CHAPTER 04

Forces in Action

It seems incredible that a man could start railway wagons moving just by pulling on a rope with his teeth. Robert Galstyan of Armenia did just that in 1992: he set a world record by pulling two carriages a distance of 7 m with his teeth. Question: how could a 100 kg man accelerate 220 t of railway carriages from rest? Had he studied Newton's laws of motion?

4.1 SOME WRONG IDEAS ABOUT FORCES

People have often been baffled by other questions about forces:

- After you shoot an arrow does it keep going until the force runs out?
- If it takes a force to keep a thing moving, why doesn't the Moon crash into the Earth?
- Why do racing cars have 'spoilers' to increase wind resistance when really they want to go faster?
- Are there any forces acting on you if you're weightless?
- Cream seems more dense than milk so how come it floats on top of the milk?
- Cork is very lightweight — but could I lift a 1 metre diameter ball of it?
- Can rockets take off faster if they have a concrete launch pad?
- Which weighs more — a tonne of feathers or a tonne of lead?

Every one of these statements is based on a misconception about forces. Many of them go back 2000 years to Aristotle's idea that a moving thing had an internal source of 'impetus', which it was given when first thrown or moved. Such an idea acted as an obstacle to the understanding of motion for 1500 years and it still persists in students and others even today. Other *wrong* ideas are:

- If a body is not moving there is no force on it.
- The speed of an object depends on the amount of force on it.
- When the force stops, motion stops.

It's hard to convince people that these are wrong because they do sound 'right' — they seem to agree with what we see. But two cases should help to clear up misunderstandings.

Case 1: Space travel

Objects travelling in space keep going at constant velocity when there is no external force acting on them. The *Voyager* spacecraft left our solar system several years ago and is travelling on long after the jets ran out of fuel. On the other hand, a hockey ball rolls to a stop because frictional forces act on it and slow it down.

Case 2: Ice skater

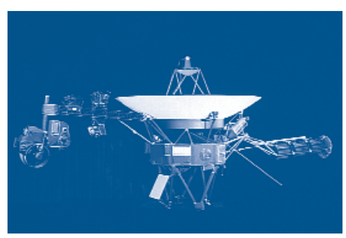
An ice skater will continue on at constant velocity until she tries to turn. The turning is a change in direction and hence a change in velocity. She will slow down unless she pushes off again.

Italian scientist **Galileo** (1564–1642) used the same logic to conclude that it is unbalanced forces that cause objects to slow down and stop. We call this force **friction**, a force that resists motion between two surfaces in contact. He took the word from the Latin *frictaire*

NOVEL CHALLENGE

The average mass of Sumo wrestlers in 1974 was 126 kg. In 2003 their average mass had risen to 157 kg. If this trend continues, when will they no longer be able to stand up? (The maximum mass that two legs can carry is 180 kg.)

Photo 4.1
Voyager spacecraft.



meaning 'to rub'. Galileo's ideas were very bold for his time because he was not able to verify them experimentally. He ended up in hot water with the Church when he asserted that other planets were much the same as Earth and revolved around the Sun, whereas the Church taught that the Sun revolved around the Earth.

Photo 4.2 Spring balances.

MEASURING FORCE 4.2

Simply stated, a force is a push or a pull and it is fitting that the unit of force be named after one of the world's greatest physicists, Isaac Newton.

The **newton** (N) is commonly measured in the laboratory with a device called a spring balance. This has a spring that extends when masses are hung on it or when other forces are applied. The scale is calibrated in grams for mass or in newtons for force. Because the direction of the force is important, **force is a vector quantity**.

EI Activity 4.1 FEELING A NEWTON

The size of 1 newton is not familiar to most people. The 'feel' of a newton helps you in your problem solving.

1. Obtain a spring balance calibrated in newtons and check that it reads zero when held vertically. Adjust it if it doesn't. Pull gently to feel forces of 1 N, 2 N, 3 N etc.
2. Hang masses of 100 g, 200 g etc. on the hook to see what force is needed to hold them up.
3. Hold a 100 g mass stationary in your hand. This requires a force of about 1 N.
4. When you sit on a bicycle, what force does your total mass exert on the bike?
5. Use bathroom scales under the front and rear wheel of your bike to see how this force is distributed.

BALANCED AND UNBALANCED FORCES 4.3

To study the effect of forces acting on an object we need to distinguish between **balanced** and **unbalanced** forces. When spring balances are hooked onto either end of a cart and given equal pulls in opposite directions (Figure 4.1), the carts remain at rest because the forces are balanced — they are **equal and opposite**.

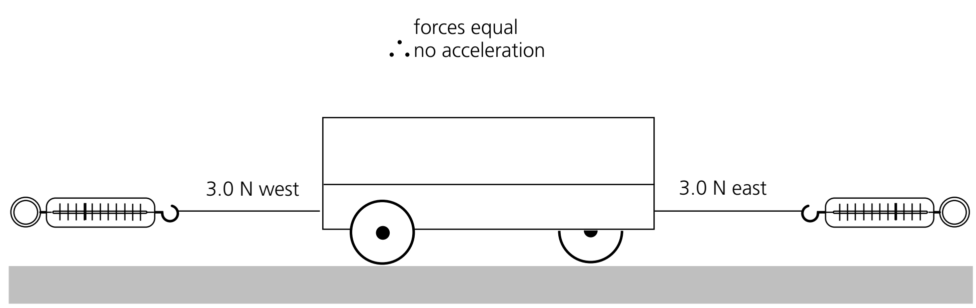


Figure 4.1 The forces on the cart are balanced — they are equal and opposite in direction.

