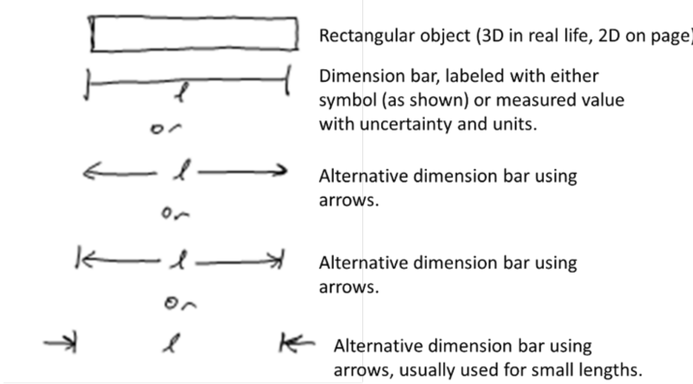
Anatomy of a Notebook

Lab notebooks are primary records of experiments, with entries created at the time of data collection. These notes should be sufficient for someone else familiar with the equipment to reproduce that experiment and achieve similar results. They should be written in pen, you should simply cross out mistakes with a single line.

1. **Title of Lab**
2. **Names of lab group members (name for group optional)**
3. **Date of lab**

4. **Procedure**
   Describe the methods you employed to collect the data and the design of the experiment. This should also include information on the purpose of the experiment.

5. **Schematic**
   Most of the experiments that we will do this semester will have an apparatus that is important to detail within a schematic. It is a great way to show and define the quantities that you measure. These should be representative sketches and not fancy 3D drawings. The quantities you measured should be clearly labeled on the schematics. Every length you measure should be indicated with a labeled dimension bar, as shown.



6. **Data**
   Data include qualitative observations and quantitative measurements. All the raw data in the lab should be present within the notebook. If you decide to not use specific data from a data set, you should still include it in your notes, but with an X through the data to show you threw it out. Scientists do not erase raw data from their notebooks. You should also include additional details of the experimental set-up and any specific methods that you employed, as well as any observations you've made during the experiment. These details might include:
   - Were there specific settings on the instrument that you used?
   - Did you take a particular approach when measuring?
   - Did you do something to reduce error?
   - Was there something unique about your set-up?
   - Any other notes that would be important to understand and reproduce your data

   This section can also include diagrams, graphs, and tables. All numbers must include units and all graphs should be properly labeled with axes and titles/captions.
7. **Analysis and Results**

This can be done separately for each section of the experiment. Include equations and algebra with uncertainty propagation as required to achieve your results, and put a box on any important results. The process that you have used to get to these results should be clear.

8. **Summary and Conclusion**
   Assess your results and what they mean. What do the results show? Are they consistent with your hypotheses? With other data? Is there evidence of a systematic error? Comment on sources of error and other approaches that might improve the measurements (if any). What is the 'take home' message from this experiment? You may find it quite helpful to discuss this section especially with your lab groupmates.

Grading Lab Notebooks

I will consider the following list of items when evaluating your submitted work:

Repeatability

Is the procedure correctly summarized in the students' own words? Does the student say what they did?
Are parts of the procedure that were not specified in the instructions also included?
Does the schematic drawing include everything important to the procedure?
Does the schematic avoid unnecessary detail?
Is the schematic well-labeled?
Could another physics student use your written record to repeat the experiment?

Analysis

Is the raw data displayed in an organized manner and appropriate format?
Are all algebraic symbols and measured quantities clearly defined in words or with a schematic?
Are observations clear?
Are all necessary plots included?
Are all axes clearly labeled? (Axis labels may be in English or with clearly-defined algebraic symbols. Don't forget units!)
Does the schematic drawing include everything important to the analysis?
Did the student solve the puzzle of how to take the measurement and use the data to arrive at a conclusion?

Correct Physics

Is the physics correct?
Are all of the units correct?
Does the write-up describe the most important physics at play?
Are equations accurate and relevant?
Are calculations shown as necessary?
Is uncertainty propagated correctly throughout the calculations?
Do the results and conclusions follow from the raw data?
Was there evidence of a systematic error and/or a random error?

