LAB OBJECTIVES

Welcome to Intro Experimental Physics 1! This class represents a semester long project to build an experimental apparatus and use it to make a cool measurement. By the end of this two week lab, you should have assembled the apparatus and verified it works.

BACKGROUND

You are building a driven and damped Foucault pendulum. The ultimate goal will be to use this pendulum to measure the rotation of the earth from within your room.

The **pendulum** itself will consist of a steel ball hanging from a nylon fishing line. You'll attach a magnet to the bottom of your pendulum bob[1]. You'll use this magnet to detect the position of the bob and to apply force to drive it.

The pendulum will be **supported at the top** by a small plate that you can screw to the ceiling, attach to a shelf, or attach to a board you put on top of a bookcase, etc. Because we like things to be extra awesome in this class, the support will also have some bright LED lights you can flash on and off using your control board (see below).

Underneath the pendulum, you'll build an **instrumented platform** on leveling feet. The platform will support an electromagnetic coil for detecting and driving the bob, a magnetometer for measuring the position of the magnet at the bottom of the bob, and an aluminum ring that will help control the motion of the bob.

Finally, to detect the position of the bob, talk to the magnetometer, turn on and off the coils, flash the lights, record measurements, and do all your other coursework for you (well most of these things), you'll use a **custom circuit board** fitted with a microcontroller[2]. We got this board made and assembled for you, but you have to solder on the microcontroller board.

PRE-LAB

Read the adafruit soldering guide. In your lab notebook, write the steps to make a good solder joint, for through hole and surface mount components.

In your lab book, write how many seconds you should aim to have the iron in contact with the board at a time.

When you see the LEDs and the Pico, mark in your lab book whether you think you will follow surface mount or through hole instructions for each part.

LAB STATIONS

This lab is structured as independent stations. You can do jobs 1-4 in any order.

1. Make the bobs

You will make a large (2" dia) steel bob and a smaller (1.5" dia) steel bob. Gather the following:

Material	Quantity
Steel ball 2 inch dia	1
Steel ball 1.5 inch dia	1
M-6 x 1 metric screw	2
Nylon spacers .252 inch ID by .875 inch OD by 1.75 inch long	2
JB Weld epoxy	a dab
Sandpaper	1/2 square
Threaded rod eye nut - M-6 x 1	1
.017" nylon line	about 20 feet

[1]The bob is the heavy thing at the bottom of a pendulum, in this case your steel ball

[2]A microcontroller is like a miniature computer that only runs one program you put on it in advance. Unlike your desktop computer, a microcontroller is specialized for low level circuit operations, like turning things on and off quickly, sending data from one chip to another, and reading signals without delays. Microcontrollers are also incredibly cheap. The assembled circuit board you are using, the Raspberry Pi Pico, which has some additional electronics, buttons, and connectors, costs $4. The actual microcontroller on the board, the RP2040, costs $1.

You will glue the screws to the steel ball so you have a point of attachment. It's important that the axis of the screw be aligned with an axis of the ball. Think of the screw as an ice cream cone (the larger round part at top is the opening) and the steel ball as a big scoop of ice cream.

1. Find a spot you can leave the balls overnight. Write your name on a sheet of paper and set things up on the paper.

2. Roughen the top of the screw (the socket end) and a spot on the small steel ball with sandpaper.

3. You want to hold the screw vertically, so put it into one of the spacers and set it on the counter. Now balance the ball on top. If it doesn't fall over, you are ready for glue.

4. Take a small amount of mixed epoxy and put it on the socket end of the screw. Fill the socket up and make sure there's epoxy on the rim.

5. Place the roughened part of the ball onto the epoxy. Spin the ball a little around the axis of the screw (like the screw is a finger and the ball is a basketball you're spinning on it) to make sure the epoxy is distributed.

6. Make sure everything looks good. If you're happy, leave it where it is for 24 hours. If you are not happy, you can wipe the epoxy off with a damp paper towel and start over.

