Experiment No. 9
Conservation of Linear Momentum

Objective:

To verify experimentally that momentum is conserved during one-dimensional and two-dimensional collisions.

Apparatus:

Flex-track, balls (steel spheres), ruler, electrical balance, sheets of legal paper to be used as target paper and sheets of carbon paper.

Theory:

The total linear momentum of an isolated system is conserved or is constant. When two particles with masses m_1 and m_2 moving initially at velocities $\vec{v}_{1i}$ and $\vec{v}_{2i}$ collide, their total momentum is conserved. From Newton's third law at the instant of collision, (action force = – reaction force),

$$\vec{F}_{12} = -\vec{F}_{21} \qquad \Rightarrow m_1\vec{a}_1 + m_2\vec{a}_2 = 0,$$

Where, $\vec{a}_1$, and $\vec{a}_2$ are the accelerations at the instant of contact.

$$\frac{d}{dt}(m_1\vec{v}_1 + m_2\vec{v}_2) = 0 \quad \Rightarrow m_1\vec{v}_1 + m_2\vec{v}_2 = constant \;\; quantity$$

$$\vec{p}_{total}(initial) = \vec{p}_{total}(final)$$

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

Where $\vec{v}_{1f}$ and $\vec{v}_{2f}$ are the velocities of the two particle after collision. Which means that the momentum in a specific direction before a collision must be equal to the momentum in that same direction after the collision.

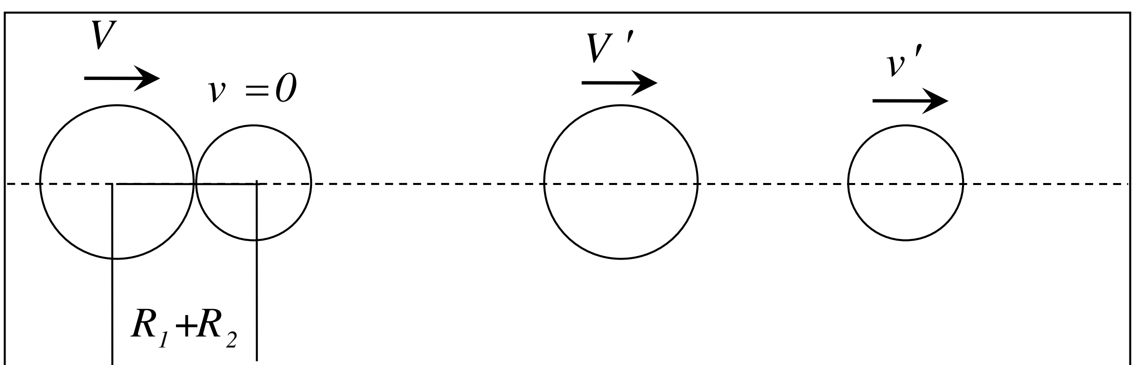
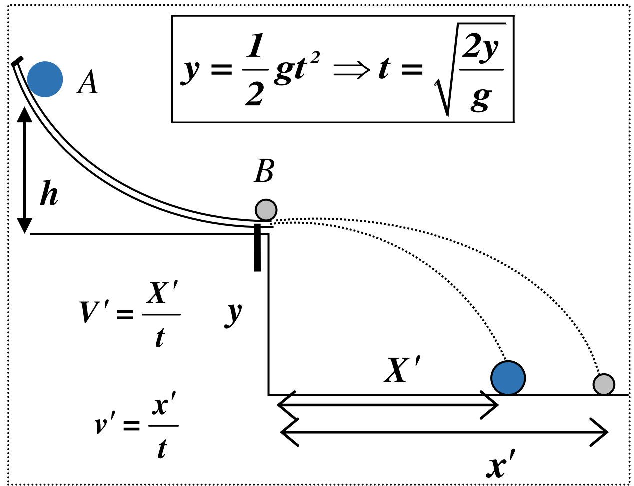


Fig. 8.1: 1D head on collision – motion along the same line

Collisio

The colliding particle undergoes collision and move before and after collision in the same direction. (Fg.8.1)

In this experiment, a larger mass **M falls from rest at point. A** and rolls down the flex track and reach the point B with **velocity V**, where it collides **a head –on –collision** with the small sphere **m** at **rest**, after collision the two spheres move along the same line and fall down on ground with **horizontal distances X and x** for **M and m, respectively**, measured from the vertical line at the point **below B** on the floor.



