# Colliding Pucks on a Carrom Board

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Collisions are ubiquitous in nature. They occur at microscopic levels between elementary particles as well as at grander scales when galaxies collide, merge and scatter. In all such processes, the linear momentum of the complete system is always conserved. In this experiment, we will study the collision of two objects in a controlled setting using video motion analysis. We will show that the law of conservation of momentum holds in random 2-D collisions and determine the type of collision through quantitative analysis.

**Essential pre-lab reading**: *"Physics for Engineers and Scientists : Extended 3rd Edition"* by Ohanian, H.C. and Markert, J.T. (W.W. Norton and Company, 2007); (Sections 11.1-11.4)

# 1   Test your understanding

1. What is the difference between an elastic and an inelastic collision?

2. Refer to Figure 1a. Write down two scalar equations which must be satisfied for the illustrated collision.

3. How can you evaluate the angles $\theta'_A$ and $\theta'_B$?

# 2   The Experiment

The collision between two nearly identical carrom pucks will be recorded using a high-speed video camera. We will use markers of different colours for each puck to track their positions separately. The position data acquired will then be used for quantitative analysis. Perfect! Now, let's move on to the experiment.

For this experiment, we have constructed a special tripod as shown in the experimental set-up (figure 1c). Place the camera facing downwards on top of the tripod. Ensure that the lens is horizontal by placing a bull's eye level on the top (figure 1b). (You may also use a 1-D bubble
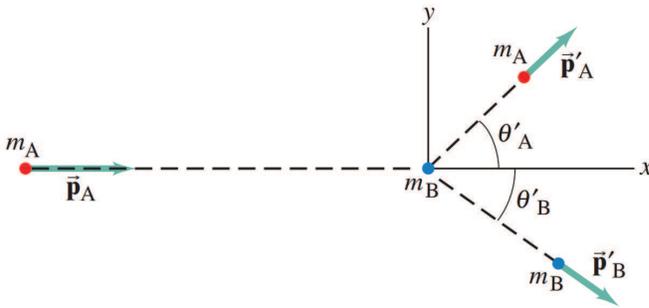
(a) Illustration of the collision.


(b) Bull's eye level.


(c) Arrangement showing placement of camera and the tripod over the carrom board.


(d) Sample Frame. The pucks are artificially outlined for visual clarity.

Figure 1: Experimental set-up.

level but ensure the balance by checking the level in both directions.) The video will be recorded at 240 fps.

**Q 1.** Measure the mass and diameter of each puck and record in your lab notebook. Take a few readings and calculate the mean.

Now, turn on the camera and place one puck so that it appears on the center of the frame and zoom in. Use figure (1d) as a reference. Now, place the other puck just inside the zoomed frame and start recording. Strike this puck so that it strikes the one in the centre. As soon as the pucks collide, **STOP** the recording. Repeat as many times as necessary.

A single video should be enough for quantitative analysis but you can repeat as many times as you wish to obtain a few datasets.

# 3 Analysis

## 3.1 Preparing Data for Quantitative Analysis

Make sure the video is in the same folder and then run the MATLAB function "**trackmob.m**". This function automatically tracks the position of *both* markers placed on each puck frame by frame and returns the time and tracked position data in cartesian coordinates. The syntax for using this function is "[*time, positionblue, positiongreen*]=**trackmob**('*filename.mov*', *knownDistance*);". Identify two points of known distance (in metres) on the first frame using crosshairs. Make sure that the value of *knownDistance* is correct and in metres.

**Q 2.** Which two points did you choose?

When you obtain the results, plot the position data for both markers and try to identify the frame of collision.

**Q 3.** Why did you pick this exact frame? What convinced you that this is the frame in which the pucks collide?

We need to obtain the position of the markers just before and just after the collision. Follow these steps to identify the region of interest. (Refer to Figure 1a).

1. Identify the frame of collision.

2. For puck A, the 30 datapoints before (and including) the frame of collision represent $\vec{r}_A$. Extract these points and store in a separate variable.

3. The 30 datapoints after (and including) the frame of collision represent $\vec{r}'_A$. Extract these points and store in a separate variable.

4. Similarly, for puck B, 30 datapoints after (and including) the frame of collision represent $\vec{r}'_B$. Extract these points and store in a separate variable.

Now, we have separate data sets for each of the datapoints. We can move on to the quantitative analysis. You are free to use your own variable names. However, the following scheme suggested in table (1) is recommended to avoid confusion and keeping track of your data.

