Mechanics – Clarifications (11 pages; 24/4/23)

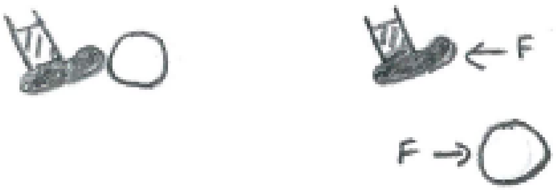
[This note only covers areas of potential confusion. Please see main notes for further details.]

Contents

(1) Newton's 3rd Law

This says that "if object A exerts a force on object B, then B exerts an equal and opposite (reaction) force on A".

Example: Football being kicked



If a football is kicked, then we know from experience that the ball exerts a force on the player's foot. Note though that, despite the apparent symmetry, it is the foot that is the cause of this force.

In this example, the force and reaction force 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 only be able to exert a small force on the balloon.

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

(2) Friction

(i) Static and dynamic friction

The value of the coefficient of friction, μ may reduce significantly once an object is moving; ie $\mu_k < \mu_s$, where μ_k is the 'kinetic' (or 'dynamic') coefficient of friction, and μ_s is the 'static' coefficient of friction.

No distinction is generally made between the two types of friction for the purpose of A Level exams.

(ii) Direction of friction

If an object is at rest on a slope, the frictional force could be acting up or down the slope. An applied force may be just sufficient to stop the object from sliding down the slope, in which case friction will be opposing the attempted motion, which is down the slope, so that the frictional force is up the slope - aiding the applied force. If instead the applied force is not quite enough to move the object up the slope, then the attempted motion is up the slope, and the frictional force is down the slope - countering the applied force).

(iii) Friction and rolling wheels

Friction enables a wheel to roll. If there is no sliding as well (it is possible for there to be a combination of rolling and sliding), then the point of contact of the wheel with the surface will be stationary and so no work is done by the (static) frictional force. Friction will only offer resistance to motion if the wheel slides (and there is dynamic friction).

However, in practice the wheel will be deformed near the point of contact, and this will result in so-called 'rolling friction'. As the edge of the wheel is in prolonged contact with the surface, the rolling friction does negative work; ie constitutes a resistance force.

See "Rolling Wheel – Friction" for further details.

(3) Reaction forces

(i) Consider an object of mass m resting on a horizontal surface. It is tempting to just say that the surface experiences a force of mg due to the weight of the object. The correct reasoning is as follows:

Drawing a force diagram for the object, and applying Newton's 2nd law gives: $R = mg$. Then, by Newton's 3rd law, the reaction force on the surface from the object is R, which we have found to equal mg.

(ii) If a rod, say, is attached to a surface, then there will be a reaction force on the rod, at a particular angle. In practice, it is usually convenient to resolve this reaction force into two perpendicular components: along and perpendicular to the surface. Were the rod to be resting on the surface (say, if it were a ladder placed against a wall), then the component along the surface would be the frictional force (and this is taken to be zero if the wall is smooth).

(iii) In the case of a man in a lift, the reaction force will not equal the weight of the man if the lift has a non-zero acceleration, as can be seen by applying N2L to the man:

$R - mg = ma$, where m is the mass of the man, and a is the upward acceleration of the lift (and hence the man)

(iv) In Fig. 1, where a ladder rests against a vertical wall, the ladder is constrained to move up or down the wall. In most cases the attempted motion is down the wall, and so friction acts up the wall. In Fig. 2 however, the ladder can only move initially along the line of the ladder, and so (in most cases) friction acts up the ladder. This means that the normal reaction R has different directions in the two cases. Note that the total reaction force is made up of the two perpendicular components F and R (where F may be zero).

