- Precision consistent with uncertainty (proper significant digits)
- Propagation of error for calculated quantities
- Your lab instructor's initials.

If you happen to forget your lab manual, then you will take your data on notebook paper. Your lab instructor will initial that as your data sheet and you will turn that in with your lab report as well as your own data sheet from the lab manual. <u>You may not use your lab partner's datasheet and then make a photocopy.</u>

IV. Graphs: You must follow the guidelines in the lab manual for all graphs. The first graphs of the semester must be made by hand, not computer software. After your lab instructor gives permission, you may use computer software to make graphs. Those graphs must also conform to the guidelines in the lab manual. Remember that when plotting data with units, both the slope and intercept of a graph also have units.

V. Sample Calculations: Show calculations in a neat and orderly outline form. Include a brief description of the calculation, the equation, numbers from your data substituted into the equation and the result. <u>Do not include the intermediate steps</u>. <u>*Numbers in the sample calculations must agree with what you recorded in your data sheet*</u>. For calculations repeated many times, you only include one sample calculation. Answers should have the proper number of significant figures and units. (It is not necessary to show the calculation for obtaining an average, unless your TA requests that you do so.)

Typing the equation into the lab report is not required; it is easier and faster to print these calculations neatly by hand. If you wish to type this section, then use the equation editor in Microsoft Word. Your lab instructor can give you information on using the equation editor.

VI. Discussion of Results: This is the most important part of the lab report; it is where you analyze the data. (In the future, you may not actually collect data; a lab technician or other people may collect the raw data. Regardless of your discipline, the most challenging and rewarding part of your work will be analyzing the data.)

Begin the discussion with the experimental purpose and briefly summarize the basic idea of the experiment with emphasis on the measurements you made and transition to discussing the results. State only the key results (with uncertainty and units) quantitatively with numerical values; do not provide intermediate quantities. Your discussion should address questions such as:

- What is the relationship between your measurements and your final results?
- What trends were observable?
- What can you conclude from the graphs that you made?
- How did the independent variables affect the dependent variables? (For example, did an increase in a given measured (independent) variable result in an increase or decrease in the associated calculated (dependent) variable?)

Then describe how <u>*your*</u> experimental results substantiate/agree with the theory. (This is not a single statement that your results agree or disagree with theory.) When comparison values are available, discuss the agreement using either uncertainty and/or percent differences. This leads into the discussion of the sources of error.

In your discussion of sources of error, you should discuss all those things that affect your measurement, but which you can't do anything about given the time and equipment constraints of this laboratory. Included in this would be a description of sources of error in your measurement that bias your result (*e.g.* friction in pulleys that are assumed frictionless in the formula). Your analysis should describe the qualitative effect of each source of error (*e.g.* friction slowed motion, causing a smaller value of acceleration to be measured) and, where possible, provide an estimate of the magnitude of the errors they could induce. Describe only the prominent sources of error in the experiment. For example, the precision of the triple balance beam, a fraction of a gram, compared to the 250.0 g lab cart is not significant. *Note that a tabulation of all possible errors without any discussion of qualitative effect of the error will receive no credit.* Your discussion should address questions such as:

- Are the deviations due to error/uncertainty in the experimental method, or are they due to idealizations inherent in the theory (or both)?
- If the deviations are due to experimental uncertainties, can you think of ways to decrease the amount of uncertainty?
- If the deviations are due to idealizations in the theory, what factors has the theory neglected to consider? In either case, consider whether your results display systematic or random deviations.

A conclusion is not required in the rubric. You will not lose points for leaving this out. However, in order to receive the points for a very well written report in Achievements and Flaws, a brief conclusion is recommended.

Considerations: These are not questions to be answered as a separate part of the lab report. They are hints. They are things for you to think about. Some of them should be addressed in your lab report. Not because your TA says to do so, but because it adds depth to your discussion. **You are never to simply list answers to considerations.**

Endnotes:
The report should not be a big production. It should not take hours to write. The objective is to write down the significant details of the experiment, the analysis of the experimental data. A few neatly written pages, including your data sheets will suffice for most experiments. Hopefully the sample lab report that follows will help you.

Note:
1. No student should copy data from anyone who is not his or her lab partner.
2. You may discuss the experiment with your lab partner and other classmates, but **the lab report that you turn in must be your own work.** Lab reports are subject to all the rules governing academic honesty.
3. Photocopies of any parts of the lab report are not permissible.

Hooke's Law Experiment

Objective: To measure the spring constant of a spring using two different methods.

Background: If a weight, $W = mg$, is hung from one end of an ordinary spring, causing it to stretch a distance x, then an equal and opposite force, F, is created in the spring which opposes the pull of the weight. If W is not so large as to permanently distort the spring, then this force, F, will restore the spring to its original length after the load is removed. The magnitude of this restoring force is directly proportional to the stretch,

$$F = -kx$$

The constant k is called the spring constant. To emphasize that x refers to the change in length of the spring we write

$$F = mg = -k\,\Delta \ell \qquad (1)$$

In this form it is apparent that if a plot of F as a function of Δl has a linear portion, this provides confirmation that the spring follows Hooke's Law and enables us to find k.

