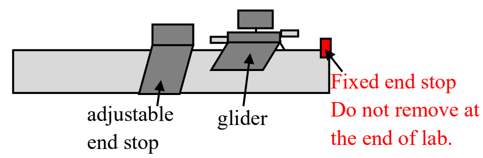
Mass Spring System

Apparatus: Air track glider (1 per track), air tracks, air track accessories kit, air track springs, air supply hoses & power cords, air track adjustable end stops, air track connectors, hanging mass sets, scissors, photogate heads, photogate interface cables, photogate stands, pulley cord or string, meter sticks, calipers, PASCO Science Workshop 750 Interface & Power Supplies

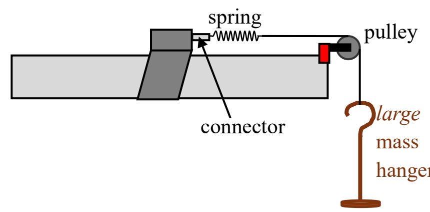
Goals: 1) Determine a spring constant using a plot of distance stretched versus hanging mass.
2) Compare theoretical & experimental oscillation rates of horizontal mass spring systems.

Before taking any measurements: Make note of how air track accessories are stored. We need your help to keep the many small parts organized! Please get *all* those small pieces back in the kit properly as replacement are pricey.

Part 1 – Determining Spring Constants



Level the air track by placing a glider on it. The figure at right is not to scale. It is impossible to perfectly level the entire track; focus on one end.
Turn on the air supply to approximately 2/3 of its maximum.
Release the glider from rest to determine the direction it slides.
Use shims under the air track legs to level the track.
The track is leveled if the glider barely moves upon being released.
Do the best you can in no more than 5 minutes. It will never be perfect.



Once the track is leveled, put the glider away until Part 2 of this lab.
Set up the system shown at right using the *large* mass hanger ($5\underline{0}$ g).
Ensure the string does not drag on the fixed end stop.
To ensure the spring never hits the end stops, keep the adjustable end stop near the middle of the air track.

TURN OFF THE AIR SUPPLY WHEN NOT IN USE.
You wouldn't think it, but running 10 air supplies eventually fatigues your ears.
Turn off the air supply when you finish taking data and need to grind through work in Excel (next page).

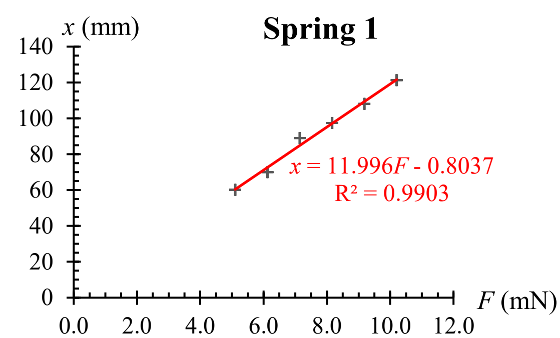
With the air supply *off*, allow the large mass hanger to reach equilibrium.
Measure x, the equilibrium distance stretched when using $5\underline{0}$ g (the mass of the hanger itself).
Note: we're using x instead of Δx to make it easier to discuss errors.
Increase the hanging mass in $1\underline{0}$ g increments until you reach $10\underline{0}$ g.
For each mass, record both the hanging mass & force applied (in units of N) as well as x.
Include error estimates for all measurements in your data table.

Repeat this data collection for a second spring.

Part 1 Continued
Plot x versus F for each spring.
WATCH OUT! This means force appears on the *horizontal* axis while distance is on the *vertical* axis.
Technically the independent variable in this experiment was m (and in turn F).
It is standard practice to put the independent variable in an experiment on the horizontal axis.

Format the plot well. Training videos are linked below.
When grading 60 reports quickly, poorly formatted work slows me down (and you lose points).

A fake plot is shown at right so you can clearly see what is expected of you.
If your plot formatting is sub-par, expect significant deductions.
TIP: save a template (on a flash drive) after doing the formatting.
Why? Formatting plots the rest of the semester is *much* faster.



I made a training video to help you.
https://www.youtube.com/watch?v=2QdBuRXkYTE&list=PL4Sl1ZPMcTDVt4a2PadxWx9d3EWoBZV3n&index=2
If you choose to use something other than a local copy of Excel on a lab computers, it is on you to figure out how to format things properly.

- The online version of Excel loses some key functionality.
- Using google sheets frequently causes headaches.
- Some shortcuts in the vid do not work on Macs…

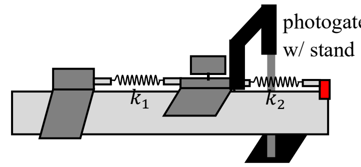
This next video shows how to replace data points with error bars (at 5:30) and use LINEST (at 10:30).
https://www.youtube.com/watch?v=EuXrl-NZ2zQ&list=PL4Sl1ZPMcTDVt4a2PadxWx9d3EWoBZV3n&index=4
Note: if for some reason the error in your slope is ridiculously small, talk to your instructor for error analysis.

