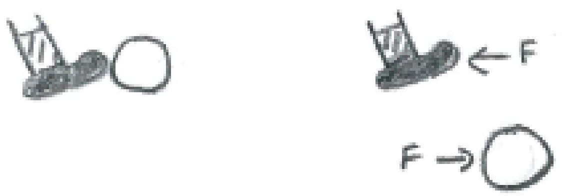
Newton's 3rd Law (7 pages; 24/10/18)

(1) "If object A exerts a force on object B, then B exerts an equal and opposite force on A"

Example 1: Football being kicked



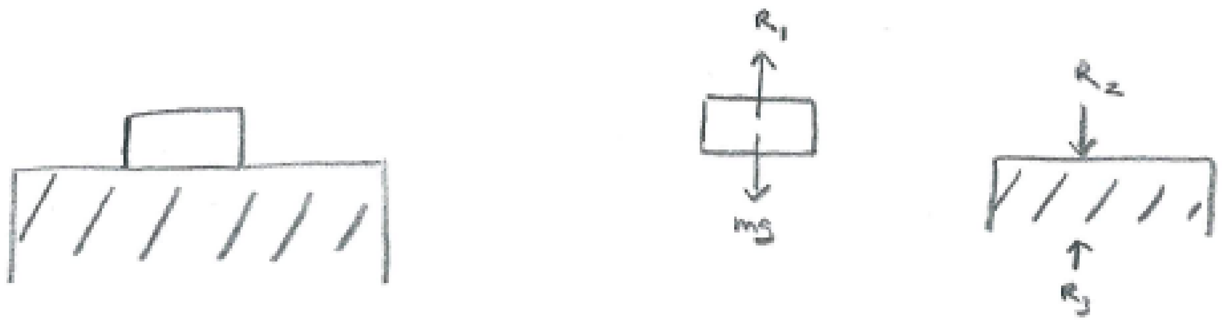
If a football is kicked, then clearly the ball exerts a force on the player's foot (even if the ball is stationary to start with).

The term 'reaction' is often used. In this case, we would talk about the reaction of the ball on the foot. In general, where neither of the objects can be said to be initiating the force, each object is described as exerting an equal and opposite reaction on the other. The size of the reaction will be determined by applying Newton's 2nd Law to the objects concerned (see Examples 2-4).

In this example, the force and reaction involved both depend on the nature of the objects in question. Thus a balloon would offer minimal resistance to a football boot, and so the boot would exert only a small force on the balloon.

Don't confuse Newton's 3rd Law with equilibrium: In the case of equilibrium, the forces being considered act on the same object, whereas in the case of Newton's 3rd Law the forces act on different objects (in this example, one acts on the ball and the other acts on the foot).

Example 2: Block resting on a table



Separate force diagrams are shown above for the block (of mass m) and the surface of the table (assumed to be of negligible mass).

The forces acting on the block are mg (the gravitational force) and the reaction, R_1, of the surface on the block. As the block is in equilibrium, Newton's 2nd Law $\Rightarrow R_1 = \text{mg}$

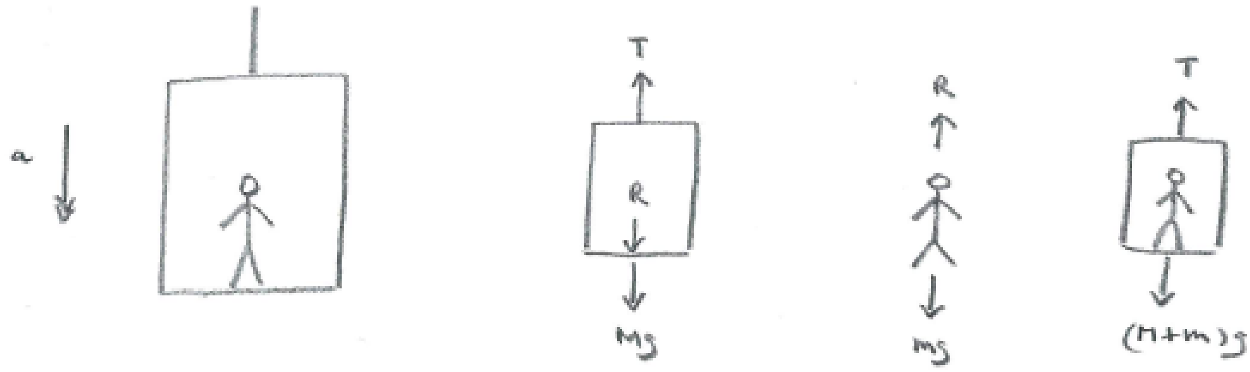
Then, by Newton's 3rd Law, R_2 (the reaction of the block on the surface) equals R_1.

For completeness, R_3 (the reaction of the rest of the table on its surface) equals R_2, by Newton's 2nd Law (since the table is also in equilibrium).

This example illustrates how a reaction force is often easier to establish via one object than another. Thus, here it is easy to determine R_1 (as equal to mg, by N2L), whereas R_2 cannot be set equal to the unknown R_3, and can only be determined by equating it to R_1, by N3L.

Example 3: Man in a lift

The man has mass m, and the lift has mass M (excluding the man). There is a tension T in the lift cable , and the lift (and the man) are moving downwards with acceleration a.