An additional approach is possible. One definition of simple harmonic motion is that it is motion under a linear, "Hooke's Law" restoring force. Note that for simple harmonic motion, the period does not depend upon the amplitude of the oscillation. For such a motion, we have

$$T^2 = 4\pi^2 m / k \qquad (2)$$

where k again is the spring constant, T is the period of the pendulum and m is the mass that is oscillating. Thus, the mass includes the mass of the spring itself. However, the entire spring does not vibrate with the same amplitude as the load (the attached mass) and therefore it is reasonable to assume that the effective load (m) is the mass hung from the end of the spring plus some fraction of the mass of the spring. Based on similar experiments, one third of the mass of the spring is a good estimation of the effective load due to the spring, thus

$$m = m_{load} + m_{es} = m_{load} + \frac{1}{3} m_{spring}$$

where m_{es} is the effective load of the spring. Using this in Eq. (2), we find

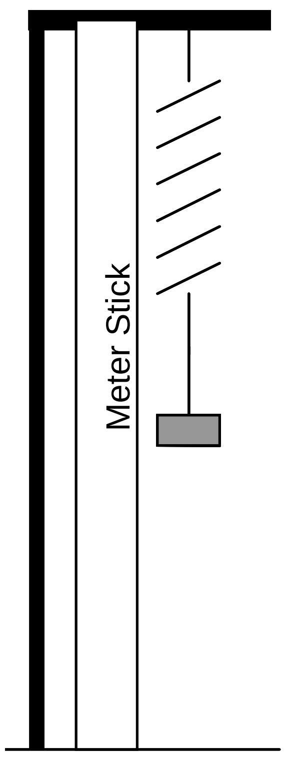
$$k = \frac{4\pi^2 \{m_{load} + 1/3(m_{spring})\}}{T^2} \qquad (3)$$

The effective load of the spring can be determined for a particular spring using the following process. The equation for T^2 can be written in terms of m_{load} and m_{es} ; m_{es} can then be determined from a graph of T^2 versus m_{load}. Note that this assumes that m_{es} is constant.

Eq (3) uses an approximation for the contribution of the mass of the spring to the oscillation. If we rewrite Eq (2) as the effective mass of the spring and hanging mass (load), then

$$T^2 = 4\pi^2(m_{load} + m_{ES})/k = \frac{4\pi^2}{k}m_{load} + \frac{4\pi^2 m_{ES}}{k} \qquad (4)$$

where m_{load} is the hanging mass and m_{ES} is the effective mass of the spring. If we assume that the effective spring mass is the same for all loads, then a graph of period squared (T^2) vs. hanging mass (m_{load}) is a straight line, where $4\pi^2/k$ is the slope and $4\pi^2 m_{ES}/k$ is the intercept.



Procedure:

Part 1

1. Hang a spring from a horizontal metal rod.
2. Attach a mass hanger directly to the bottom of the hanging spring and record the position of the bottom of the mass hanger relative to a meter stick.
3. Add masses to the spring and record the position of the bottom of the mass hanger.

Part 2

1. Hang a mass from the spring and use a stopwatch to time 15 oscillations of the mass and spring.
2. Repeat for other masses.

Assemble report using a staple in the upper left corner.

Physics 1408 Section A1

HOOKE'S LAW AND A SIMPLE SPRING

Your Name

Partner(s): Full Name(s)

A lab report should include a title page like this one, with all of the appropriate information.

Date Performed: October 21, 2005

TA: Full Name

Abstract

Two experiments were performed to find the spring constant of a steel spring. The spring constant was determined statically, by measuring its elongation when subjected to loading, and dynamically, by measuring the period of a mass hung from one end and set into vertical oscillation. The resulting values of 2.94 ± 0.01 N/m and 2.98 ± 0.02 N/m, respectively. Our spring's behavior followed Hooke's law to within the limits of accuracy of the two experiments. (76 words)

An Alternate Abstract:
The purpose of this experiment was to measure and compare the spring constant of a steel spring using two different procedures. First we investigated the relationship between the force applied to a spring and the displacement of the spring from its rest length. We hung various masses from the springs, and measured the vertical displacement. We found a spring constant of 2.94 ± 0.01 N/m. Our results confirmed Hooke's Law, $F_s = -kx$. In the second procedure, we set the spring into vertical oscillation with a suspended mass and measured the period of oscillation. Using this method, we found a spring constant of 2.98 ± 0.02 N/m. Our results verified that the period of oscillation depended on the effective mass of the spring and the period of oscillation. (128 words)

A Poor Abstract – Too long because it has too much detail and unnecessary information. ***(The worst problems are in italics.)***

The purpose of this experiment was to determine the spring constant k of a steel spring using two different methods. First we investigated the relationship between the force applied to a spring and the displacement of the spring from its rest length in order to verify Hooke's law. *We hung masses of 0.01 kg, 0.20 kg, 0.30 kg, 0.04 kg, 0.05 kg, 0.06 kg, 0.70 kg, and 0.80 kg from the springs, and recorded the vertical displacements. We made four measurements for each mass hung from the spring and used the average of the four values in order to reduce random error. In this method, the main cause of error was measurement.* We found a spring constant of k = 2.94 ± 0.01 N/m. Our results confirmed Hooke's Law, *the well known relationship that the magnitude of an elastic restoring force on a spring is directly proportional to the displacement of the spring. This relationship is named after the 17th century scientist Hooke who studied it.* Next we measured the period of a mass hung from one end of a spring and set into vertical oscillation. *We performed this process using the four different masses 0.145 kg, 0.105 kg, 0.055 kg, and 0.025kg. The period of each mass was measured three times using three different amplitudes of oscillation.* We found that the spring constant depended on the effective mass of the spring and the period of oscillation. The period of the motion was the same whether the amplitude of the oscillation is large or small. *In this method, the main cause of error was reaction time.* Using this method we found a spring constant of 2.98 ± 0.02 N/m. This value is consistent with the result obtained using the first method. (291 words)

Remember to be concise.

