

CHAPTER 08

Momentum

8.1 EXPLOSIONS, COLLISIONS AND BALLET DANCING

Ballet, bullets, bombs, baseball, boxing and binary stars have something in common. They all involve the combination of mass and velocity. They all involve **momentum**.

These are some questions that a study of momentum can help answer:

- Would you rather be hit by a 1 g ball-bearing travelling at 100 m s^{-1} or by a 100 g ball travelling at 1 m s^{-1} ?
- Which would hurt more — being tackled by a lightweight footballer travelling at high speed or by a big fat one travelling at low speed?
- Police bullets are designed to stay inside their targets and not go through them. How?
- You are standing in the middle of a frictionless frozen pond. Someone with a little knowledge of physics says that you can't get to the edge because of the laws of momentum. What can you do to prove him wrong?
- A cat that falls out of a window upside-down can right itself and land on its feet. How can this be if it has nothing to push against while falling? What's the advantage of landing on its feet anyway?
- When you shoot a bullet at a watermelon suspended on a string, the melon moves towards you. How can this be and what has it to do with the assassination of JFK?

8.2 CENTRE OF MASS

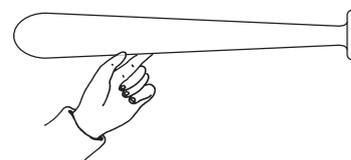
Physicists love to look at something complicated and find in it something simple and familiar. If you toss a cricket bat into the air its motion as it turns is more complicated than that of a cricket ball. A diver who executes a somersault has an even more complicated motion still. Every part of the body moves in a different way from every other part, so you cannot represent the body as a single particle as you can with a ball. However, if you look closely, you will find that there is one special point that moves in a simple path — a parabola — much as the ball does. This point is called the **centre of mass**. It is the point at which the whole mass of an object is considered to be concentrated for the purpose of applying the laws of motion.

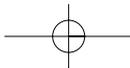
Activity 8.1 CENTRE OF MASS

You can locate the centre of mass of a bat by finding the point at which it balances on an outstretched finger.

- 1 If you can get hold of some different bats or racquets, find the balance point of each and mark it with a felt pen. Draw diagrams to show the location.

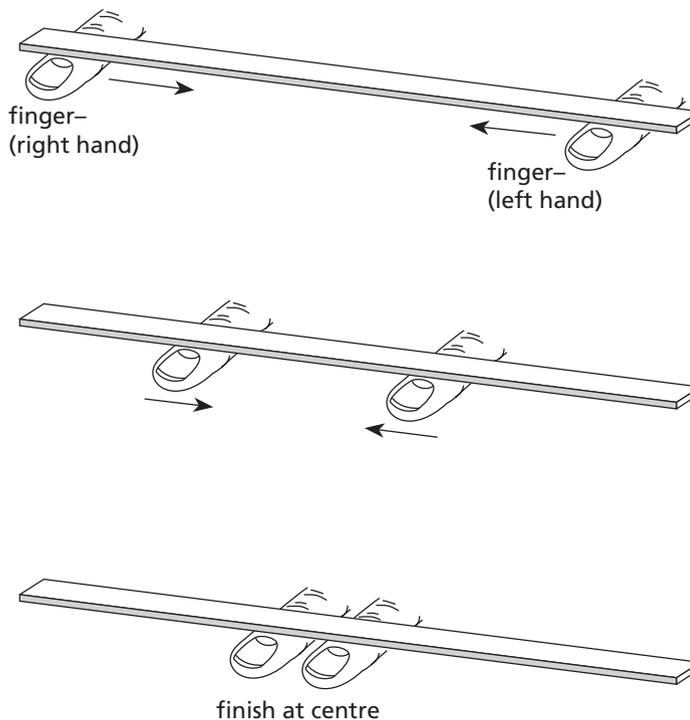
Figure 8.1
The balance point of a baseball bat.





- 2 How does the centre of mass compare with the centre of percussion as discovered in Chapter 6? (Recall letting the bat swing like a pendulum and finding its effective length.)
- 3 Hold a ruler horizontally on the outstretched index fingers of both hands as in Figure 8.2. Slowly bring your fingers in from the ends of the ruler and note where they end up. Does it matter where you start your fingers from? Why?

Figure 8.2
Where do your fingers meet?



NOVEL CHALLENGE

Imagine you place a finger under each end of a ruler and a coin is placed on one end. You pull away both fingers and the ruler and coin fall together staying in contact. But if you just pull away the finger under the coin something odd happens. What and why? Try it.