Example Lab Notebook (followed by the relevant lab handout)

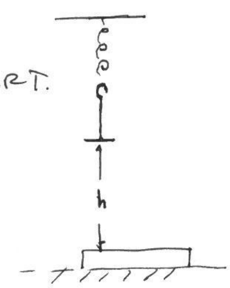
ENERGY CONSERVATION 20 JAN 2003

LAB PARTNER: LOIS SCHRÖDINGER

PART (0)

(a) START WITH 70 g mass (50 g hanger + 20 g)

(b.) ~~ADD~~ MEASURE HEIGHT ~~x~~ h + UNCERT.



(c.) ADD MASS

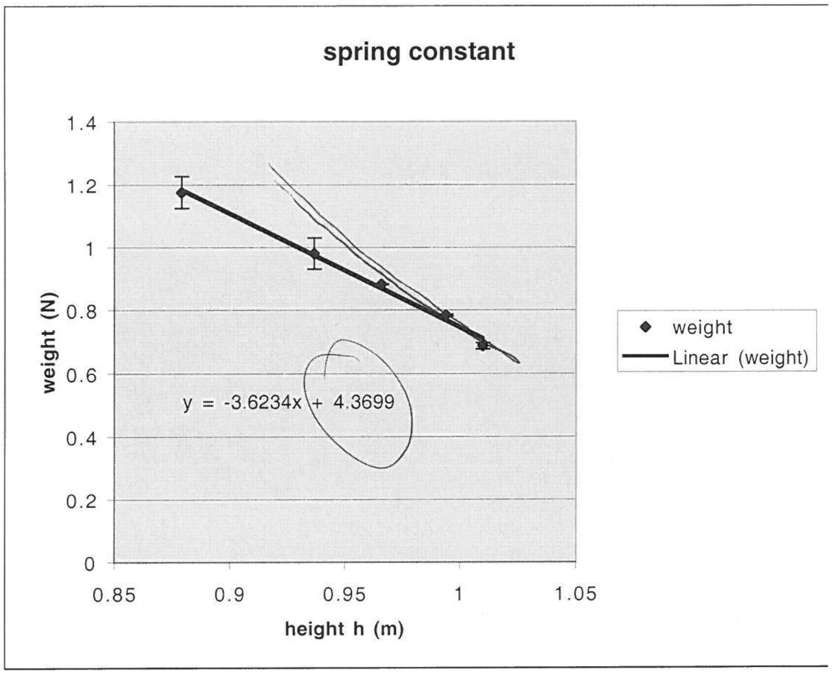
(d.) DO (b) & (c) FOR VARIETY OF MASSES

(e.) FIND ~~x~~ K VIA $\frac{\Delta F}{\Delta h} = \boxed{g \frac{\Delta m}{\Delta h} = -k}$

		h	δh	WITH STATS	
①	70g	1.01	± 0.01	1.017	0.007
②	80g	0.994	± 0.003	0.994	0.001
③	90g	0.966	± 0.002		
④	100g	0.937	± 0.05	0.937	0.003

height	mass	weight	errors in h
1.01	70	0.686	0.01
0.994	80	0.784	0.003
0.966	90	0.882	0.002
0.937	100	0.98	0.05
0.879	120	1.176	0.05

k
6.125
3.5
3.37931034
3.37931034



~~POINT (1) NON-LINEAR REGIME SEE PLOT~~

TAKE MORE DATA!

(5) 120g 0.879 ±0.05

PLOT LOOKS ABOUT RIGHT.

USE LAST TWO VALUES IN EXCEL SHEET (NOTE Y-INTERCEPT)

=> $\boxed{k \simeq 3.4 \pm 0.1 \text{ N/m}}$

PART I

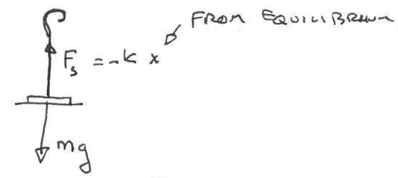
(1) EQUILIBRIUM POSITION 100g

$\boxed{h_o = 0.936 \qquad \delta h_o = 0.001}$

USED STATS AND $\frac{\text{MIN}-\text{MAX}}{2}$

(4) ~~Hold~~ / AND WHAT KINDS OF ENERGY DO I NEED?