Name: ___Your Name_________ Date:__Date Exp. Performed

Partner: ___Partners Full Name__

TA's Initials on data sheet

Hooke's Law and a Simple Spring

Part 1

Uncertainty can be written as a percentage.

You can include uncertainty for a tool such as a meter stick in the top of a data table.

Table 1

Position	Mass (g) ±1%	Location of the Mass Hanger Reference in cm ±0.05cm			
		Trial 1	Trial2	Trial 3	Trial 4
Reference	0	69.55	69.50	69.50	69.50
1	1	69.27	69.19	69.18	69.17
2	3	68.61	68.50	68.53	68.52
3	5	67.95	67.87	67.88	67.86
4	10	66.42	66.20	66.21	66.20
5	20	62.90	62.89	62.90	62.93
6	40	56.32	56.22	56.30	56.23
7	60	49.65	49.60	49.61	49.6
8	80	42.97	42.97	42.95	42.95
9	100	36.32	36.30	36.32	36.32
10	120	29.63	29.70	29.72	29.72
11	140	23.07	23.05	23.10	23.12

If the value is four sig figs then include the trailing 0.

If you drop that zero then it is 3 sig figs! This should have been 49.60!

For the subtraction all the uncertainties were the same; thus it was put in the top of a column; that was not possible for the average.

Do you know why there are only 2 sig figs here?

Table 2

Force (N) ±1%	Displacement $(x10^{-2}m)$					Spring Constant (N/m)
	Trial 1 ±0.07	Trial 2 ±0.07	Trial 3 ±0.07	Trial 4 ±0.07	Average	
0.00981	-0.28	-0.36	-0.37	-0.38	-0.35 ± 0.02	2.8 ± 0.2
0.0294	-0.94	-1.05	-1.02	-1.03	-1.01± 0.02	2.91± 0.08
0.0491	-1.60	-1.68	-1.67	-1.69	-1.66± 0.02	2.96± 0.05
0.0981	-3.13	-3.35	-3.34	-3.35	-3.29± 0.05	2.98± 0.05
0.196	-6.65	-6.66	-6.65	-6.62	-6.65± 0.01	2.95± 0.03
0.392	-13.23	-13.33	-13.25	-13.32	-13.28± 0.02	2.95± 0.03
0.589	-19.90	-19.95	-19.94	-19.95	-19.94± 0.01	2.95± 0.03
0.785	-26.58	-26.58	-26.60	-26.60	-26.59± 0.01	2.95± 0.03
0.981	-33.23	-33.25	-33.23	-33.23	-33.24± 0.01	2.95± 0.03
1.18	-39.92	-39.85	-39.83	-39.83	-39.86± 0.02	2.95± 0.03
1.37	-46.48	-46.50	-46.45	-46.43	-46.47± 0.02	2.96± 0.03

Average Spring Constant k = _2.94 ± 0.01 N/m_

Spring Constant k from Graph = _2.95 N/m_________

Calculate the standard error.

There is a way to find the uncertainty for slopes of graphs, but we will not do that in this course.

Remember to include units and uncertainty.

Name: ___*Your Name*_________

Part 2:

Mass of spring = *10.19 ± 0.02 x 10^{-3} kg*

Cross out mistakes with a single line; do not use white-out.

With 1% uncertainty in the slotted masses, the uncertainty for 145g is ±1g and for 55g, it is ±0.06g; thus for the smallest two loads, can be written in the form below.

Table 3

Load (x10^{-3} kg) (mass of spring) ±1%		145	105	55.0	25.0
Time for 20 oscillations (s) ±0.08	Trial 1 (small)	27.94	23.98	17.60	12.32
	Trial 2 (medium)	27.79	24.06	17.44	~~12.56~~ 12.40
	Trial 3 (large)	27.90	23.95	17.34	~~12.03~~ 12.34
Average 20 oscillations (s)		27.88 ± 0.04	24.00± 0.03	17.46± 0.08	12.35± 0.02
Period (s)		1.394± 0.002	1.200± 0.002	0.873± 0.004	0.618± 0.001
Period ^{2} (s^2)		1.943 ± 0.006	1.440 ± 0.004	0.762± 0.007	0.382 ± 0.001
k from Eq. (3) (N/m)		3.01 ± 0.03	2.97± 0.03	3.02± 0.04	2.94± 0.03

Do not cross out mistakes this way! Sometimes what you had was correct. You may want to be able to read it.

Average Spring Constant k = *2.98± 0.02 N/m*

Period was 12.35s/20= 0.6175s Uncertainty was 0.001; thus we write the period with 3 sig figs (0.618)

Spring Constant k from Graph = *3.01 N/m*

Spring's Effective Mass from Graph = *0.0040 kg*

% Difference between k in Part 1 and Part 2 = *2 %*

k in parts 1 and 2 was 3 sig figs; but the difference between the two values is one sig fig!!!!

Remember to include an uncertainty!