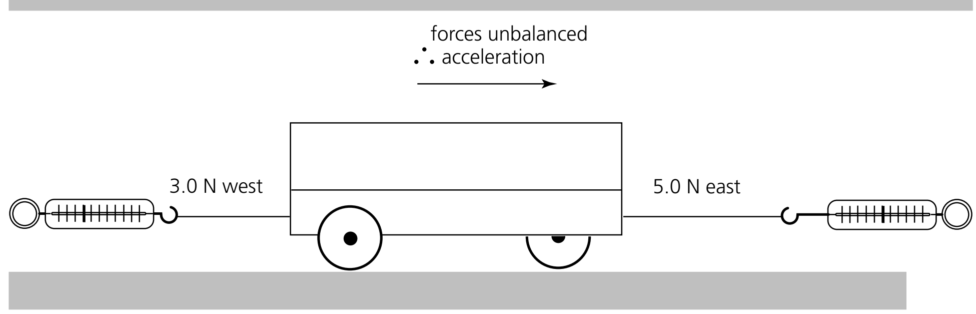


Figure 4.2 The force on the cart is unbalanced — it is greater to the right than to the left.

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If the pull on the balance to the right was increased to 5 N (Figure 4.2), then the forces would become unbalanced and the cart would move off in the direction of the larger force.

Example 1

The resultant force acting on the cart in Figure 4.2 can be calculated. It seems obvious but it is important to get the setting-out correct.

Solution

Finding the resultant force is a vector addition thus:

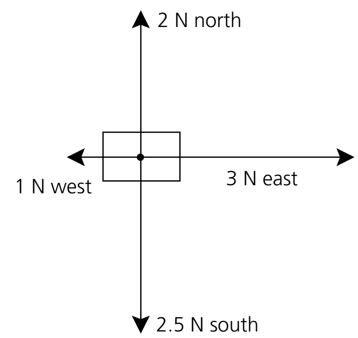
$$\begin{aligned} \boldsymbol{F}_R &= \boldsymbol{F}_1 + \boldsymbol{F}_2 \\ &= 5.0 \text{ N east} + 3.0 \text{ N west} \\ &= 5.0 \text{ N east} + (-3.0 \text{ N east}) \\ &= 2.0 \text{ N east} \end{aligned}$$

If there are several forces acting on an object you should try to reduce them to a simpler case by adding pairs in opposite directions first before combining with forces at angles.

Example 2

Calculate the resultant force acting on the object shown in Figure 4.3.

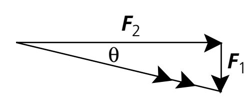
Figure 4.3



Solution

$$\begin{aligned} \boldsymbol{F}_1 &= \boldsymbol{F}_S + \boldsymbol{F}_N \\ &= 2.5 \text{ N south} + (2.0 \text{ N north}) \\ &= 2.5 \text{ N south} + (-2.0 \text{ N south}) \\ &= 0.5 \text{ N south} \\ \boldsymbol{F}_2 &= \boldsymbol{F}_E + \boldsymbol{F}_W \\ &= 3.0 \text{ N east} + (-1.0 \text{ N east}) \\ &= 2.0 \text{ N east} \\ \boldsymbol{F}_R &= 0.5 \text{ N south} + 2.0 \text{ N east (see Figure 4.4)} \\ &= \sqrt{0.5^2 + 2.0^2} \\ &= 2.1 \text{ N} \\ \theta &= 14° \text{ so the direction is E14°S} \end{aligned}$$

Figure 4.4

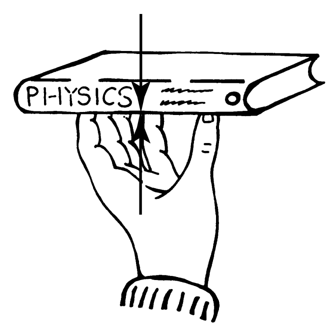


Questions

1 Calculate the resultant force when the following forces act on the same object: **(a)** 2.4 N north, 1.8 N south, 1.9 N north; **(b)** 65 N down, 92 N up and 74 N up; **(c)** 50 N north, 30 N west, 60 N south; **(d)** 26 N west, 20 N east, 30 N north, 15 N south.

2 Figure 4.5 shows a physics book held at rest in a person's hand. Two forces are shown in the diagram. One is the weight of the book pushing down and the other is the force of the hand pushing up.
(a) Are the forces balanced? Explain.
(b) Assume the hand was suddenly removed. Are the forces now balanced? What would you observe?

Figure 4.5
'Are the forces balanced?'



4.4 NEWTON'S FIRST LAW OF MOTION

Sir Isaac Newton was the first scientist to put Galileo's ideas into the form of a universal physical law, that is, one obeyed throughout the universe. In 1688, Newton proposed the first law of motion:

> An object maintains its state of rest or constant velocity motion unless it is acted on by an external unbalanced force.