1.3 Mass and weight

FOCUS POINTS

- ★ Define mass and weight and know that weights (and therefore masses) may be compared using a balance or force meter.
- ★ Define gravitational field strength and know that this is equivalent to the acceleration of free fall.
- ★ Understand that weight is the effect of a gravitational field on mass.
- ★ Describe, and use the concept of, weight as the effect of a gravitational field on a mass.

Images of astronauts walking on the surface of the Moon show them walking with bouncing steps. The force of gravity is less on the Moon than it is on the Earth and this accounts for their different movements. In the previous topics you have encountered measurements of space and time, and the rates of change that define speed and acceleration. You will now encounter a further fundamental property, the mass of an object. Mass measures the quantity of matter in a body. In the presence of gravity, mass acquires weight in proportion to its mass and the strength of the gravitational force. Although the mass of an object on the Moon is the same as it is on the Earth, its weight is less on the Moon because the force of gravity there is less.

Mass

The **mass** of an object is the measure of the amount of matter in it. It can be stated that mass is a measure of the quantity of matter in an object at rest relative to an observer.

The standard unit of mass is the **kilogram** (kg) and until 2019 was the mass of a piece of platinum–iridium alloy at the Office of Weights and Measures in Paris. It is now based on a fundamental physical constant which can be measured with great precision. The gram (g) is one-thousandth of a kilogram.

$$1\,\text{g} = \frac{1}{1000}\,\text{kg} = 10^{-3}\,\text{kg} = 0.001\,\text{kg}$$

The term **weight** is often used when mass is really meant. In science the two ideas are distinct and have different units. The confusion is not helped by the fact that mass is found on a **balance** by a process we unfortunately call 'weighing'!

Key definitions

Mass a measure of the quantity of matter in an object at rest relative to an observer

Weight a gravitational force on an object that has mass

There are several kinds of balance used to measure mass. In the beam balance the unknown mass in one pan is balanced against known masses in the other pan. In the lever balance a system of levers acts against the mass when it is placed in the pan. A direct reading is obtained from the position on a scale of a pointer joined to the lever system. A digital top-pan balance is shown in Figure 1.3.1.

▲ **Figure 1.3.1** A digital top-pan balance

Weight

We all constantly experience the force of *gravity*, in other words, the pull of the Earth. It causes an unsupported body to fall from rest to the ground. Weight is a gravitational force on an object that has mass.

For an object above or on the Earth's surface, the nearer it is to the centre of the Earth, the more the Earth attracts it. Since the Earth is not a perfect sphere but is flatter at the poles, the weight of a body varies over the Earth's surface. It is greater at the poles than at the equator.

Gravity is a force that can act through space, that is there does not need to be contact between the Earth and the object on which it acts as there does when we push or pull something. Other action-at-a-distance forces which, like gravity, decrease with distance are

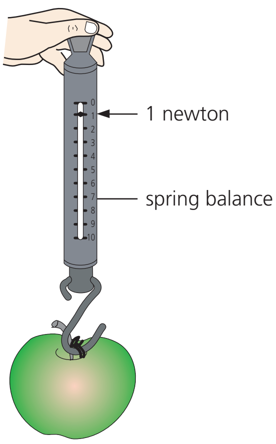
(i) **magnetic forces** between magnets and
(ii) **electric forces** between electric charges.

When a mass experiences a gravitational force we say it is in a **gravitational field**. Weight is the result of a gravitational field acting on a mass: weight is a vector quantity and is measured in newtons (N).

The newton

The unit of force is the **newton**. It will be defined later (Topic 1.5); the definition is based on the change of speed a force can produce in a body. Weight is a force and therefore should be measured in newtons.

The weight of an object can be measured by hanging it on a spring balance marked in newtons (Figure 1.3.2) and letting the pull of gravity stretch the spring in the balance. The greater the pull, the more the spring stretches.



▲ **Figure 1.3.2** The weight of an average-sized apple is about 1 newton.

On most of the Earth's surface:

The weight of an object of mass 1 kg is 9.8 N.

Often this is taken as 10 N. A mass of 2 kg has a weight of 20 N, and so on. The mass of an object is the same wherever it is and, unlike weight, does not depend on the presence of the Earth.

Test yourself

1 An object of mass 1 kg has weight of 10 N at a certain place. What is the weight of
  a 100 g
  b 5 kg
  c 50 g?
2 The force of gravity on the Moon is said to be one-sixth of that on the Earth. What would a mass of 12 kg weigh
  a on the Earth
  b on the Moon?