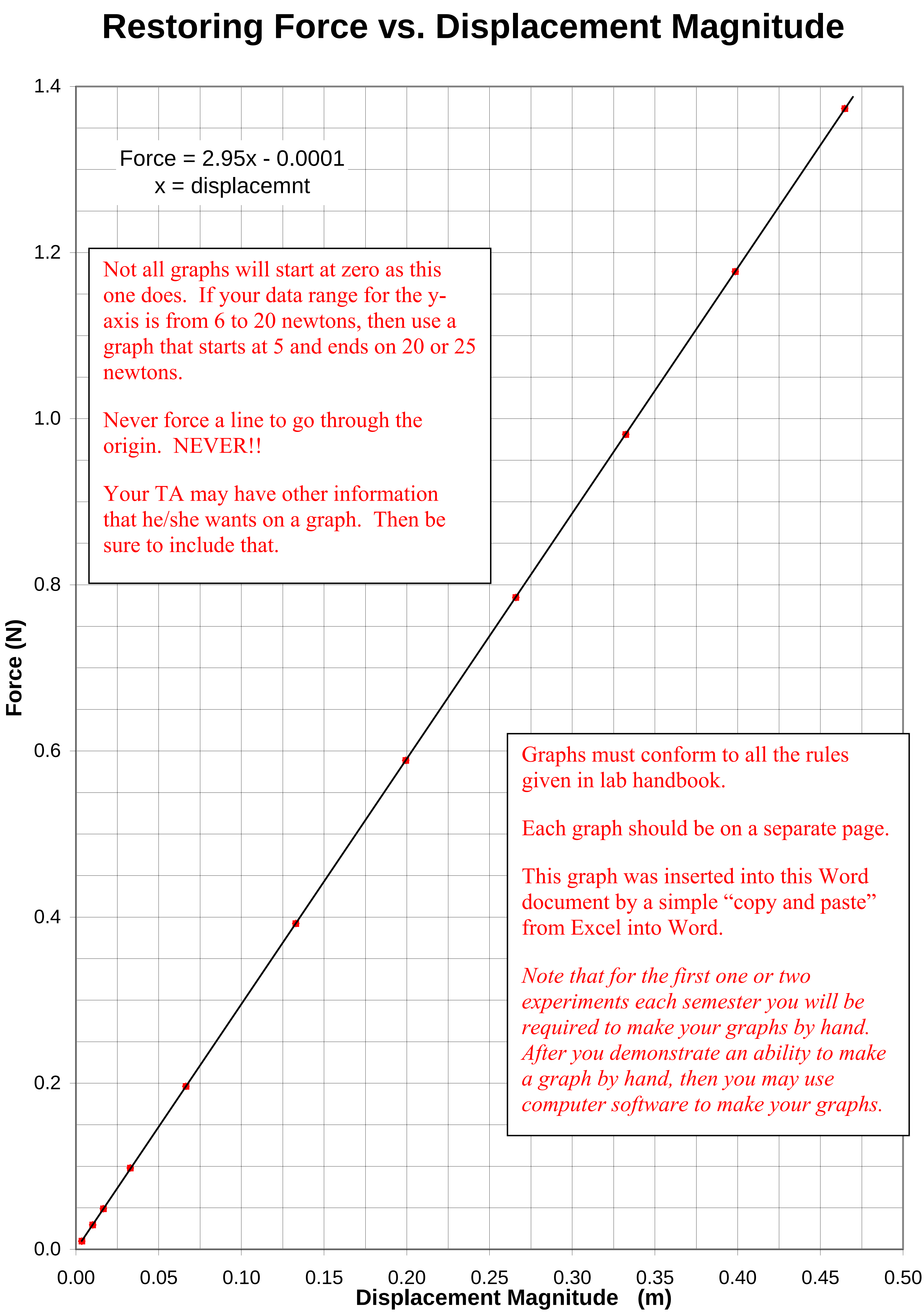
Guessing and then seeing what the value is for the average of a small number of trials helps build your ability to predict uncertainty.