The initial momentum before collision is MV and the final momentum of the two balls after collision is $MV' + mv'$**,** since the collision in one direction:

$$MV = MV' + mv'$$

To determine the velocity **V** of the incident sphere **M** at **B before collision**, **M** is released from A down the track to B **without the target ball m** on the screw, **M** will fall down to floor at a horizontal distance X. Since V=X/t:

$$M\frac{X}{t} = M\frac{X'}{t} + m\frac{x'}{t}$$

$$\Rightarrow MX = MX' + mx'$$

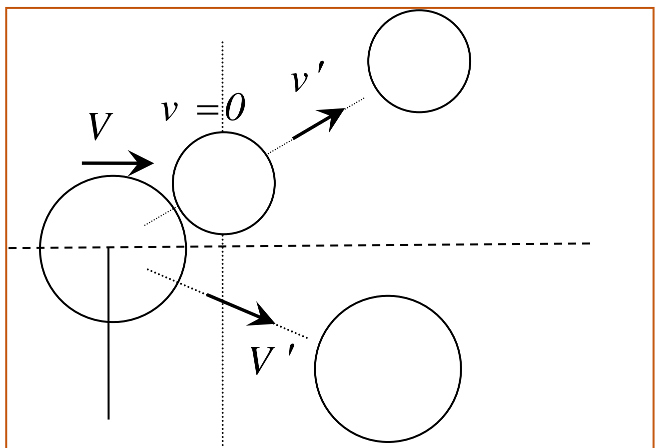
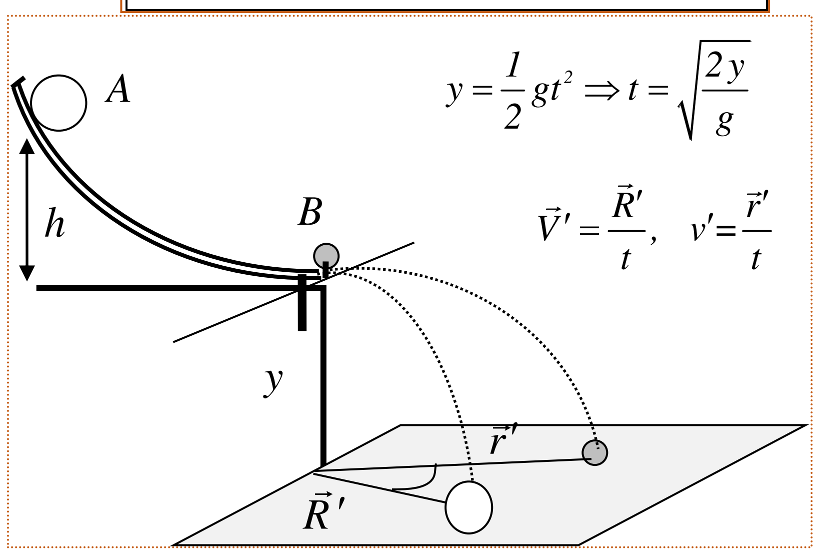


Fig. 8.3: 2D collision – Collision at glancing angle

Collision in two dimension:

When the sphere M collide with the smaller sphere at rest at **glancing angle**, after this glancing collision the two spheres move in two dimension, the hit the floor at points whose position vectors relative the point below B makes an angle **θ** as shown in **Fig. 8.3**



In **fig.8.4** the position vectors of the location where the spheres land are denoted $\vec{R}'$ for the sphere of mass M and $\vec{r}'$ for the sphere of mass m.

Initial momentum of the two spheres before collision is $\vec{p}_i = M\vec{V} = M\,\frac{\vec{R}}{t}$

And after Collision:

$\vec{p}_f = M\vec{V}' + m\vec{v}'$, Since $\vec{p}_i = \vec{p}_f$

$$M\vec{V}' + m\vec{v}' = M\,\frac{\vec{R}'}{t} + m\frac{\vec{r}'}{t}$$

Momentum conservation ensures that

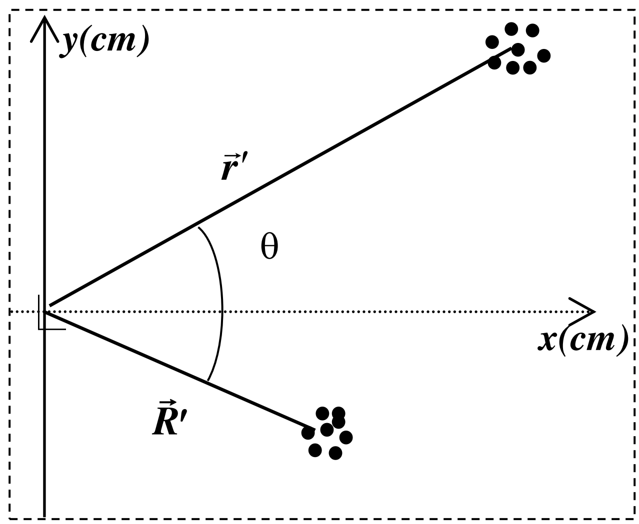
$$M\vec{V} = M\vec{V}' + m\vec{v}' \quad \text{and} \quad M\,\frac{\vec{R}}{t} = M\,\frac{\vec{R}'}{t} + m\frac{\vec{r}'}{t} \qquad \Rightarrow M\vec{R} = M\vec{R}' + m\vec{r}'$$