Weight and gravity

The weight W of an object is the force of gravity acting on it which gives it an acceleration g when it is falling freely near the Earth's surface. If the object has mass m, then W can be calculated from $F = ma$ (Newton's second law, see p. 39). We put $F = W$ and $a = g$ to give

$$W = mg$$

Taking $g = 9.8\,\text{m/s}^2$ and $m = 1\,\text{kg}$, this gives $W = 9.8\,\text{N}$, that is an object of mass 1 kg has weight 9.8 N, or near enough 10 N. Similarly, an object of mass 2 kg has weight of about 20 N, and so on.

Gravitational field

The force of gravity acts through space and can cause an object, not in contact with the Earth, to fall to the ground. It is an invisible, action-at-a-distance force. We try to explain its existence by saying that the Earth is surrounded by a gravitational field which exerts a force on any object in the field. Later, magnetic and electric fields will be considered.

The **gravitational field strength** is defined as the force acting per unit mass.

Rearranging the equation $W = mg$ gives $g = \frac{W}{m}$.

Key definition

Gravitational field strength force per unit mass

Gravitational field strength is a vector and has both magnitude and direction.

Measurement shows that on the Earth's surface a mass of 1 kg experiences a force of 9.8 N, i.e. its weight is 9.8 N. The strength of the Earth's field is therefore 9.8 N/kg (near enough 10 N/kg). It is denoted by g, the letter also used to denote the acceleration of free fall. Hence

$$g = 9.8\,\mathrm{N/kg} = 9.8\,\mathrm{m/s^2}$$

We now have two ways of regarding g. When considering objects *falling freely*, we can think of it as an acceleration of 9.8 m/s^2. When an object of known mass is *at rest* and we wish to know the force of gravity (in N) acting on it, we think of g as the Earth's gravitational field strength of 9.8 N/kg. The gravitational field strength is equivalent to the acceleration of free fall.

The weight of an object is directly **proportional** to its mass, which explains why g is the same for all objects. The greater the mass of an object, the greater is the force of gravity on it but it does not accelerate faster when falling because of its greater inertia (i.e. its greater resistance to acceleration).

While the mass of an object is always the same, its weight varies depending on the value of g. On the Moon gravitational field strength is only about 1.6 N/kg, and so a mass of 1 kg has a weight of just 1.6 N there.

Test yourself

3 An astronaut has a mass of 80 kg.

a Calculate the weight of the astronaut on the Moon where the gravitational field strength is 1.6 N/kg.

b On the journey back to Earth, the astronaut reaches a point X where the gravitational field strengths due to the Earth and the Moon are equal in magnitude but opposite in direction. State

i the resultant value of the gravitational field strength at X

ii the weight of the astronaut at X.

Revision checklist

After studying Topic 1.3 you should know and understand the following:

✓ what is meant by the mass of a body

✓ the difference between mass and weight and that weights (and masses) may be compared using a balance.

After studying Topic 1.3 you should be able to:

✓ state the units of mass and weight and recall that the weight of an object is the force of gravity on it

✓ recall and use the equation $g = \dfrac{W}{m}$

✓ describe and use the concept of weight as the effect of a gravitational field on a mass.

Exam-style questions

1 a i Explain what is meant by the mass of an object.
ii Explain what is meant by the weight of an object.
iii Describe how weights may be compared. [4]
b State which of the following definitions for weight W is correct.
A $W = g/\text{mass}$
B $W = \text{mass}/g$
C $W = \text{mass} \times g$
D $W = \text{force} \times g$ [1]
c Which of the following properties is the same for an object on the Earth and on the Moon?
A weight
B mass
C acceleration of free fall
D gravitational field strength [1]
d State the SI units of
i weight
ii acceleration of free fall
iii gravitational field strength. [3]
[Total: 9]

2 a Define gravitational field strength. [2]
b On the Earth the acceleration of free fall is about 9.8 m/s^2. On Mars the acceleration of free fall is about 3.7 m/s^2.
The weight of the Mars Rover Opportunity on the Earth was 1850 N.
i Calculate the mass of the Rover. [2]
ii Calculate the weight of the Rover on Mars. [2]
[Total: 6]

3 a Explain what is meant by a gravitational field. [2]
b State the effect of a gravitational field on a mass. [1]
c Define gravitational field strength. [2]
d The gravitational field strength on Venus is 8.8 N/kg. The mass of a rock is 200 kg.
Calculate the weight of the rock on Venus. [2]
[Total: 7]