In-Lab Exam
Galileo's Inclined Plane Revisited
Procedure

Deliverables: checked lab notebook, checked circuit, oscilloscope screen shot (attached to email) and measured parameters (typed in body of email) submitted to lab instructors and TA via email

Exam Rules

This is an in-lab final exam designed to test your *individual* laboratory skills. Sharing results with other students will be considered a violation of the academics honor code.

You have 50 minutes to perform the procedure, make the deliverables, and email them to your TA and lab instructors. You are to make an entry into your lab notebook as you have been doing throughout the semester. Your lab notebook entry must follow the lab notebook guidelines posted on the resources page of the course website (https://www3.nd.edu/~prumbach/AME20216/resources/notebook_guidelines.pdf).

You must demonstrate you working system to the lab instructor, have them sign your lab notebook, then email the deliverables to the TA and lab instructors before the 50 minutes is up. (See Data Analysis and Deliverables section for details).

Photogate

For this in-lab exam, you will build an optical photogate to measure the speed of a ball rolling down an inclined plane. The photogate will consist of a red laser beam aligned with a CdS photocell. The transient output voltage $V_{out}(t)$ of the photocell circuit will be measured with the oscilloscope to determine the time it takes the ball to pass through the laser beam Δt. The speed of the ball v_f can be calculated using the diameter of the ball $D = 5.7$ cm and the measured pulse width Δt.
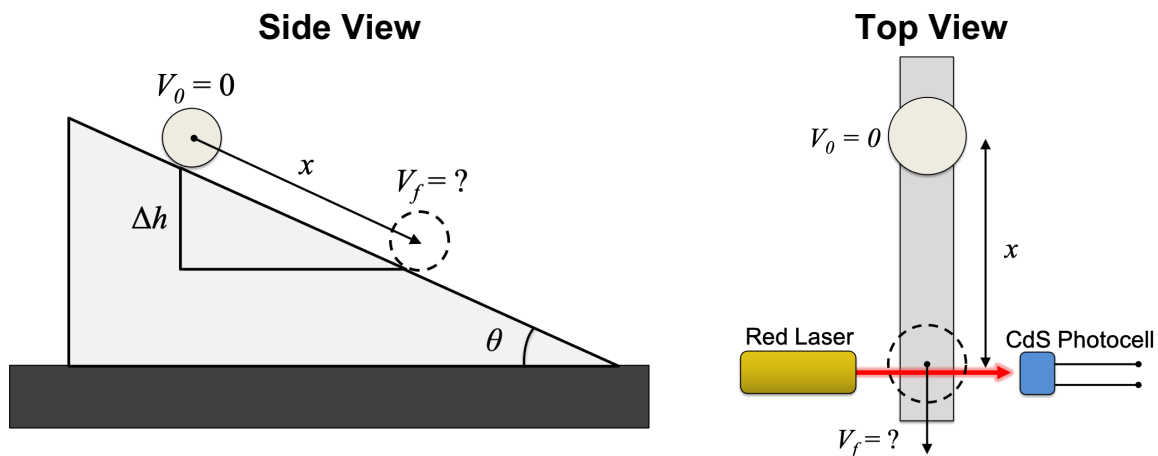

Figure 1 – The speed of a ball rolling down an inclined planed (left) is measured using a photogate (right).

Pre-lab

Sketch the "side view" schematic shown on the left of Fig. 1 in your lab notebook. Then, derive a formula for the theoretical speed v_f of the rolling ball as function of the change in vertical height Δh. Assume the ball is initially at rest. Write this formula down in your lab notebook. You will need it to calculate the *theoretical* speed, which you will compare to your measured speed.

Procedure

Safety First – Do NOT point the laser into your eye or anyone else's eye.
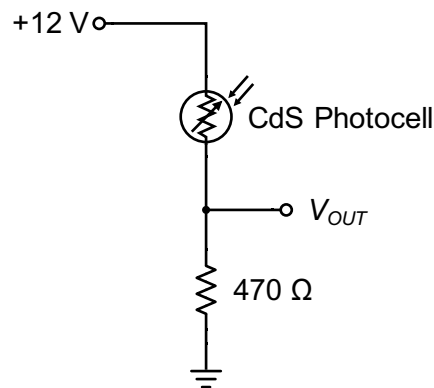

Figure 2 – The CdS photocell circuit converts light intensity to a voltage.

1. Turn on the breadboard. Use the handheld DMM to verify that the +5V and variable +15V DC power supplies are working. Let the instructor know immediately if they are not functioning properly.

2. Sketch the circuit shown in Fig. 2 in your lab notebook.

3. The vertical height Δh that you will use for your experiment is written on the whiteboard. Write down the value in your lab notebook, then use geometry to estimate what distance x along the track this corresponds to. (Note the similar triangles in Fig. 1.)

4. Using the breadboard, construct the CdS photocell voltage divider circuit shown in Fig. 2. Use a multimeter to test it and make sure it works.

Pro-tip: Measure each resistor before you place it in your circuit to make sure you have the correct value.

5. Use the clothes pin and steel 1-2-3 block to mount the CdS photocell on one side of the track, near the bottom, such that it will be level with the center of the rolling cue ball.

6. Use the 5V DC power supply on the breadboard to power the laser diode module. The white wire goes to 5V, and the gray wire goes to ground. The laser should light up, if it is connected properly.