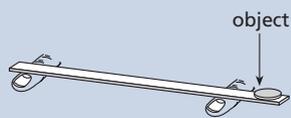
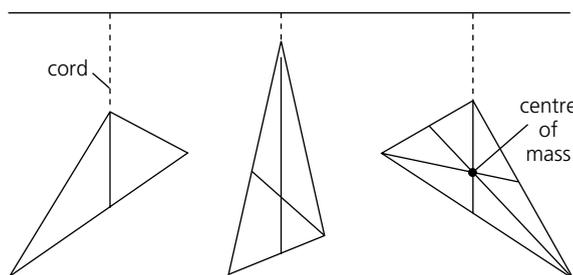


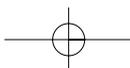
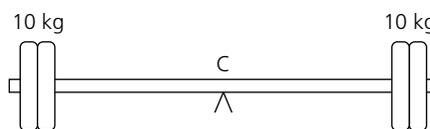
Figure 8.3
Locating the centre of mass.

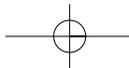
For regular shaped objects like a metre ruler, the centre of mass is at the midpoint. That's why you pick up a plank of wood in the middle. For irregular objects, though, the centre of mass can be found by letting the object hang from a pivot hole or point and drawing a vertical mark on the object. When this is done several times, the point at which the lines cross marks the centre of mass.



For more regular rigid bodies, some simple principles can be used to find the centre of mass mathematically. Consider a set of weights on the ends of a steel bar (Figure 8.4).

Figure 8.4





Intuitively, the centre of mass is at the centre of the bar. In this case the products of each weight and its distance from the pivot point are equal. When the masses are unequal, obviously the centre of mass is closer to the heavier mass. Children use the ideas of centre of mass when operating a seesaw. The seesaw has a fixed pivot point. If two children of very different mass get on, the heavier child has to sit closer to the pivot point. This positions the centre of mass of the system of two children at the pivot point.

This suggests an inverse relationship between the weights or masses of the children and their distance from the centre of mass:

$$\frac{F_{w1}}{F_{w2}} = \frac{s_2}{s_1}$$

or, in general:

$$F_{w1} \times s_1 = F_{w2} \times s_2$$

Example

Masses of 4 kg and 10 kg are on the ends of a 1.2 m long bar as shown in Figure 8.5. Determine the centre of mass of the system.

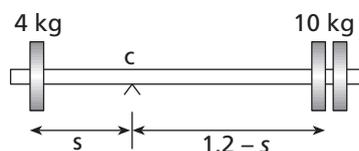


Figure 8.5

Solution

Point C is located s metres from the 4 kg mass and $(1.2 - s)$ metres from the 10 kg mass. For the bar to balance:

$$\begin{aligned} F_1 \times s_1 &= F_2 \times s_2 \\ 40 \times s &= 100(1.2 - s) \quad \text{using } g = 10 \text{ m s}^{-2} \\ s &= 0.86 \text{ m} \end{aligned}$$

Later in this chapter, the product of $F \times s$ in similar situations will be defined as **torque** and discussed in detail as it applies to rotating bodies.

— Motion of the centre of mass

Knowledge of the motion and properties of the centre of mass gives some good insights into everyday phenomena.

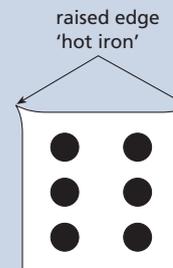
The grand jeté

When you do a long jump, chances are that your body will follow a parabolic path like a baseball thrown in from the outfield. But when a skilled ballet dancer does a split leap across the stage in a grand jeté, the path taken by her head and torso is nearly horizontal during much of the jump. She seems to be floating across the stage. The audience may not know Newton's laws of motion, but they can always sense that something magical has happened. The secret is that she raises her arms and legs as she jumps upward. These actions shift her centre of mass upward through her body. Although the shifting centre of mass faithfully follows a parabolic path across the stage, its movement relative to the body decreases the height that would be attained by her head in a normal jump. The result is that the head and torso follow a nearly horizontal path.

NOVEL CHALLENGE

There are several types of 'crooked' dice used by cheats. For each one described, deduce why they are crooked:

- 1 Green's Load (1880) — two spots drilled out and mercury added.
- 2 Tapping dice — hollow centre filled with mercury but with a small tube to one corner. Tap to make them crooked.
- 3 Bevelled — rounded on some edges.
- 4 Slick — one surface highly polished.
- 5 Hot iron — a ridge along one edge.
- 6 Capped — one face capped with rubber.



NOVEL CHALLENGE

It is easy to stand a pencil up on its base but impossible to stand it up on its point. *But why? What if you could put it in a sealed container free of air currents and arranged it so that its centre of mass was exactly over the point — could you do it then? Still no! But what is the physics behind the failure?*