From which it follows:

$$P_i^2 = (MR)^2 \;\; = \;\; P_f^2 = (MR')^2 + (mr)^2 + 2(MR)(mr)\cos\theta$$

Procedure:

I. Collision in 1-Dimension



(1) Measure the mass of both ball bearings.

(2) Lay the carbon paper on the floor, carbon side up, and put a sheet of 18” by 24” paper on top, with the **plumb bob hanging over the middle of the shorter side**. (“Plumb” means vertical).

(3) Mark the point under the **plumb bob**.

(4) adjust the screw at the bottom end of the track so that **its top is at the same height** as the **bottom of the groove in the ramp**. This way, the incident ball will knock the target ball cleanly off the screw.

(5) Without the target ball in place, **release the other ball at least a dozen times**. This will locate the distance X **to determine the velocity of the incident sphere M at B before collision**.

(6) Sit the **target ball in the dimple of the screw** in such way **that M will hit m at B, and falls at the two points along same line on floor after collision**, so that that the collision **is head on collision.**

(7) Try this one-dimensional collision a dozen of times.

(8) Turn the paper over to see the dots better.

(9) Measure the distances from the plumb bob to each cluster of impact points, these are X, X’, and x’

(10) Tabulate your results in table 8.1.

II. Collision in 2 Dimension:

(1) Repeat the steps **1-5** as in **part I** for **collision in 1-Dimension**.

(2) Turn the arm to which the screw is attached **about 50° or 60° to the side**, such that the ball will **go fast enough to miss hitting the arm as it falls**.

(3) In a trial collision, check that both balls land **at least 10 cm from the plumb bob**. Otherwise, **readjust the angle** the arms make.

(4) Put the target **ball m** on the screw and allow the **ball M** to fall to the target making **a glancing collision**.

(5) Do at least another 10 trials.

(6) Turn the paper over to **see the dots better**.

(7) Measure **the distance from the plumb bob** to each cluster of impact points on the paper (a layout for **the collision in two dimensions** is shown in Fig. 8.5

(8) Repeat **step 6** for the same pair of balls but for a different h.

Tabulate your results as in table (2).

---------------------- **You can do this part only for 2D collision**

(9) Repeat steps **1-8** choosing m_1=m_2, fill table (3) and from the dots on the paper obtained measure the distances X, X', x'.

Exp. No. 9

Conservation of Linear Momentum

Name: ……………………………………………… Grade: …………………..…………

Student's No.: ………………………………………Day and Date: ……………………………

Partners Names: …………………………………………………………Sec: ………………….

Part 1: Collision in 1D. (Table 1)

Mass1	Mass2	h(cm)	y(cm)	X (cm)	X′ (cm)	x' (cm)	V(cm/s)	V′(cm/s)	v'(cm/s)

MV (gm.cm/sec)	mv' (gm.cm/sec)	MV' (gm.cm/sec)	MV'+ mv' (gm.cm/sec)

Q1. Compare the values calculated in columns 1 and 4. (They must be equal)

Part II: Collision in 2D. (Table 2)

Mass1	Mass2	h(cm)	$\vec{R}$ (cm)	$\vec{R}'$(cm)	$\vec{r}'$ (cm)	θ_1	θ_2	$\theta=\theta_2-\theta_1$

h(cm)	$P_i^2 = (MR)^2$	$P_f^2 = (MR')^2 + (mr')^2 + 2(MR')(mr')\cos\theta$

Table (3)

Mass1=Mass2	h(cm)	X (cm)	X'(cm)	x'(cm)	θ	$\vec{X}+\vec{x}$
						$\theta=\theta_2-\theta_1$

Q2. Compare the values calculated in columns 2 and 3. (They must be equal)

Q3. Since $\vec{p}_i = \vec{p}_f$ and $\vec{p}_i$ is along the x-direction, check whether $p_{fy} = 0$.

Q4. From table 3, measure vectors X, X', and x', find the sum <u>from the graph</u>, does this sum equals vector X