The Harmonic Oscillator

This is the outline of exercises that we want you to do in lab. This is a complement to the material in the lab manual. Please read the manual to learn about the tools and techniques; use this document to guide your experiments and calculations in the lab.

You should aim complete the first three problems below. Fill your remaining time with the fourth - an activity of your own design. We encourage you to download the [Physics Toolbox Sensor Suite](https://www.vieyrasoftware.net/), available at https://www.vieyrasoftware.net/ - it can record data from your phone's various sensors, and produce useful data and graphs.

Problem #1: Mass on a Spring

The mass on a spring is a model system that we will use to describe a wide range of phenomena. Your Task: **get to know it well**. You can use the springs and masses provided, or strap on a body-harness and run the experiment on yourself.

First, make some measurements and some calculations:

- Hold one end of your spring in your hand. Suspend a ball from the other end of the spring. Sketch out a force diagram for this situation.
  - Determine the spring constant of your spring
- Predict what the period of its oscillation should be.
  - Is your prediction reasonable? Discuss.
  - What, then, will be the system's frequency?
- In just a moment, you'll set the system oscillating with an amplitude of 5cm by lifting then releasing the sphere. Predict: What will the maximum velocity and acceleration of the ball be?

Now, take a video. Remember, if you choose slo-mo, time will be off by a factor of 4.

- Lift the ball up by about 5 cm, and let it go. It will bounce repeatedly on the spring - this is simple harmonic motion.
- Take a video of the motion if you can, and graph the position, the velocity, and the acceleration.
  - Sketch out your position graph in your report. Let's make this graph a bit richer:
    - On that graph, note which point(s) correspond to the highest speed, the highest magnitude of acceleration. (You may want to plot out velocity and acceleration graphs to help you do so!)
    - Discuss: why do these points occur at those spots on the position graph?
      - How might you use your knowledge of forces and energy to explain this?
  - Determine the magnitudes of the maximum speed and the maximum acceleration.
  - Determine the period.
    - Do these values match your earlier predictions? Discuss.

Next, add a different mass to your system - borrowed from the front.

- Discuss: without measuring, how should the new mass change the system? What should stay the same? How should the measurable vary?
- Let the new un-measured mass undergo simple harmonic motion as before, starting from the same 5cm amplitude.
  - Take a video of the motion, and graph the position, the velocity, and the acceleration.
    - How do the period, the maximum speed, and the maximum acceleration differ with this new mass? Explain the changes you see.
    - Determine the mass of the new system - without measuring any forces. How can you do this?

Problem #2: Pendulum Properties

The questions to answer: **What is the length of the department's Foucault pendulum? What it its maximum speed?**

First steps:

- Head outside the lab room and make your way to the pendulum. Take whatever measurements you require. Note: You cannot (due to obvious reasons) measure the length directly, and record your methods so that your TA can follow what you did.

Now, calculate:

- What is the length of the pendulum? Explain how you determine this.
- What is its maximum speed? At what point of its motion does it reach this speed?
  - Is your result reasonable?

Problem #3: Leg Pendulums

The question to answer: **When you walk fast or slow, which changes more: Your stride frequency or your stride length?**

First steps:

- Find an open area where you can walk a fixed distance that takes 20 strides or so.

- Design an experiment to determine the answer to the above question.

Now, do some analysis:

- Describe your experimental setup. Under what conditions is your model reasonable?
- As the person changes their speed, which changes more - their stride frequency or their stride length?
  - Explain this result in terms of the physics of oscillation that we are learning.

Problem #4: Oscillators Everywhere

Earlier in the lab we had you walk, and examine that through the lens of the simple harmonic oscillator model. The question to answer now: **What other day-to-day things can you model as a harmonic oscillator? How well does the model fit?** Let's see how well the models work. First steps:

- Pick a thing or activity (perhaps a video of such) which has some kind of periodic motion.
- Describe: is it more like a mass on a spring, or a pendulum?
  - Explain: If a pendulum, what would be the "length" bit? If not, what's the "mass" bit? What is the restoring force driving the oscillator back towards it's equilibrium?

Next, make some measurements:

- You know what system you are discussing, and so what can you measure/estimate about it?
- What parameters can you vary to test your model? What are you hoping will (or will not) change?
- Run your experiment, analyze your data, and then report on your results and discuss.

If, for example, you wanted to explore your arms or legs swinging in more detail, we will have some weights out which you can use to affect your leg's or arm's motion. What can you determine, predict, and measure about this system?

Once you look for these kind of things, you start to see them everywhere. Three options I have investigated in the past: I recently had a Fondue Night at home, and without any prompting the broth began to oscillate. Later on in the evening, it began to oscillate in a different mode - how could you describe these as a harmonic oscillator? I also have a trio of fairly differently sized dogs at home: Their panting happens to fit the harmonic oscillator model fairly well - how would you describe them with such a model? What would you expect to vary as you compare their mass? Length? Height? And a recent addition, msy Yuvi lost her leg to cancer a year back, and now she hops around everywhere she goes. How does that affect how she locomotes? When out on a run, is it easier or harder (better/worse?) for her to go fast, or slow? There really is a bunch of physics everywhere you look, what can you find?

Report

You'll be recording your work on the whiteboard tables as you go, and so be clear when summing up your process and your conclusions. Keep your discussions short, sweet, and to the point, please. Be sure to indicate what work you did on the report (as opposed to what your lab partners did).

Remember: The point of the report is to show your TA how well each of you understand the material, how well you designed and performed experiments, how well you can discuss your results, and how much of a scientist you were - not to show them you can parrot the textbook, always get the "right" answer, or do everything. The process, your reasoning, and your improvement are the key to earning full credit.

Be sure that each of your group members submit this assignment as soon as possible (ideally at the end o your lab), and take some time to consider how lab went for you and your peers, and how you can improve the experience next week.

Looking Ahead: Waves, Waves Everywhere

This isn't something to calculate today, but something to think about: The Harmonic Oscillator model is a very useful one to physicists because so many things can be modeled as such. The math to describe it is not terribly complicated, and even for quantum systems it is solved perfectly - that makes it a very useful tool indeed! What other systems can you model as a harmonic oscillator? Obviously anything that's swinging back and forth, or if it contains a spring, but what other "systems" around your home can you model as one?