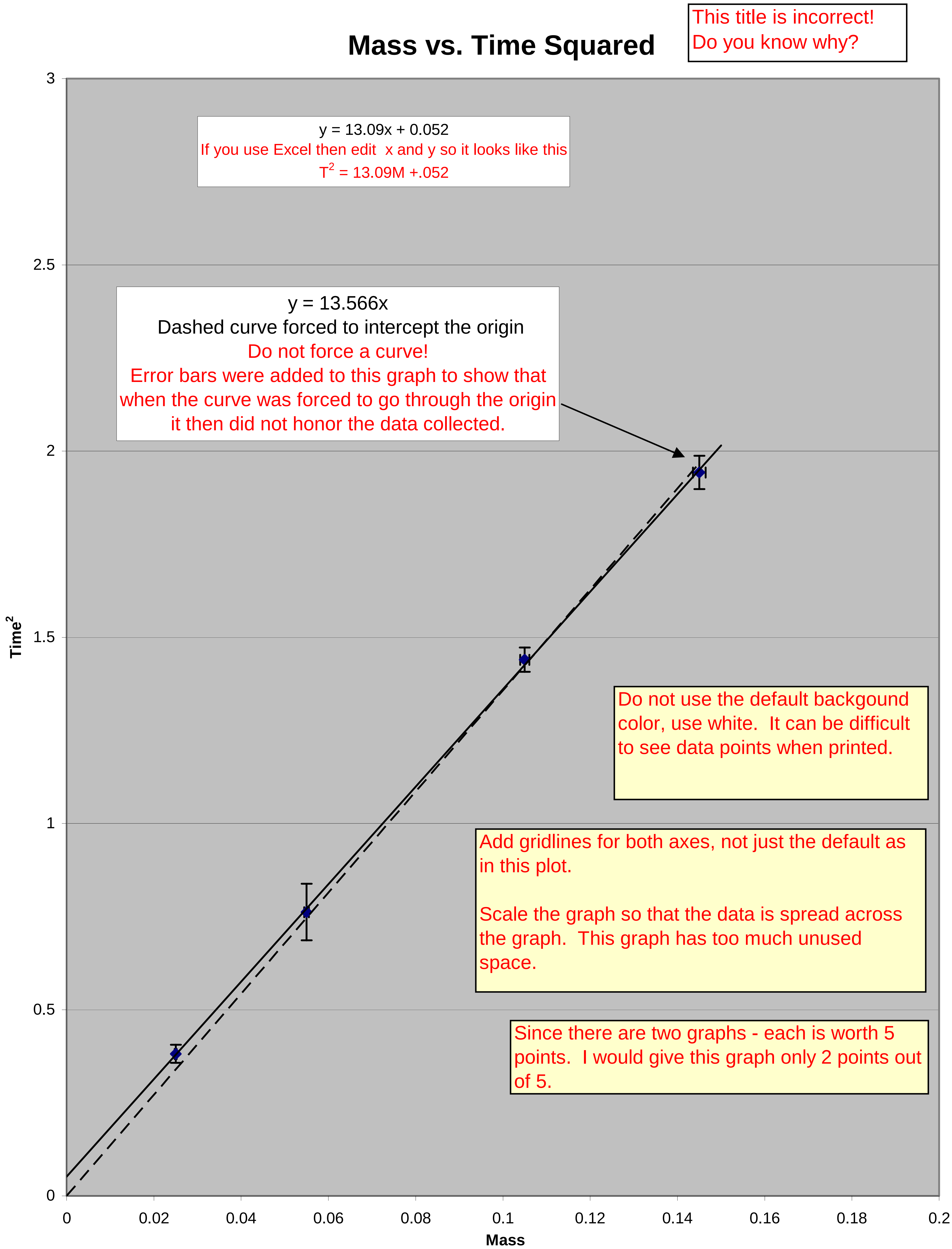
Why 0.08 in this case? One way to measure your reaction time is to have a friend hold a meter stick vertically between your thumb and first finger; note the cm mark between your fingers; the friend drops the meter stick, and you catch it. Determine how far it fell before your caught it. Since it had no initial velocity and the only force acting on the meter stick is gravity, then $d=\frac{1}{2}gt^2$. For most people, the distance the meter stick falls is about 15 cm. However, there is a difference between someone dropping a meter stick and timing an oscillating object. When timing an object, we can observe the motion and use the rhythm to reduce reaction time error. This might reduce the timing error to a third of the original value: $t_{reaction\ time}/3 = \text{sqrt}(2d/g)/3 = 0.06$ s

However, there are two uncertainties – starting the stopwatch and stopping the stopwatch; thus, we need to propagate the error. $\Delta t = \text{sqrt}(\Delta t_{start} + \Delta t_{start}) = \Delta t_{reaction\ time}\ \text{sqrt}(2) = 0.08$s

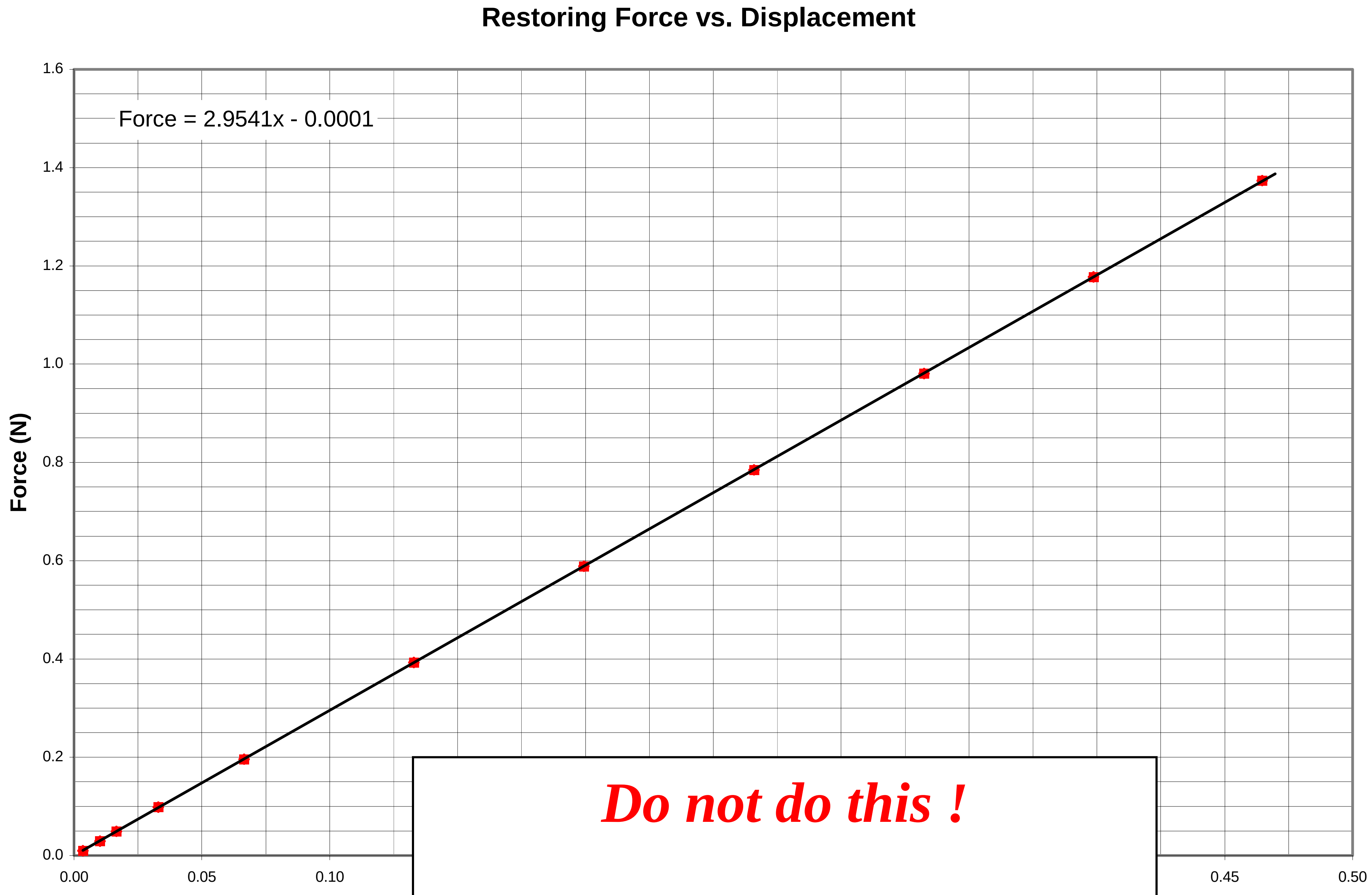
We might have made a different assumption, then we might have used had a value or 0.05 to 1.0 s.