LOOKS LIKE TWO TYPES OF FORCES.



⇝ 2 TYPES OF POTENTIAL? LET'S SEE

$U = \frac{1}{2}kx^2$ X MEASURED FROM EQUILIBRIUM

$$= \frac{1}{2}(k)(h-h_0)^2$$

$$= \frac{1}{2}kh^2 + \cancel{\frac{1}{2}kh_0^2} - khh_0$$

CONSTANT: NO PHYSICS HERE!

WHAT IS THAT LAST TERM?! HOW IS h_0 DEFINED?

— AT EQUILIBRIUM $mg = kh_0$ AH! SO

$-khh_0 = -mgh$ THE GRAV. POTENTIAL!! (THE − SIGN OCCURS SINCE $\uparrow +$ FOR h) SO ~~X~~ IF I WRITE $U(x)$ (FROM EQUILIBRIUM) ~~IT~~ $\frac{1}{2}kx^2$ ACCOUNTS FOR ALL POTENTIALS!

HOORAY! IT IS EASY:

$$\boxed{E = \frac{1}{2} m v^2 + \frac{1}{2} k x^2}$$

WITH $x^2 = (h - h_0)^2$

(5.) – (6.)

OH DEAR, YUCKY DATA – MOTION SENSOR MUST HAVE SEEN MY HAND

(7.) · LOWER h IS 'BETTER' SMOOTHS OUT THE E CURVE

- LOWER k ALSO 'LOOKS' BETTER

CHANGING EQUILIBRIUM POSITION RENORMALIZES THE POTENTIAL ENERGY.

ROUGH CALC OF ~~var~~ % UNCERT:

AT $t = 4\,s$ $\quad E = \frac{0.01284 - 0.01227}{0.01284} \sim 4\%$

(9.) SEE PLOT

- ENERGY IS CONSERVED WHEN THE MOTION 'LOOKED GOOD' ~ 4.2s – 7s ACCOUNTING FOR UNCERTS. (PERHAPS UNDER ESTIMATED? DIDN'T INCLUDE UNCERTS IN K AFTERALL.)

- AT THE 'RELEASE POINT' CRAZY THINGS HAPPEN. SYSTEM <u>LOOSES</u> ENERGY (OR ~~DETATOR~~ DETECTOR SEES HAND.)

- I'M NOT SURE WHAT HAPPENED AT THE END $\gtrsim$ 8s – LATERAL OSCILLATIONS??

- ON LONG (~ 6s) TIME SCALES THIS LOOSES ENERGY, PERHAPS DUE TO DRAG?