## 3.2 Quantitative Analysis

We require the velocity $\vec{v}_A$ just before the collision and the velocities $\vec{v}'_A$ and $\vec{v}'_B$ just after the collision to test the law of conservation of momentum. Let's first find the angles $\theta'_A$ and $\theta'_B$

**Q 4.** Plot the position data $\vec{r}_A$ and fit this data to a linear function.

**Q 5.** Repeat for $\vec{r}'_A$ and $\vec{r}'_B$.

| Physical Quantity | Variable Name |
|---|:---:|
| Positions of puck A before collision | $r1i$ |
| Positions of puck A after collision | $r1f$ |
| Positions of puck B after collision | $r2f$ |
| Displacement of puck A before collision | $d1i$ |
| Displacement of puck A after collision | $d1f$ |
| Displacement of puck B after collision | $d2f$ |
| Time variable for $\vec{r}_A$ | $td1i$ |
| Time variable for $\vec{r'}_A$ | $td1f$ |
| Time variable for $\vec{r'}_B$ | $td2f$ |
| Velocity of puck A before collision | $v1i$ |
| Velocity of puck A after collision | $v1f$ |
| Velocity of puck B after collision | $v2f$ |
| Time variable for $\vec{v}_A$ | $tv1i$ |
| Time variable for $\vec{v'}_A$ | $tv1f$ |
| Time variable for $\vec{v'}_B$ | $tv2f$ |
| Angle between $\vec{r}_A$ and $\vec{r'}_A$ | $theta1$ |
| Angle between $\vec{r}_A$ and $\vec{r'}_B$ | $theta2$ |

Table 1: Suggested variable names for the experiment

**Q 6.** Find the angles $\theta'_A$ and $\theta'_B$. Show the working to the Lab Instructor before proceeding. Refer to your answer to question 3 in section 1 for reference.

Now, run the function "**processdata.m**" to get the displacement relative to the starting position for each of these datasets (Syntax: "$[d1i, d1f, d2f] = processdata(r1i, r1f, r2f);$" ). We now need to fit the processed data to a mathematical model. Since, we are only dealing with kinematics, a suitable model function for the displacement is the general quadratic function which is

$$f(t) = c_1 t^2 + c_2 t + c_3. \tag{1}$$

**Q 7.** Why do you think that equation (1) is a valid model? What do the coefficients $c_1$, $c_2$ and $c_3$ represent?

You will fit the extracted datasets to this model using the least-squares fitting function "**lsqfun.m**". The syntax for using this function is "$c = $ **lsqfun**$(xdata,ydata);$". The variable "$c$" stores the three unknown parameters in the model described above.

**Q 8.** Use the model function above and the values of the three parameters to interpolate the time and position data by a factor of 10 for each of the three datasets.

You will now differentiate the interpolated data to obtain the velocity using the "**deriv.m**" function. The syntax for using this function is "$[xd, yd] = $ **deriv**$(xdata, ydata, order)$" where order is 1 for computing a first-order derivative and 2 for a second-order derivative.

**Q 9.** Compute the first order derivatives for each dataset. Plot your results to obtain graphs for velocity.

Now, we need to verify the following two relationships to conclude that the momentum of the system is conserved.

$$m_A v_A = m_A v'_A \cos \theta_A + m_B v'_B \cos \theta'_B \qquad (2)$$
$$m_A v'_A \sin \theta_A = m_B v'_B \sin \theta'_B \qquad (3)$$

We can also determine the type of collision using the data we have gathered and processed. We can find whether the collision was elastic or inelastic.

**Q 10.** Calculate the kinetic energy of puck A before and after the collision. Repeat for puck B.

# 4  Exploration Point (Optional)

For the following question, the uncertainty in $|\overrightarrow{r}|$ is ±4 mm at 95% confidence (calculated prior to the experiment).

**Q 11.** Estimate the numerical uncertainties in your results.

**Q 12.** What is the maximum acceptable numerical difference between the two sides of equations 2 and 3?

**Q 13.** What is the total kinetic energy of the system before and after the collision takes place? Is there any difference between the two values? What does this tell you about the type of collision between the two pucks in this experiment?

Change the mass of one puck by sticking two pucks together. Now, repeat the experiment and analyse the results.

**Q 14.** What are the major differences that you noticed between the results of the two types of collisions you have observed?