Remember to include units and uncertainty


Restoring Force vs. Displacement Magnitude
Force = 2.95x - 0.0001
x = displacemnt
Not all graphs will start at zero as this one does. If your data range for the y-axis is from 6 to 20 newtons, then use a graph that starts at 5 and ends on 20 or 25 newtons.
Never force a line to go through the origin. NEVER!!
Your TA may have other information that he/she wants on a graph. Then be sure to include that.
Graphs must conform to all the rules given in lab handbook.
Each graph should be on a separate page.
This graph was inserted into this Word document by a simple "copy and paste" from Excel into Word.
Note that for the first one or two experiments each semester you will be required to make your graphs by hand. After you demonstrate an ability to make a graph by hand, then you may use computer software to make your graphs.
Force (N)
Displacement Magnitude (m)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

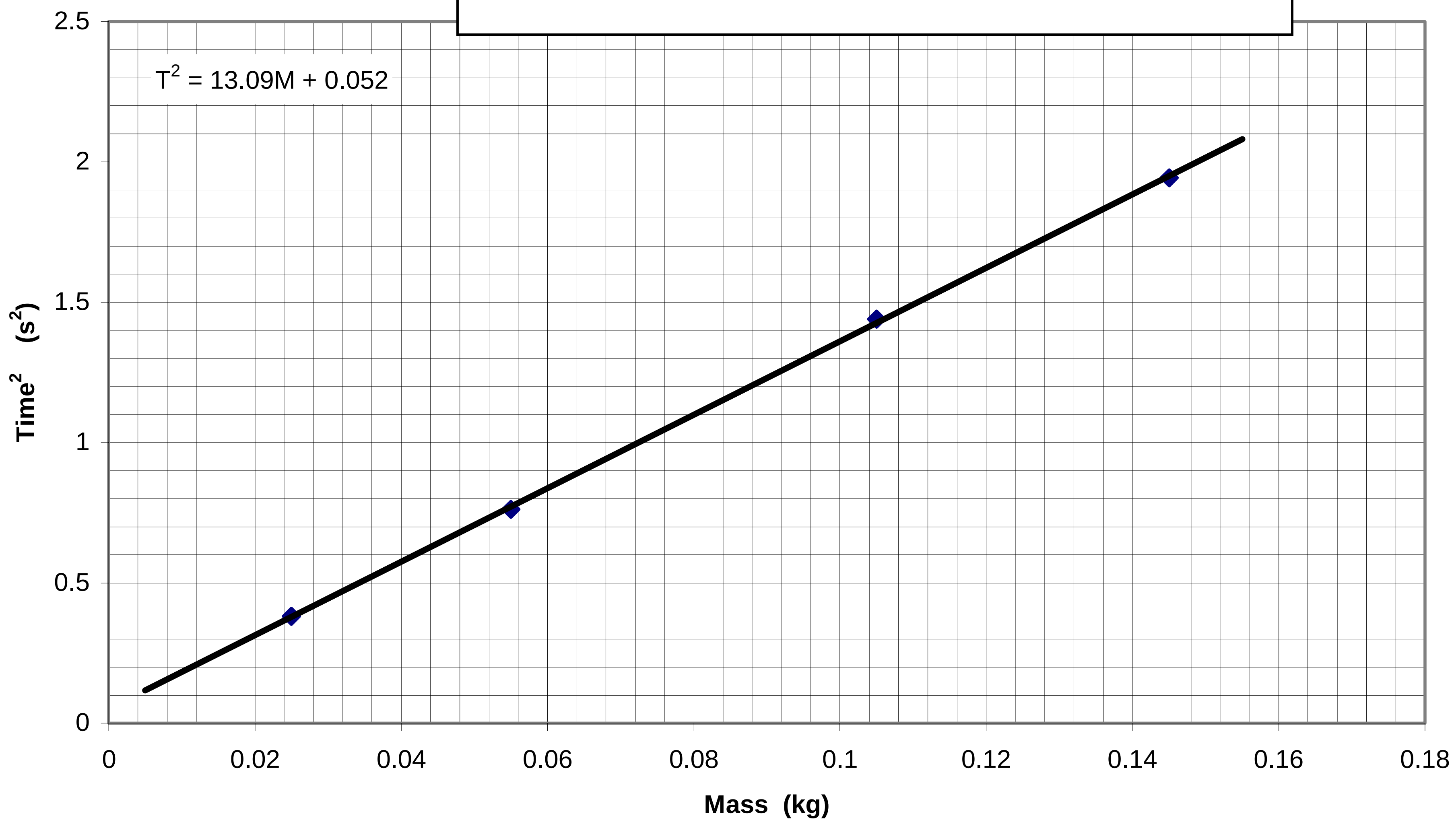


Mass vs. Time Squared
This title is incorrect! Do you know why?
y = 13.09x + 0.052
If you use Excel then edit x and y so it looks like this
T2 = 13.09M +.052
y = 13.566x
Dashed curve forced to intercept the origin
Do not force a curve!
Error bars were added to this graph to show that when the curve was forced to go through the origin it then did not honor the data collected.
Do not use the default backgound color, use white. It can be difficult to see data points when printed.
Add gridlines for both axes, not just the default as in this plot.
Scale the graph so that the data is spread across the graph. This graph has too much unused space.
Since there are two graphs - each is worth 5 points. I would give this graph only 2 points out of 5.
Time2
Mass
0
0.5
1
1.5
2
2.5
3
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2



Do not do this !

One graph per page. Not two or more per page and not embedded in text.



Sample Calculations

1. Displacement: the length that the spring is stretched

   x = Displacement = Location with Mass 1 (0.010kg) - Reference Location

   $x = 66.42\times10^{-2}\,m - 69.55\times10^{-2}\,m = -3.13\times10^{-2}\,m$

2. Uncertainty of displacement ($\Delta\ell$): Propagation of error for addition and subtraction

   $\Delta x = \sqrt{(\text{uncertainty in reference})^2 + (\text{uncertainty in location 1})^2}$

   $\Delta x = \sqrt{(0.05\times10^{-2}\text{m})^2 + (0.05\times10^{-2}\text{m})^2}$

   $\Delta x = 0.07\times10^{-2}\text{m}$

3. Force on spring from the hanging mass

   $F = mg$

   $F = (10.0g)(1kg/1000g)(9.81m/s^2) = 0.0981N$

4. Standard Error for Average Displacement for 0.9811N force

   $$\text{Standard Error} = \sqrt{\frac{\sum(x_i - \bar{x})^2}{(N-1)N}}$$

   $$\Delta x = \{[(-3.13\times10^{-2}\text{m} - (-3.29\times10^{-2}\text{m}))^2 + (-3.35\times10^{-2}\text{m} - (-3.29\times10^{-2}\text{m}))^2 + (-3.34\times10^{-2}\text{m} - (-3.29\times10^{-2}\text{m}))^2 + (-3.35\times10^{-2}\text{m} - (-3.29\times10^{-2}\text{m}))^2]/[(4-1)4]\}^{1/2}$$