Caution! – Do not look directly into the laser diode module.

7. Use the other clothes pin and steel 1-2-3 block to mount the laser diode.

8. Position the laser such that it is aimed directly at the CdS photocell with the red laser spot hitting the active area of the photocell. Position them along the rail such that the height of the beam is level with the center of the passing cue ball. Be careful not to point it into your eye or anyone else's eye.

9. Use the handheld DMM to verify that blocking the laser beam results in a considerable change in the output voltage of the photocell circuit. **Demonstrate this to the lab instructor to receive points on the scoresheet.**

    a. It should output $V_{out} > 8$V when the laser is hitting the photocell.

    b. It should output $V_{out} < 5$V when the laser is blocked.

10. Connect the output of the photocell voltage divider circuit V_{OUT} to CH1 on the oscilloscope.

11. Press the yellow CH1 button to bring up the CH1 menu. Make sure it is set to "DC coupling".

12. Adjust the vertical scale on Channel 1 to be 5 V per division.

13. Adjust the horizontal scale to be 40 ms per division.

14. Set up the oscilloscope to record a single pulse on CH1.

    a. Press the Trigger "Menu" button near the upper-right corner of the scope.

    b. Set the "Slope" to be a falling edge trigger by pressing the appropriate button at the bottom of the screen. (Press the button to select the image of the line with a negative slope.)

    c. Set the "Mode" to be a "Normal" by pressing the appropriate button at the bottom of the screen. (Press the button, then select "Normal" using the button on the right hand side of the screen.)

    d. Adjust the Trigger "Level" knob near the upper-right corner of the scope. Set the trigger level to be between 6 to 7 Volts.

    e. Press "Menu Off" once to clear the menu from the right side of the screen.

15. Make sure the laser beam is hitting the photocell. Press the "Single" button on the top of the scope. Roll the ball down the inclined plane from any height. You should see a voltage waveform recorded onto the screen.

16. Press the "Single" button again to reset the scope. Repeat the measurement using your assigned vertical height Δh and the corresponding distance x. (Dry erase markers are available to mark the distance x on the track.)

17. Use the cursors to measure the width of the voltage pulse Δt. Press the "Cursors" button and use the multipurpose a and b knobs to position the cursors at the top edges of the dip in the signal. Record the value of Δt in your lab notebook.

18. Insert the thumb drive into the oscilloscope.

19. Press the "menu" button below the screen, and press "Save screen image" then "OK" to save a screenshot to the thumb drive. Transfer the screenshot to your laptop or the lab computer. (The oscilloscope screenshot has a timestamp on it, so no funny business!)

20. **Delete the screen shot from the thumb drive** after you have transferred it to your computer.

21. Use the pulse width Δt and the ball diameter $D = 5.7$ cm to compute the speed v_f in m/s.

22. Email your results to your lab TA, Prof. Rumbach, and Prof. Ott for grading. See the "**Data Analysis and Deliverables**" section for details.

23. **IMPORTANT:** Ask the lab instructor to grade your lab notebook. **Do NOT take apart your set-up until it has been graded.**

24. Return the lab bench to its initial state:

    a. Press the "Default Setup" button on the oscilloscope.

    b. Disassemble the experiment.

    c. Return all resistors to the appropriate bins.

    d. Return the thumb drive to the lab instructor.

Data Analysis and Deliverables

Please email the following deliverables to your lab section TA, Prof. Ott, and Prof. Rumbach—**all 3 of us**—with the subject line "LAB FINAL – AME20216". A list of the TA email addresses can be found in Appendix B.

1. A **screenshot** from the oscilloscope showing the measured voltage pulse $V_{out}(t)$ from the CdS photocell circuit with the correct time and date stamp in the bottom right corner. (Attach it to the email.)

2. Type the following parameters into the body of the email.

    a. The change in vertical height Δh that you were assigned (in units of cm).

    b. The distance along the inclined plane x corresponding to the change in vertical height (in units of cm).

    c. The measured pulse width Δt (in units of milliseconds).

    d. The measured speed v_f (in units of m/s).

    e. The theoretical speed v_f (in units of m/s).

Appendix A

Equipment Required

- Tek DPO3012 oscilloscope
- BNC to minigrabber cable
- Digital multimeter with minigrabber leads
- Breadboard with jumper wires
- Resistor kit (normally on lab bench)
- CDS Cell 520nm 4 ~ 11 kOhms @ 10 lux (Digikey # PDV-P8101-ND) with orange and yellow wires
- Red laser diode modules with white and gray wires
- 1-2-3 blocks with clothes pins (2 per lab bench)
- 8020 slotted rail inclined plane
- 2.25" Diameter Regulation Size Cue Ball
- Meterstick

Appendix B

TA Contact Info

Lab TAs

Tues. 1:00 – 3:00 – Jack Yost, jyost4@nd.edu

Tues. 3:30 – 5:30 – Nicholas Adrian, nadrian@nd.edu

Weds. 3:00 – 5:00 – Alin Stoica, astoica@nd.edu

Thurs. 11:00 – 1:00 – Ibu Akintola, iakintol@nd.edu

Lab Instructors

John Ott – jott@nd.edu.

Paul Rumbach – prumbach@nd.edu