(A) (B)

(C)

Separate force diagrams are shown above for the following objects:

(A) The lift on its own

N2L $\Rightarrow Mg + R - T = Ma$ (1)

(where R is the reaction of the man on the lift)

Note: It is tempting to think that the reaction of the man on the lift should just be equal to mg. However, consider the extreme case where the cable is cut, so that the lift and man are both falling freely under gravity. In that case, the reaction of the man on the lift would be zero.

(B) The man on his own

(By N3L, the reaction of the lift on the man equals the reaction of the man on the lift.)

N2L $\Rightarrow mg - R = ma$ (2)

(C) The lift and man combined

N2L ⇒ $(M+m)g - T = (M+m)a$ (3)

Note that adding (1) & (2) gives (3); ie the three equations are not independent, and we can use only two of them without duplication.

If we were given m, M and a, then we could use eq'n (2) to obtain R, and eq'n (3) to obtain T. Eq'n (1) is less useful (at least initially), since it involves two unknowns, T and R. (It could, however, be used as a check.)

Example 4: Man in a lift holding a parcel by a piece of string

Suppose that the lift, man and parcel have masses 300kg, 75kg and 2kg, respectively, and that the lift is accelerating upwards at 0.5 ms^{-2}.

Let the tension in the lift cable be T.

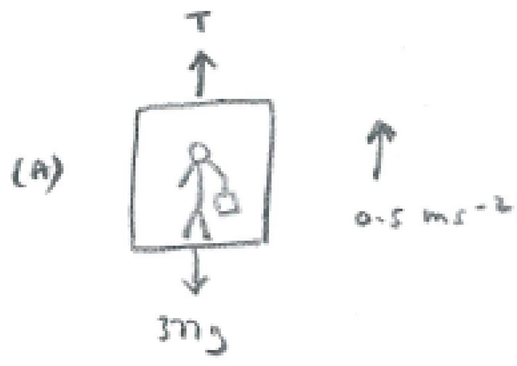
Let the tension in the string be T_p.

Let the reaction between the man and the lift be R.

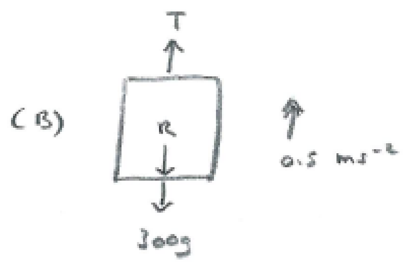
[See "Tensions" note in respect of the tension in the string.]

There are now 5 force diagrams that could be drawn (each giving rise to an equation, due to N2L):

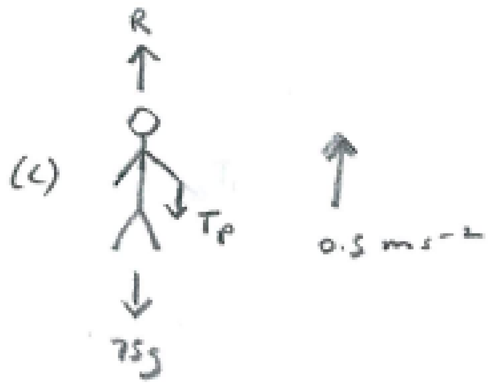
The lift, man and parcel combined:



The lift:

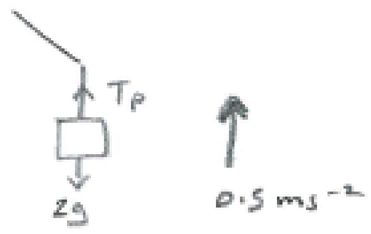


The man:



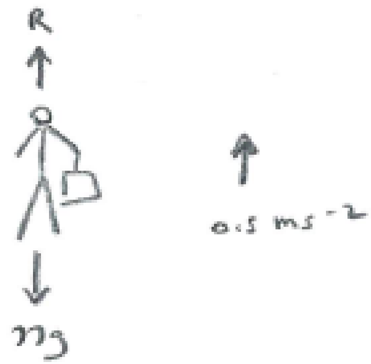
The parcel:

(D)



The man and parcel combined:

(E)



However, only 3 equations can be used (the number of actual objects involved; ie lift, man and parcel) without duplication, and these enable the unknown forces (T, T_p and R) to be determined.

Suppose that we are being asked to find the unknown forces in the order T_p, R and T.

We would first use (D) to find T_p:

N2L ⇒ $T_p - 2g = 2(0.5)$, so that $T_p = 2(9.8) + 1 = 20.6$N

Then we can use (E) to find R (though (C) would also be possible):

N2L ⇒ R – 77g = 77(0.5), so that R = 77(10.3) = 793.1N

Finally, the simplest way to obtain T is from (A):

N2L ⇒ T – 377g = 377(0.5), so that T = 377(10.3) = 3883.1N

(in practice, these answers would usually be given to 3sf)

The other diagrams can be used to check the figures:

From (B), N2L ⇒ T – R – 300g = 300(0.5) = 150

Using the results found above, the left-hand side =

3883.1 – 793.1 – 300(9.8) = 150 (ie agrees with the right-hand side)

From (C), N2L ⇒ R – T_p – 75g = 75(0.5) = 37.5

Using the results found above, the left-hand side =

793.1 – 20.6 – 75(9.8) = 37.5