   $\Delta x = 0.05\times10^{-2}$ m

5. Using Hooke's Law (F = - kx) to find the spring constant

   $k = -F/x$

   $k = -0.0981/(-3.29\times10^{-2}) = 2.98$

   No units! No credit would be given for this sample calculation.

6. Spring constant uncertainty: Propagation of error for multiplication and division

   $\Delta k = k\sqrt{(\Delta F/F)^2 + (\Delta x/x)^2}$

   $$\Delta k = 2.98\text{N/m}\sqrt{\left(\frac{0.01\times0.0981N}{0.0981N}\right)^2 + \left(\frac{0.05\times10^{-2}\,m}{3.29\times10^{-2}\,m}\right)^2} = 0.05\text{ N/m}$$

7. Spring constant from period of oscillation

   $$k = \frac{4\pi^2\{m_{load} + 1/3(m_{spring})\}}{T^2}$$

   $$k = 4(3.14)^2(145\times10^{-3}kg + \frac{1}{3}\left(10.19\times10^{-3}kg\right))/\left(1.392s\right)^2$$

   $k = 3.01$ N/m

8. Spring constant uncertainty: propagation of error for T^2

$\Delta A = nA(\Delta T/T)$ where $A= T^n$ $n = 2$

$\Delta T = 2(1.394s)^2(.002s/1.394s)= 0.006\ s^2$

9. Spring constant from the slope from T^2 vs. M_{load} graph

$$slope = \frac{(2\pi)^2}{k} \qquad k = \frac{(2\pi)^2}{slope}$$

$$k = \frac{(2\times 3.14)^2}{13.09\,\text{s}^2/\text{kg}} = 3.01N/m$$

10. Spring's Effective Mass, $M_{ES,}$ from the intercept

$$Intercept = \frac{(2\pi)^2 M_{ES}}{k} \qquad M_{ES} = \left(k \times Intercept\right)/(2\pi)^2$$

$$M_{ES} = \left(3.01\text{N/m} \times 0.052s^2\right)/(2\times 3.14)^2 = 0.0040\ kg$$

11. % difference for spring constant k

$$\%\ difference = \frac{\left|\text{Measured Value1 - Measured Value 2}\right|}{\left|\text{Measured Value1+Measured Value 2}\right|/2} \times 100\%$$

$$\%\ difference = \frac{|\ 2.94\text{N/m - }2.98\text{N/m}\ |}{|\ 2.94\text{N/m} + 2.98\text{N/m}\ |/2} \times 100\% = 1\%$$

Discussion

(One to three sentences are enough to introduce what was done. The procedure is in the lab manual. Do not rewrite the procedure. More than that is wasting your time and the lab instructor's time.) In part 1, a spring was hung vertically with a mass hanger attached to the lower end of the spring, and masses from 1g to 140g were added. The downward location of the spring was measured once it came to rest. *(A succinct explanation of the physics principle used in the experiment.)* In this configuration, two equal and opposite forces acted on the hanging mass: gravity directed downward and the spring's elastic restoring force directed upward, in the opposite direction of displacement. Using Hooke's Law (F = -kx), a spring constant was calculated for each measurement. *(How the result demonstrated a physics principle.)* The spring constants for each value of displacement are the same, within experimental uncertainty (Table 2), which verifies Hooke's law. *(Only the important result is provided. Not a list of each and every number on the data sheet. Note that final numerical values include an estimate of uncertainty.)* The average spring constant is 2.94±0.01 N/m.