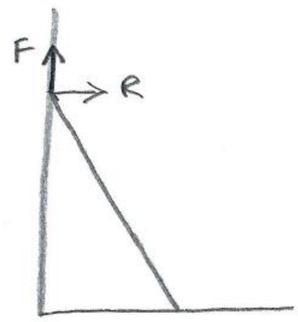


Fig. 1

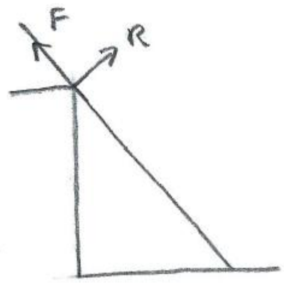


Fig. 2

(4) Tension and compression in rod etc

(i) Why the forces at each end of a rod (in the case of a tension or a compression) or rope (in the case of a tension) can be treated as being the same:

Suppose that a car is pulling a trailer by means of a towbar, and that the towbar is subject to forces T_1 and T_2 at its two ends, as shown in the diagram.

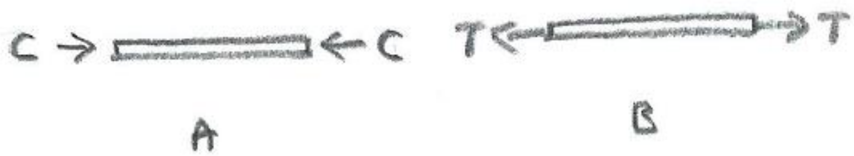
Applying N2L: $T_1 - T_2 = ma$,

where m is the mass of the towbar, and a is the acceleration of the car, trailer and towbar.

If the towbar is assumed to be of negligible mass (or 'light'), so that $m \approx 0$, then $T_1 \approx T_2$.

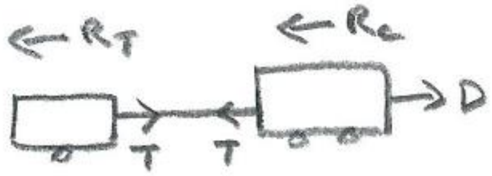
(ii) Tension v Compression:

Consider a force diagram for the towbar. There are two possibilities: the towbar may be under compression (diagram A), or under tension (diagram B).



Tension will be the more usual situation, with compression generally only occurring in the case of heavy braking (as seen below). For this reason, the symbol T is invariably used - on the understanding that it may turn out to be negative. (Then, for example, a tension of $-500\ N$ would be described as a compression of $500\ N$.)

Textbooks have been known to include all the forces on a single diagram, and draw the arrows on the towbar pointing away from the car and the trailer. These are intended to be forces on the car and trailer (rather than on the towbar) - see the diagram below.



To avoid this confusion, it is better to have separate force diagrams for the car and trailer.

(iii) Circumstance in which a towbar will be under compression

When a car and trailer are decelerating, we can show that the towbar will be under compression if there is heavy braking, or if the resistance on the trailer is sufficiently small:

If the car and trailer are decelerating at a rate d, then the tension T in the towbar is given by:

$R_T - T = m_T d$,

where m_T is the mass of the trailer, and R_T is the resistance on it.

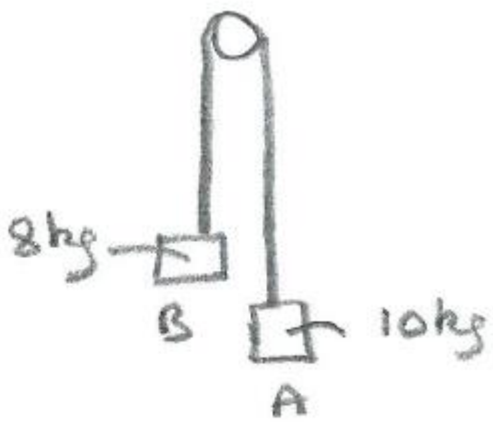
Thus the towbar will be under compression if

$T = R_T - m_T d < 0$; ie if $R_T < m_T d$;

ie if either the deceleration is big enough (due to heavy braking), or if R_T is sufficiently small.

(For large R_T, the trailer would decelerate at a rate greater than d if it were uncoupled from the towbar, and the tension is needed in order to obtain the smaller deceleration of d.)