7. Repeat with a different screw and spacer for the large ball.

Epoxy is easy to clean up when it's wet but impossible once it dries. Make sure you clean up any contaminated surfaces promptly

Cut about 20 feet (6 meters) of nylon line, wrap it in a circle and tape it to keep it wrapped up. You shouldn't need more than 10 feet (3 meters) but it's good to have extra.

2. Assemble the leveling platform

Letter	Material	Quantity
	Aluminum ring	1
	Aluminum disk	1
	MDF (wood) support piece	1
	sandpaper	1/2 square
A	3/4" long 4-40 hex standoff	6
B	4-40 x 1/4" brass Phillips[3] head screw	6
C	4-40 x 3/8" brass Phillips head screw	6
D	1/2" long 2-56 hex standoff	3
E	2-56 x 1/4" brass Phillips head screw	4
F	2-56 x 3/8" brass Phillips head screw	4
G	10-32 x 1.5" brass Phillips flat head screw	3
H	10-32 aluminum hex nut	6
I	nylon 1/4-20 nut	1
J	nylon 5/16" x 5/8" shoulder screw 1/4-20	1
K	nylon plastic washer .26 ID	1
	small screwdriver	

Run the sandpaper along the edges (the corner where the top and sides meet) of the aluminum parts. Make sure there aren't any sharp edges (your fingers will thank you later) or any burrs (little pieces sticking out). Lightly sand the edges of the MDF piece if it seems sharp to you.

The large brass screws (10-32 x 1.5") are the feet for platform. The angled top of the screw will sit on the ground/counter. Screw one aluminum 10-32 nut about 0.5" onto each of 3 screws. Then put the platform onto the screws and screw the other aluminum nuts on top. Later, you will level the platform by adjusting the height of the nuts.

Now attach the four small (2-56) standoffs to the center of the MDF platform using the longer (3/8") of the smallest (2-56) screws. These should face *down* - towards the angled screw heads. Go ahead and screw the shorter (1/4") 2-56 screws into the other side of the standoffs so you don't lose them.

If you've already wound your magnet, you can attach it now, through the central hole. The magnet mounts on the top surface. Put the shoulder screw through the white circular aligbnment pcb, then through the magnet, and then through the platform, with the head facing up and the other end extending through the platform. Put the washer around the screw the bottom of the platform and then attach the nut. If you haven't wound your magnet, just go ahead and put the shoulder screw through the pcb and platform and attach the washer and nut to the other side so you don't lose anything.

The six larger (4-40 x 3/4") hex standoffs all screw onto the top surface (opposite the direction of the standoffs you just put in). Attach them using the longer (3/8") of the 4-40 brass screws. 4-40 are bigger than 2-56 but much smaller than 10-32

To keep everything together, screw the aluminum disks onto the standoffs. You'll be taking these disks on and off throughout the lab to control the damping.

3. Wind your magnet

Material	Quantity
Black pulley	1
Red magnet wire (29 AWG)	about 100 feet
scotch tape	

1. Pull about a foot (30 cm) of wire off the spool. Tape the wire to the inside of the pulley rim or hold it in place with your finger. **Make sure you leave at least a foot free to make a connection later.**
2. Keeping tension on the wire, wrap it around the pulley 150 times. Try to keep things as neat and even as you can and evenly fill the space in the pulley.
3. Pull another foot (30 cm) of wire off the spool then cut the wire from the spool.
4. Twist the leads together up against the pulley to hold the tension.

The magnet wire is insulated. You'll need to remove the insulation to make electrical contact to the leads. One way is to scrape the last 1/2" to 1" of each lead with a razor blade on all sides. The other is to BURN it with FIRE. Obviously the second option is way more fun.