IN SUM,

- IT IS POSSIBLE TO ACCOUNT FOR mgh POTENTIAL WITH $U = \frac{1}{2}kx^2$ WHEN x IS MEASURED FROM EQUILIBRIUM

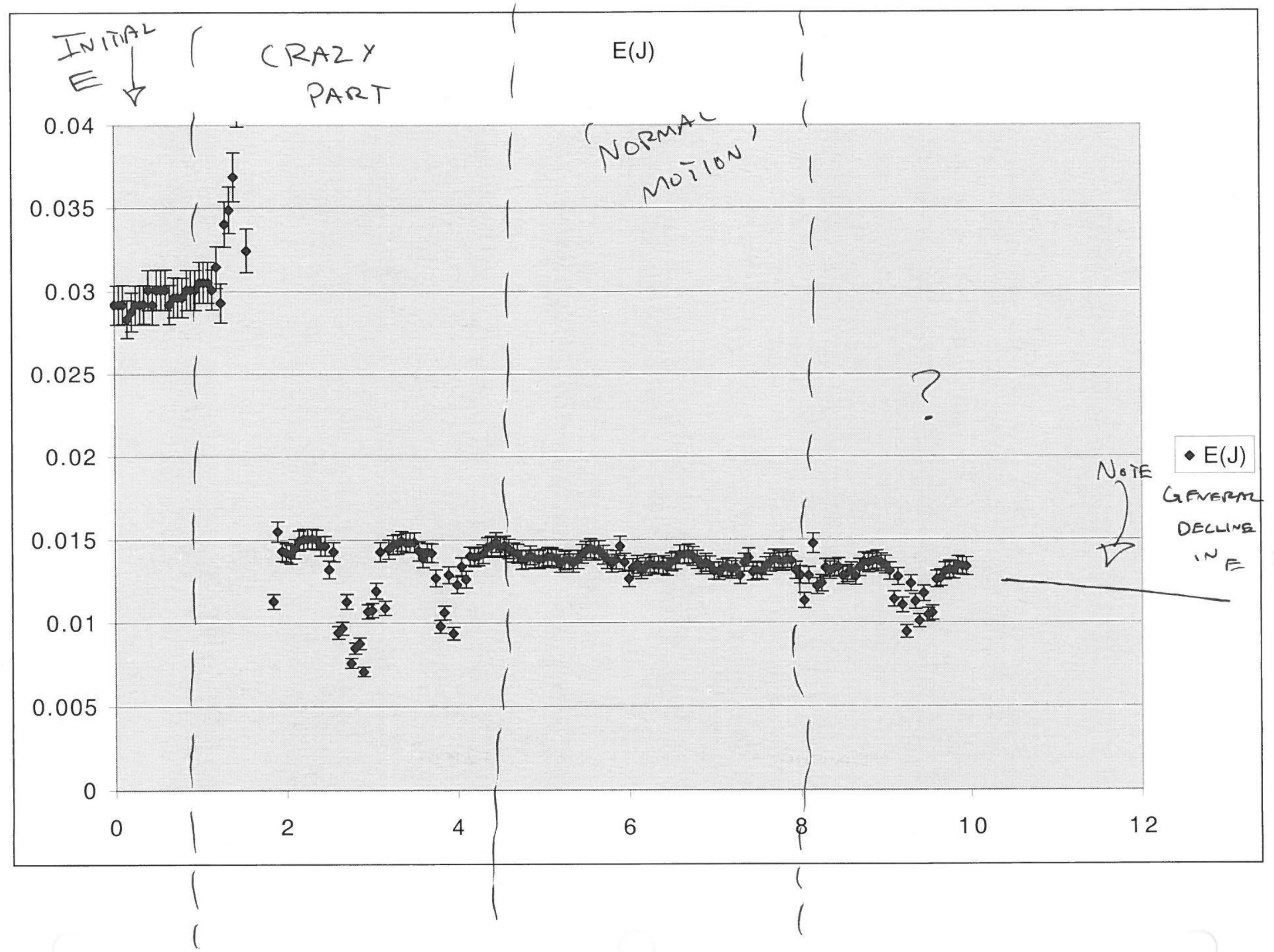
- THANKS TO UNCERTAINTY IT IS POSSIBLE TO TEST CONS OF E EVEN WITH 'NOISY' DATA

- 'THERE BE DRAG HERE' (OR SOME MECHANISM REDUCING TOTAL E.

- WORTH TAKING CARE ON DATA COLLECTION

- ONLY WITH FURTHER TESTS CAN WE DETERMINE WHETHER E IS CONSERVED IN THIS SYSTEM

- ARE THERE BETTER WAYS OF 'DOING' UNCERTs? E.G. $\delta h \to \delta E$?


INITIAL E
CRAZY PART
E(J)
(NORMAL MOTION)
?
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
2
4
6
8
10
12
◆ E(J)
NOTE GENERAL DECLINE IN E !

ENERGY CONSERVATION AND UNCERTAINTY

Objectives: • Review energy of a simple mass on a spring.
• Investigate conservation of energy in the mass on a spring system.

To Do Before Lab:
• Read this lab
• Read Taylor Ch. 1 and 2.1-2.3 (15 pages)
• Think about Part 0 (1)
• What is the energy of a spring/mass system?

Apparatus: Sonic ranger, k= "3.5" Nm^{-1} spring, mass hanger, 50 g mass, labels, Mac-motion, Excel

Introduction:
When investigating physical systems it is very useful to have a quantity which stays the same, an *invariant.* For example, in dynamical systems with no frictional forces, total mechanical energy is conserved; it stays invariant during the time evolution of the system. Such invariants are very useful when solving problems. On a more fundamental level they are also very useful because the existence of an invariant usually means that there is a symmetry behind it. This is a great aid in formulating a physical theory.

