

Experimental Test Selection Test

3 hours allowed

Because it was not possible to do physical lab experiments this year, the labs used for team selection have been replaced with this single, simulation-based lab.

The Future Circular Collider

1 Safety Warnings

There are no unusual safety concerns in this experiment.

2 Overview

Particle physicists, condensed matter physicists, atomic physicists, and chemists all gain insight into the structure of matter by scattering experiments. In these experiments, we smash particles into other particles, look at what comes out, and infer what happened during the collision. In this lab, you will carry on this tradition by analyzing simulated collisions involving circular disks sliding on a horizontal table, with specified initial conditions. The disks always lay flat on the table, which is frictionless. In the simulation, collisions between objects obey the following rules:

- The relative velocity along the normal direction is flipped in sign and multiplied by the coefficient of restitution c , where $c = 1$ for a perfectly elastic collision.
- The relative velocity along the tangential direction is changed by friction in the usual way: if it is zero, static friction tries to keep it zero, and if it is nonzero, it is pushed towards zero by a kinetic friction force μN , where N is the normal force.

There are many ways to extract the requested parameters, so you will be graded primarily on the precision and accuracy of your results. The initial conditions you specify will receive both inherent absolute and relative uncertainties, so you should choose appropriate values and perform multiple trials to get an accurate result. **An uncertainty estimate is expected for all parts**, but depending on how you carry out the experiment, each subpart might or might not require a graph. As always, include in your report any diagrams, supporting calculations, and other information necessary to show how you obtained your results.

3 Equipment

This is a pure simulation experiment, with no physical equipment. The only thing required is the `collision-black-box` program to simulate collisions, which can be downloaded [here](#).

The procedure to run the program depends on the operating system. On **Windows**:

- Search for *powershell* in the start menu and run it to open a terminal. You will do the entire lab by typing commands into this terminal.
- Navigate to the folder containing the downloaded `collision-black-box` program, by running `cd <path-to-folder>`. On most computers, the right command to run is `cd ~/Downloads`.
- Use `collision-black-box-windows.exe wall` to run the first part of the experiment, and use `collision-black-box-windows.exe disk` to run the second part.

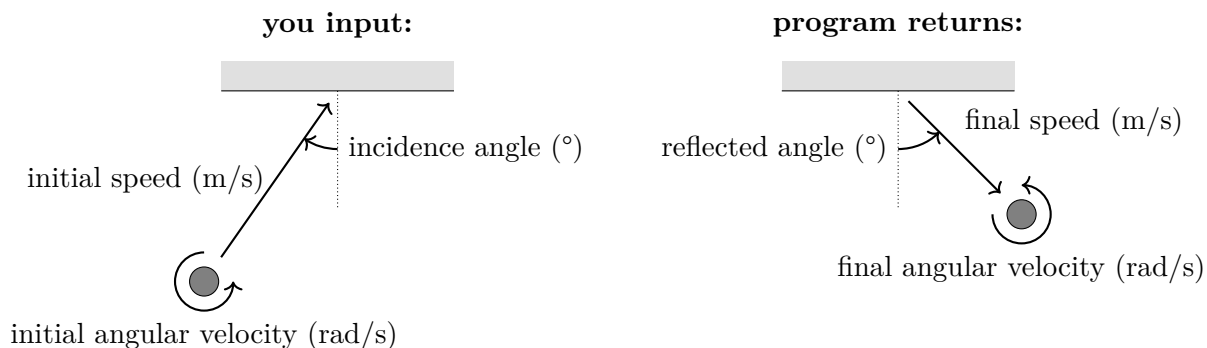
On **macOS**, the procedure is somewhat more complicated:

- Launch the *Terminal* app. You will do the entire lab by typing commands into this terminal.
- Navigate to the folder containing the downloaded `collision-black-box` program, by running `cd <path-to-folder>`. On most computers, the right command to run is `cd ~/Downloads`.
- Run `chmod +x collision-black-box-macos` to mark the file as an executable program.
- Run `open .` to open the current folder in Finder. In Finder, control-click the `collision-black-box` program to open a menu, and select *Open*. Confirm the dialog box that comes up. Another terminal will quickly appear and disappear. The program has now been granted permission to run.
- Return to the terminal and use `./collision-black-box-macos wall` to run the first part of the experiment, and use `./collision-black-box-macos disk` to run the second part.

4 Experiment

4.1 Collision with Wall

In this part, you will launch a disk with mass M , radius R and moment of inertia $I = \beta MR^2$ towards a fixed, long vertical wall. You specify the initial speed and counter-clockwise angular velocity of the disk, and the angle of its initial velocity incident to the normal of the wall. The program will simulate the collision and return the final values of these parameters after collision.



The parameters you specify must be in the following ranges:

- $0.5 \text{ m/s} \leq \text{initial speed} \leq 10 \text{ m/s}$.
- $-50 \text{ rad/s} \leq \text{initial angular velocity} \leq 50 \text{ rad/s}$.
- $0^\circ \leq \text{incidence angle} \leq 75^\circ$.

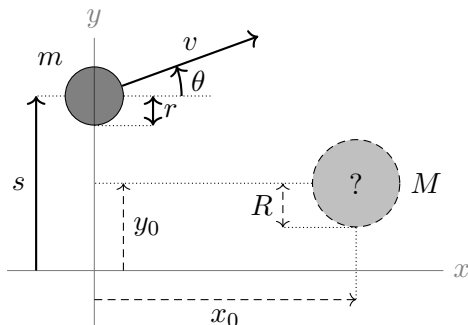
To simulate imperfections in the disk-firing mechanism, the initial values you specify are always affected by the following uncertainties:

- Initial speed: relative uncertainty 5%, compounded with absolute uncertainty 0.05 m/s.
- Initial angular velocity: relative uncertainty 5%, compounded with absolute uncertainty 0.2 rad/s.
- Incidence angle: absolute uncertainty 1° .

1. (a) Find the coefficient of restitution c between the disk and wall.
(b) Find the radius R of the disk, and the values of μ and β .

4.2 Collision with Disk

In this part, you will launch a “probe” disk towards a hidden, second disk on the table, which begins at rest with its center at an unknown position (x_0, y_0) (where $x_0 > 0$), with mass M and radius R . The probe disk has radius $r = (0.250 \pm 0.001)$ m, but you may choose its mass m , initial position $(0, s)$, initial speed v , and the initial direction θ of its velocity (as an angle relative to the horizontal). Both disks are frictionless, so that rotation is irrelevant. The program will simulate the collision, if it occurs, and return the final velocity (speed and angle) of the probe disk.



The parameters you choose must be in the following ranges:

- $1 \text{ kg} \leq m \leq 5 \text{ kg}$.
- $-2 \text{ m} \leq s \leq 2 \text{ m}$.
- $0.5 \text{ m/s} \leq v \leq 10.0 \text{ m/s}$.
- $-90^\circ \leq \theta \leq 90^\circ$.

The parameters you specify are affected by the following uncertainties:

- m : relative 1%, plus absolute 0.05 kg.
- s : absolute 2 mm.
- v : relative 1%, plus absolute 0.05 m/s.
- θ : absolute 0.1° .

2. (a) Find the initial position (x_0, y_0) of the hidden disk.
- (b) Find the radius R of the hidden disk.
- (c) Find the mass M of the hidden disk and the coefficient of restitution c between the disks.