(5) Pulleys



(i) In the case of two blocks on either side of a pulley (as in the diagram), we cannot treat the two blocks and the connecting rope as a single object, as they are not moving in the same direction.

(However, when N2L is applied separately to the two blocks, the equations can be combined to obtain the same effect as though a single object existed.)

(ii) The pulley will usually be described as 'smooth', to indicate that there is no frictional force acting on the connecting rope. This will ensure that the tension is the same at both ends of the rope. This can be demonstrated as follows:

In general, a rope (of mass m) over a pulley has 3 external forces on it: the tension at the two ends (T_1 & T_2) and the frictional force (F) due to the pulley.

Applying Newton's 2nd law to the rope,

$T_1 - T_2 - F = ma$ (where a is the acceleration of the rope)

If the rope has negligible mass, and if F is also negligible, then $T_1 \approx T_2$.

(iii) The rope will usually be described as inextensible, in order to ensure that all components of the system have the same acceleration.

(6) Moments

(i) It can be shown that, provided the forces are in equilibrium, it doesn't matter which point we choose to take moments about. Also, the point needn't actually be within the object itself (though it usually is).

(ii) Moments can be taken about a point in two ways:

(a) Multiplying each force by the perpendicular distance from the line of action of the force to the point

(b) Resolving the force into perpendicular components at ANY point on its line of action, and then determining moments for the two components (often so that the line of action of one component passes through the point, so that its moment is zero).

(iii) Once N2L has been applied in two perpendicular directions and moments taken about a particular point (so that 3 equations have been created), it isn't possible to obtain an independent 4th equation by taking moments about another point; ie it will just duplicate information already obtained.

However, it is possible to take moments about 2 points and apply N2L in just one direction - provided that this direction isn't perpendicular to the line joining the 2 points.

Alternatively, it is possible to take moments about 3 points (and not use N2L) - provided that the 3 points don't lie on a straight line.

(iv) Hinged joints

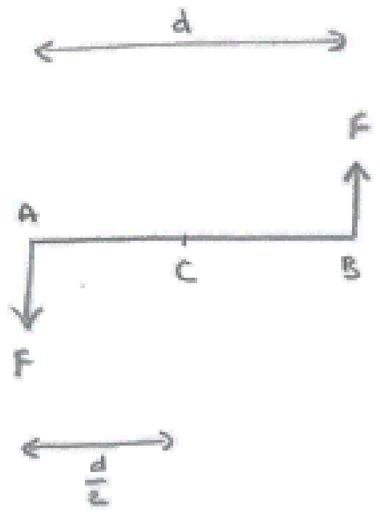
Suppose that a rod is attached to a wall by a hinged joint (ie so that the angle can be varied). The hinge will often be described as 'smooth' or 'free'. This means that it offers no resistance to being turned; ie there is no moment within the hinge countering any external forces. (Were the hinge not to be smooth then the resistance to turning within the hinge could be thought of as due to the moment of a frictional force acting at a short distance from the centre of the hinge.)

(v) Couples

The term 'couple' is used to describe a pair of equal but opposite forces, applied to an object, which don't have the same line of action, so that there is a turning effect. (It is sometimes also used in situations where there are more than two forces, which have a resultant of zero but a net non-zero moment.)

As usual, the fact that the forces are balanced means that it doesn't matter which point we take moments about, and so there is no particular point about which a couple can be said to turn.

Thus, referring to the diagram below, we could take moments about A, for example, to give a net moment of Fd.



(7) Conservation of momentum

Momentum is conserved when there are no external forces, and consequently if objects are colliding on a surface then that surface is usually described as smooth, so that any friction can be ignored. However, the MEI Further Maths specification says (on page 43): "The impulse of a finite external force (e.g. friction) acting over a very short period of time (e.g. in a collision) may be regarded as negligible." [as Impulse = Force x Time] This enabled Conservation of Momentum to be justified in the Oct. 2021 A Level Mechanics Minor paper, in the case where the surface was specified as being rough.