4. Solder your driver board and support plate

Material	Quantity	Digikey Part #
Driver circuit board with presoldered components	1	n/a
Top support board (small, no components)	1	n/a
Raspberry Pi Pico	1	n/a
bright 5 mm white led	3	C503D-WAN-CCBEB151-ND
speaker wire	about 10-15 feet	
soldering iron		
solder		
diagonal cutters		
wire strippers		
small screwdriver		

Before lab: have a look at the adafruit soldering guide, especially the 'preparation' and 'making a good solder joint' sections, and watch the embedded video.

1. Attach the raspberry pi pico to the control board. Read this through so you understand. **It's important when you are soldering that you do not touch the iron to any of the components already on the board.**

1. Put some #2 screws (the smallest kind) or M2 screws through 2 holes on the pico. If your pico is like mine, the holes are a little tight, and you might have to screw the screws in a little to get them to go through. That's OK. They don't need to go all the way, just 1/16" or so.
2. Push the pico with the screws lined up on the control board so that it sits flush on top of the circuit board.
3. **Check that things look right.** You should see that all the pads on the pico line up with pads on the circuit board. There are 3 pads on top of the pico that should line up with 3 pads on the circuit board. You actually don't have to solder these 3 pads, but do check the alignment. The usb connector on the pico should be pointed off the bottom of the board. The pico should be sitting flat on the circuit board.
4. (Optional) Mount the control board in a vice so you can easily reach the pads on the pico.
5. You are in control. Adjust the orientation of the board to make things easy for you. Don't hold the iron at an awkward angle.
6. Heat the soldering iron.
7. Clean the tip.
8. Touch a little solder to the end of the iron. This solder isn't to make a connection, it's just to help the soldering iron make contact with the board.
9. Push the tip of the iron up against the edge of the pad on the pico while also touching the pad on the control board. **Be careful to hold the iron so that you don't touch any of the other components on the board with the iron**
10. Touch the solder to the joint between the two pads. The solder should flow up the side of the pico and maybe fill the hole. It should also "wet" the bottom pad at least a little.
11. Pull away the solder then the iron. Try to drag a little melted solder onto the pad with the iron as you pull it back towards you.
12. This whole process should be fast, less than 5 seconds (for 1 pad). The video says not to spend more than 2 seconds with the iron in contact with the board. That's good advice, but don't freak out if you need slightly longer. Ask your TA for help if you're having trouble getting started.
13. Repeat for the remaining pads. The pads marked "GND" may take longer because you have to heat up a larger amount of metal.
14. You don't need to solder the 3 pads at the top of the pico.
15. When you are done, clean the iron and **turn it off**
16. Remove the screws.
17. **Did you turn the iron off?** It's super important to turn the iron off when you're not using it.

2. Solder the leds and wire to the support bracket.

    1. (optional) Put the support bracket into the vise with the bottom surface (circles for LED placement visible) facing up.
    2. LEDs have an orientation. One lead is longer than the other. This lead should face the outside of the circle for each LED. If you feel the bottom rim of the LED, you can feel that the side next to the shorter lead is flat. This flat matches the flat on the silkscreen drawing. If you aren't sure, check with your TA before proceeding.
    3. Bend the leads to hold the led in place. Make sure it sits flat against the board.

4. Flip the support bracket top side up. Solder the LEDs into place, using as little solder as you can. Once you've done all 3 LEDs, clip the leads as close to the board as you can using diagonal clippers.

5. Separate the strands of the speaker wire slightly and strip the ends of insulation (strip about 1/8" to 1/4"). Tightly twist the wires to make them stiff and pointy.

6. Put the ends of the speaker wire into the holes on the support board. The wire should enter from the opposite surface as the LEDs (so if the LEDs are on the bottom, the speaker wire will be on the top, and the little ends you twisted will stick out the bottom)

7. Bend the wires to hold them in place, flip the board and solder the wires on the bottom surface.

8. Clip the leads.

9. On the other end of the speaker wire, again separate the strands, strip the insulation and twist the wires together to make them pointy.

10. Put a **little** solder on the iron, then touch it to each of the two free ends of the speaker wire so that the solder runs into the wire. This will keep the wire from untwisting. You don't want to make the wire thicker or give it weird bumps.