However, it is a matter of experiment to determine whether a quantity is in fact an invariant. Is the initial quantity equal to the quantity some time later? The answer always comes down to the question of uncertainties. This lab will take a close look at how you can determine whether energy is conserved.

Part 0: Spring Constant
(1) As a class or in lab groups decide on a procedure to find the spring constant of your spring. Record your procedure and write out the formula to find k. Box this equation. It will be very useful.

(2) Set up the sonic ranger and mass hanger so that you can accurately record the height. Use the sonic ranger to find the equilibrium height (and its uncertainty of course) of the mass hanger. Use the formula from (1).

(3) Find an uncertainty in k by first recording your lowest and highest positions then finding the corresponding value for k. Finally record your result as your best estimate plus/minus the range. Assume the masses and g are exact.

(4) Identify your spring with the labels provided so your group can use the same one next week.

Part I: Data and Energy
We will use the sonic ranger to record the position vs. time of your mass on a spring. This data can then be copied into Excel where we can compute the energy.

(1) Set up the sonic ranger and mass hanger so that you can accurately record the full motion. Use the sonic ranger to find the equilibrium height and its uncertainty. How can you use the ranger to find the uncertainty? The "Analyze Data A" feature is most helpful. Change the scale on the axes in MacMotion to better see the uncertainty due to noise.

(2) Before making a quantitative measurement of the energy of the pendulum you need to adjust MacMotion to reduce a systematic error. In the interest of producing nice smooth curves, MacMotion averages a number of distance measurements to determine the velocity. You can increase the accuracy by changing the **Collect:Averaging** to 3 points instead of 7. This will improve the accuracy of the velocity values calculated by MacMotion at the cost of increasing the "noise" in your graphs.

(3) Starting with the mass pulled down and at rest, record ~15 seconds worth of data. If all goes well, your plot will show a little level piece before the oscillations. Under the 'Windows' menu select 'Data A Table' to view the raw data. Start up Excel and copy the data table directly from Mac-motion into the Excel worksheet. Leave space at the top for labels and constants. Delete the acceleration and force columns.

(4) Now find the total energy: Using your book, memory, last week's homework, or other means find the expression for total mechanical energy. Recall that this has two parts, kinetic and potential. How do the variables you used in the energy compare with what the sonic ranger measures (and what you have in your spreadsheet)? Perform the necessary conversion and enter this into a new column in your worksheet.

> Note: Excel uses two different kinds of addresses: **relative** and **absolute**:
> A **relative** reference is like giving someone directions that explain where to go, based on where the person starts--"Go up 2 blocks and over 1." A relative reference tells Excel how to find another cell, starting from the cell that contains a formula. "A4" is a relative reference. If you type a formula in C4, which refers to A4, you are telling the computer to use the number 2 columns to the left in the calculation.
> An **absolute** reference tells Excel how to find a cell based on its exact location in the spreadsheet. To make a reference absolute, dollar signs are added before the column and row labels: "A4".

(5) Now enter the energy formula into Excel. Use absolute referencing for your constants including the equilibrium position and your spring constant from Part 0

(6) Graph the total energy as a function of time. What do you think?

(7) Find the fractional uncertainty due to uncertainty of the equilibrium position, which is one of your constants.

> Note: One way to estimate the uncertainty in energy is to type in the minimum equilibrium position in Excel and record the new initial energy for this value. Do this again for the maximum value for the equilibrium position. With the difference of these energies you can find the fractional uncertainty. Express this as a percentage.

Qualitatively, how do you think the energy changes when the equilibrium position varies a little? Is there a way you could derive the effect on the total energy of slightly changing the equilibrium position?

DOMINANT ERROR IS IN K?

(8) Add uncertainties to your plot by double clicking on a data point. Select "y error bars" in the pop-up window and enter your percentage. Your plot should now resemble a snake with hedgehog tendencies.

(9) Now some physics! **Is energy conserved?** Answer this carefully. Instinctively we know that the mass will not bounce forever. Is mechanical energy conserved on short times scales of a few cycles? What about on longer scales (such as 15 seconds)? Use your data and uncertainties when you answer these questions.

WIGGLES WON'T GO AWAY!

STAND OSCILLATES THROWING h₀ OFF?