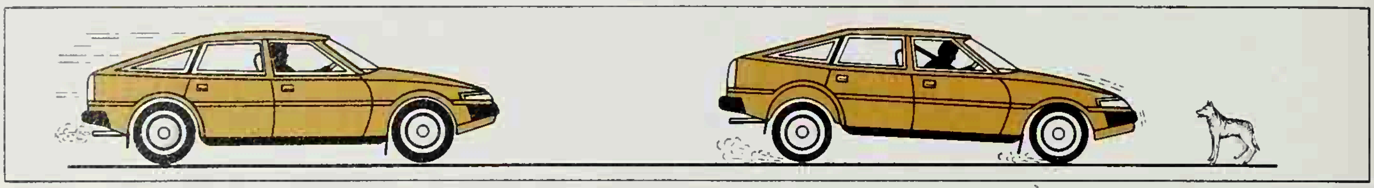
Fig. 8·4
An example of inertial mass – the movement of a driver towards the windscreen when his vehicle stops suddenly.



8·4). It is inertia that carries the driver forward. On the other hand we can consider the mass of a body as a measure of the force that acts on it in a gravitational field. This is its **gravitational mass** and when we weigh something we are measuring the force, which gives a gravitational mass its weight. In general relativity, Einstein realized that it must be a basic principle that inertial mass is exactly equal to gravitational mass, and experimental comparisons between them have shown that they appear to be equal, at least to one part in 10^{11}.

Because inertial and gravitational mass are equivalent, it is impossible (relativity states), to make any measurement which will distinguish between the presence of a uniform gravitational field and the uniform acceleration of a moving reference frame. In other words, a gravitational field of force is equivalent to an artificial field of force (due to an accelerating reference frame). There is also no way of detecting any difference between a non-accelerating (inertial) reference frame and freely falling frames of reference. Force – gravitational or otherwise – is relative. Two examples will illustrate this. First, consider an observer in a box, isolated so that he can not get any clues from the rest of the universe (Fig. 8·5). If the box is in a uniform gravitational field and its occupant drops a coin, he will see it fall to the floor. If there is no gravitational field and, instead, the box moves upwards at the correct acceleration, the coin 'dropped' by the observer will appear to fall just the same because the floor of the box will move upwards to meet it. Since any measurements of the gravitational mass (first case) and the inertial mass of the coin will be the same, the observer will be unable to determine whether the field is there or not.

For the second example, consider astronauts aboard an orbiting spacecraft. Here the spacecraft is moving in two directions – one straight ahead and, the other, falling towards the Earth – these two motions resulting in an orbit round the Earth (Fig. 8·3, page 219). In this case, the motion towards the Earth is called 'free fall', and is equivalent to being in non-accelerated motion – that is, in an inertial reference frame. Therefore, although subject to the Earth's gravity (otherwise the craft would not continue to orbit), the astronauts will experience 'free fall', that is they and everything else around them will experience a floating sensation, popularly referred to as **zero gravity**. From their isolated experience in the spacecraft they have no means of telling whether they are in free fall in a gravitational field, or whether there is no gravitational field at all.

The curvature of space-time

The principle of equivalence covers uniform gravitational fields, yet over anything but a very small volume of space, a gravitational field is not uniform. This is particularly noticeable when we deal with astronomical and cosmological distances; then gravitational attraction is different in different parts of so large a field. Einstein saw that this meant that space-time and gravitation must be intimately linked. Indeed a mathematical analysis showed that while, for a uniform field over a very small volume, space-time was 'flat' or not detectably curved (that is, its geometry approximated to that devised by Euclid and met with in small areas on Earth), for larger volumes, where gravitational attraction is not uniform, space was 'curved'. The curvature was best expressed in

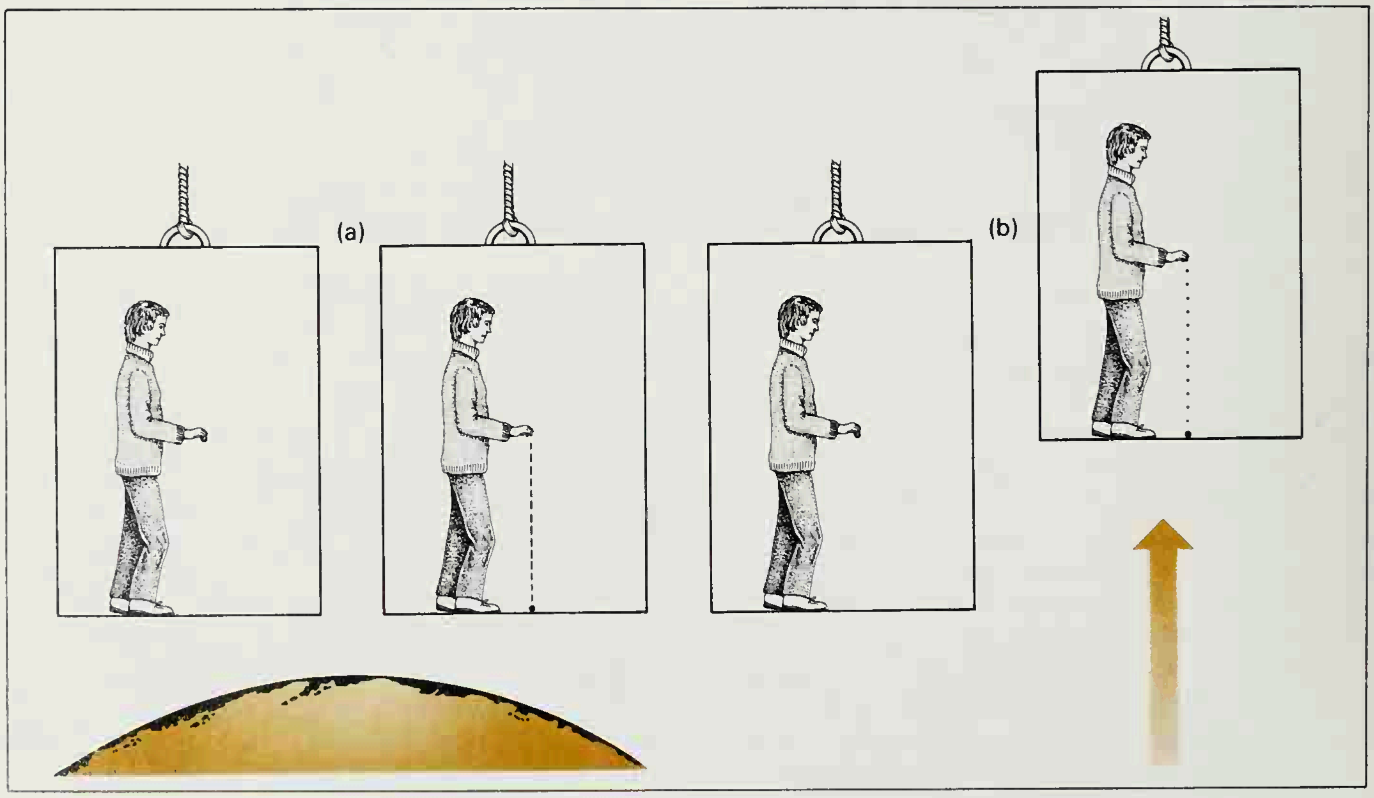


Fig. 8·5
An observer in an isolated box, (a) in a gravitational field, and (b) in an upward accelerating box with no gravitational field.