Once your plots are well formatted, determine the spring constant from each *plot* (*not* the data tables).
For a linear plot, we typically say

$$vertical\ coordinate = slope \cdot (horizontal\ coordinate) + intercept$$

For the plots in this lab, the vertical coordinate is x and the horizontal coordinate is F.
Think: does the slope correspond to k or $\frac{1}{k}$? Also, think about the units on the slope if we use mm & mN.

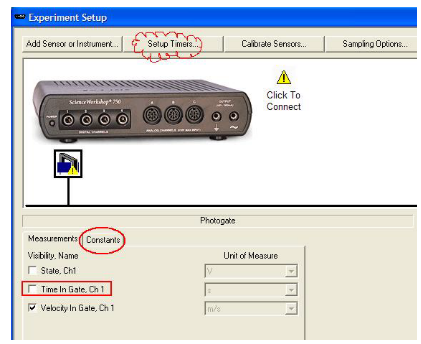
PART 2 – Mass Spring Oscillations



Now set up the apparatus shown at right.
Position the adjustable end stop so each spring (k_1 & k_2) is stretched at least 25 cm.
Turn on the air supply (at max power this time) and pull the glider a small distance (perhaps 15 cm?) *to the left*.
Release the glider from rest and watch it oscillate.
Verify both springs are under tension during the entire oscillation.
Position a photogate such that the glider flag enters the photogate *but does not pass all the way through*.
Verify the flag enters the photogate (*but does not pass through*) for several oscillations in a row.

Open DataStudio and set up an oscillation timer.
Click on Channel 1 and select a “Photogate” in the pop-up window.

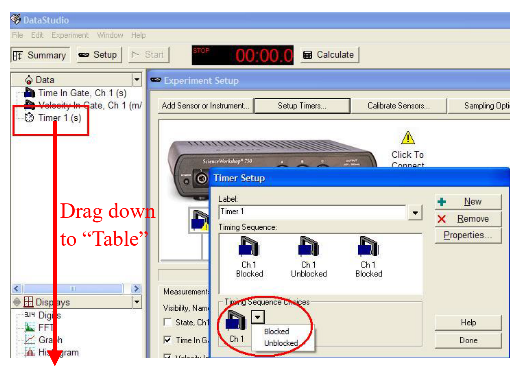
Set up the photogate to time an entire period of oscillation.
Click on the “Setup Timers…” button.



In the pop-up window, select the following timing sequence:

BLOCKED-UNBLOCKED-BLOCKED

This starts the timer when the flag first enters the photogate and stops it when the flag re-enters the photogate (exactly one period).



When done setting up the timer, look on the left side of the main window.
Drag “Timer 1” down to “Table” as shown.

Hot the start button near the top of the screen and you should be ready to record the period.

Do a test run to verify the periods measured in the table match what you get with a stopwatch (or your phone).
Once this looks right, we can assume the photogate will do a much better job than using a stopwatch.

Part 2 Continued
Determine the mass of the glider including all attachments (flag and two connectors).
Pull the glider to the left and record the periods of five oscillations and average them.
Record this value in the spreadsheet as T_{exp}. I used T instead of $\mathbb{T}$ to save time creating the spreadsheet.

Think: δT_{exp} is found using the standard deviation.
If the standard deviation is tiny, we'd use $\frac{\delta T_{exp}}{\sqrt{N}}$ where δT_{exp} is the error associated with measuring a single period.
Note: the manufacturer states the resolution of the timer in the image show at right. This sets a lower limit on δT_{exp}.

Product Specifications

Photogate Width	7.5 cm
Fall Time	<50 ns
Spatial Resolution	<1 mm
Timing Resolution	0.1 millisecond
Connector	Stereo phone plug

Repeat this data collection two more times with additional masses placed on the glider.
Always load the air track symmetrically.
During your *first* repeat, place *one* additional mass on each side of the glider.
During your *second* repeat, place *two* additional masses on each side of the glider.
The additional masses are in the air track accessories kit and look like the image at right.
Assume each additional mass is 50.0 g.

TURN OFF THE AIR SUPPLY WHEN NOT IN USE!
WATCH OUT! Leave the apparatus entirely set-up until *after* answering the conclusion questions.
Having the apparatus to play with will probably help with is at least one conclusion question!

The theoretical formula for the period is

$$T_{th} = 2\pi\sqrt{\frac{m}{k_{eff}}}$$

While it is not obvious, the two springs in our apparatus operate in parallel with

$$k_{eff} = k_1 + k_2$$

WATCH OUT! Think carefully about what units to use for glider mass when using this formula!
Record the **three *theoretical* values** of the period from your calculations.