11. When you are done, clean the iron and **turn it off**

5. Finish assembly and test your apparatus

Material	Quantity
qt/qwiic cable	1
lis3mdl breakout	1
.25" dia neodymium sphere magnet	1
3/8" dia x 3/16" thick neodynmium cylinder magnet	1
white alignment pcb	1
platform from step 2	
magnet coil from step 3	

1. If you haven't already, attach your magnet to the platform. The magnet mounts on the top surface of the platform above the central hole. Put the shoulder screw through the white circular alignment pcb, then through the magnet, and then through the platform, with the head facing up and the other end extending through the platform. Put the washer around the screw the bottom of the platform and then attach the nut. The magnet sits directly on top of the platform; the white circular alignment pcb sits on top of the magnet. The shoulder screw inserts down through the pcb, magnet, and board.

2. Attach the LIS3MDL magnetometer board to the 4 small standoffs on your leveling platform, using the short 2-56 screws. The flat side of the board (no parts, no connectors) should face the platform.

3. Stand the platform up on its feet.

4. Attach one end of the 4-color qt/qwiic cable to the magnetometer and the other to your board. Be careful, the connectors can be fragile, especially on your board.

5. Attach the leads of the coil to the middle spring terminal block on your board (labeled coil)

6. Flip both dip switches under the third terminal block to ON.

7. Hook up the pico to a lab computer.

8. In this order, press and hold the "reset" button on the control board, press and hold the button on the pico, release the "reset" button, release the button on the pico.

9. The pico should show up as a drive on the lab computer.

10. Copy the file "foucault-firmware-pico-vX.uf2" (where X will be the latest version number) onto this drive. The drive will disappear and the pico will reboot.

11. Start the labview software. You should see readings on the magnetometer and a voltage of about 0 from the coil (white trace).

12. Wave a magnet over the platform. You should see the white trace wiggle and the magnetometer values change.

13. On the control software, turn the coil on. You should see a blue light turn on on the board near the capacitor (the big cylinder). Turn the coil off. The blue light should go off.

14. On the control software, turn on "autofire." Wave the magnet over the platform again. You should feel a "kick" on the magnet as you wave the magnet past the coil.

15. Connect your support plate lights to the board: Put the speaker wires into the spring terminals on the top-left corner of board (labeled LED). The wire you soldered into the "+" hole connects to the "LED HIGH" terminal.

16. Slide the "LED level" control on the software to the right (to 255). Your lights should get bright.

Mounting the pendulum at home

You will bring your platform back and forth with you. You can mount your pendulum at home.

The pendulum can be mounted on a shelf you hang on the wall; on a shelf or board you attach to an existing piece of furniture; or using a second support PCB and some standoffs as a bracket. Please have a look at how things are mounted in the lab, examine your room, and think about where/how you will want to mount your pendulum. A longer pendulum will ultimately make it easier to measure Foucault precession, so ultimately you'll want to mount the pendulum as high as possible.

Software installation

On your own computer, first install the labview runtime engine version 2021 for your OS.

Then install the NI-VISA package, latest version for your OS.

Then finally install the foucault control panel software: (github link to follow)

DELIVERABLES

Please mark your progress in your lab book as you complete the stations. Make notes of anything that went well/badly and anything you'd want to know if you did this again - if you ask your TA for help, you should make a note of the problem and the resolution in your book.

Sketch the assembled platform in your lab book and mark all the parts.

Finally, take a screenshot of the working software after your device checks out. Print this screenshot out and tape it in your lab book, or save a copy in your lab book if it's electronic. Describe the tests you ran and how you know your device passed.

Have your TA check your lab book over each week.

Lab book checkoff

Pre-lab questions	2	
bobs assembled	4	
magnet wound	4	
platform assembled	5	
pico soldered	5	
top support soldered	5	
apparatus tests out	5	