(Analysis of graph: shape of curve, for a straight line, the meaning of slope and intercept for your graph.) A graph of force versus the magnitude of displacement resulted in the expected straight line in the range of forces examined and is consistent with Hooke's law. The slope of this line, 2.95 N/m, is the spring constant, which agrees with value found by taking the average of the calculated spring constant (2.94±0.01 N/m). *(You do not have to explain how they agree if you show the numbers or refer to a Table; but do not write that values agree without some reference.)* The intercept for the best fit straight line intersects close to the origin, which is also consistent with Hooke's law.

(Sources of error are offered that are consistent with the experimental results.) The sources of error in this part of the experiment are due to the precision of the location measurement using the meter stick and the accuracy of the slotted masses. The meter stick was mounted vertically and behind the spring. The location was measured relative to the base of the mass hanger. Effort was made to sight the measurements directly; however, because of the location of the meter stick it was necessary to view the meter stick at a slight angle. However, this sighting was required for each measurement, and the displacement was the difference between the location and the reference. Thus, this systematic error due to parallax should be minimal. However the random error of measurement precision remains. For displacements 20 cm or more, the uncertainty of the displacement of the spring is 0.5 % or less and has little impact on the uncertainty of k; in those cases the 1% uncertainty in the slotted masses has the greatest contribution to the uncertainty of k. However, for small displacements the displacement uncertainty has the largest impact on the uncertainty in k. For example, the 1.0 g mass displaced the spring by -0.0035 ± 0.0002 m, a relative uncertainty of 6%. *(You may offer a suggestion for improving the experiment, but it must focus on the most prominent error and be consistent with the sources of errors. This is not a place to "trash" the experiment.)* Using a motion sensor to measure distance would increase the precision for small displacements.

(A brief introduction to part 2.) In Part 2, we determined k dynamically using the period of an oscillating mass. The time for twenty oscillations was measured for five different masses; for each mass the period of oscillation was measured three times using different oscillation amplitudes, as suggested by out lab instructor. *(A succinct explanation of the physics*

principle used in the experiment.) The period of a mass oscillating vertically on a spring depends on the spring constant and the mass of the oscillating object, but not on the amplitude of the oscillation. *(How the result demonstrated a physics principle.)* Our measurements confirmed that the amplitude of oscillation, within experimental uncertainty, did not affect period (Table 3),

To reduce the reaction time, we observed the motion and used the rhythm to start and stop the stopwatch. *(How the independent variables affected the dependent variables.)* For small masses, the period of the oscillation is shorter; this is consistent with Eq (2). These shorter periods for the 55g and 25g masses made accuracy in the timing both critical and difficult. The measured times for 20 oscillations of the 55g mass are not as consistent as for the other masses. This was the result of reaction time random error. Two measurements for 20 oscillations of the 25g mass were so different from the other measurements that we made additional measurements and replaced those data points. There was another complication for these smaller mass, large amplitude oscillations caused the slotted masses to bounce on the mass hanger. This meant that we had to use smaller amplitude differences between the large and small amplitude oscillations for the smaller masses.

(You may need to combine two equations.) Using Eq (3), we found k for the four different loads added to the spring. The four values of k for the four different masses were in agreement (Table 3). The average value of k is 2.98±0.02 N/m. *(Always include units; 2.98± 0.02 without units would be meaningless.)*

(Analysis of graph.) A graph of T^2 vs. M_{load} is a straight line and consistent with the theory that the period is a function of the effective mass of the spring and the spring constant of the spring, Eq, (4). *(Important results.)* The spring constant k from the slope is 3.01 N/m; the effective mass of the spring M_{ES} from the intercept of the best fit line is 4.0g, which is approximately 40% of the mass of the spring, which is somewhat higher than the fraction used in Eq. (3).

The sources of error in this part of the experiment are due to the accuracy of the slotted weights and the accuracy of the time measurements. *(There is no need to repeat what you have already discussed.)* As mentioned previously, the reaction time uncertainty is greater for the smaller loads. However, due to the care that taken in the time measurements and the fact that 20 different oscillations were measured, the uncertainty in the time measurements was not as important in this experiment as the uncertainty in the slotted masses. There is uncertainty (1%) in the mass of the slotted weights. It would have been prudent to have measured the masses on the triple beam balance so that we would have less uncertainty in the mass of the oscillating weights; however, we did not make those measurements.

The value of the spring constant found in Part 1 (2.94±0.01 N/m) and Part 2 (2.98± 0.02 N/m) do not agree. *(Discuss how results agree using either uncertainty and/or percent differences.)*However, the percent difference between the two values is only 1%. One possible explanation for the small discrepancy may be that the time measurements were precise, but not accurate due to a systematic error in the timing. If our time measurements of the twenty oscillations were low by as little as 0.05s, then the spring constant values would agree.

(A brief conclusion.) Besides measuring the spring constant using two very different methods, we verified Hooke's law, verified the linear relationship between period squared and load for a vertically oscillating spring, and observed that the amplitude of the oscillations did not affect the period.

Answers to Questions (if any): Answer questions in complete, grammatically correct sentences.