Based on propagation of error formulas, we expect

$$\delta T_{th} = T_{th}\sqrt{\left(\frac{1}{2}\cdot\frac{\delta m}{m}\right)^2 + \left(\frac{1}{2}\cdot\frac{\delta k_{eff}}{k_{eff}}\right)^2}$$

Compute of percent difference using

$$\%\ \text{difference} = \frac{\text{exp} - \text{th}}{\text{th}} \times 100\%$$

Also compute net percent precision using

$$\%\ precision = \left[\left(\frac{\delta T_{exp}}{T_{exp}}\right)^2 + \left(\frac{\delta T_{th}}{T_{th}}\right)^2\right]^{1/2} \times 100\%$$

Before cleaning up the lab, answer the conclusion questions on the next page.

CONCLUSIONS:

1) Does simple harmonic motion theory accurately predict the period of oscillations for a mass spring system? Answer this question by comparing the % precision to the % difference.
2) What effect does increasing amplitude have on the period of the system?
   Does the period increase, decrease, stay the same, or is it impossible to determine?
   Explain your rationale.
   Turn on the air compressor and verify your answer matches what you see experimentally.
3) What effect does increasing mass have on the period of the system?
   Does the period increase, decrease, stay the same, or is it impossible to determine?
   Explain your rationale.
   Did your experiments match your prediction?
4) In this experiment we assumed the error associated with g (the magnitude of acceleration due to gravity).
   Do you think this was a reasonable assumption?
   Support your answer by including a table with percent errors associated with each *measurement* in a table.
   Think before you write: which parameters were *measured* versus *calculated*?
   For instance, was force measured directly or was it calculated from a direct measurement?
   Percent error of a measurement is given by

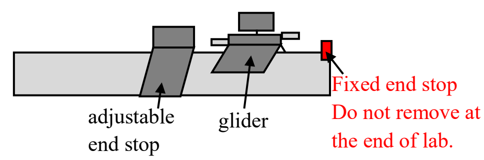
$$\%\ error\ of\ x = \frac{\delta x}{x} \times 100\%$$

TURN OFF THE AIR SUPPLY WHEN NOT IN USE!

Now clean up the lab.

Remember to leave the fixed end stop on the air track.

A submission checklist is on the next page.



Submission Checklist

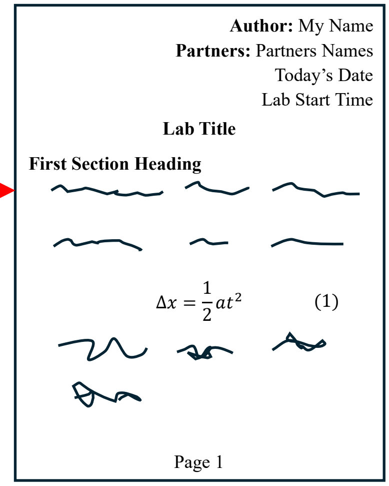
Use blank white paper or engineering paper (or lose points).

Use one side of the paper only (or lose points).

Include the following sections (in this order) in your report this week.

First page typically looks something like this.

Full formatting guidelines (with examples) are found in the Lab Manual Appendices.



Introduction (on page 1).

- Briefly describe the key theoretical equations:
  - How did spring force relate to mass?
    - Consider showing an FBD…
  - How did k_{eff} relate to individual spring constants?
  - How did T_{th} relate to mass and k_{eff}?
- You want the final product to look like a textbook.
  - Center equations on their own line & number them.
  - Variables are defined just before (or after) 1st use.
  - Do NOT re-define a variable if it is used again later.
  - Often it is unnecessary to discuss units (we'll see them in the data table).
- This is *not* a procedure. Avoid technical details on how measurements were made. Focus on the equations.
- Do NOT include any procedural comments (i.e., how measurements were taken or what units were used).
- Do NOT use a bulleted list for this part. I want to see a *brief* example of your writing.
- Use 3rd person.
  - Avoid I, we or you.
  - Avoid commands like "Measure this." That implies "*You* measure this." (2nd person).
- Past tense is always acceptable for all parts of the lab.
  - Present tense is acceptable in the introduction if it clarifies your writing.
  - Avoid future tense.
- Use full sentences. Double space. Start each section on a new page!

Data Sheet

- Delete all red text in the spread sheet.
- Hit print preview to ensure it fits on one page.
- Print a single copy and let me look over it for mistakes.
- Fix the mistakes and *then* print one copy for each group member.

Calculations

When I ask you to show a calculation in your submission, I expect the following steps:

1. Start with an algebraic equation or derivation.
2. Show a line plugging in the numbers without doing any work.
3. Show a line or two of work as needed (useful for long calculations or to clarify how sig figs work out).
4. Show your final *unrounded* answer.
5. Lastly, show the final rounded answer with appropriate units.

Conclusion Questions

- Most sections of your submission should be in paragraph form (so I can see examples of your writing). HOWEVER, conclusion questions should be answered in a numbered list.
- Answer in complete sentences which make clear what question was asked.
- You do not need to rewrite the questions as long as you paraphrase the question in your answer.