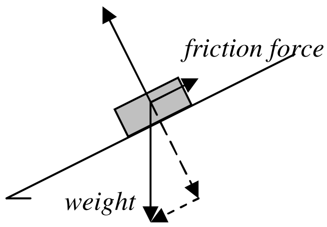
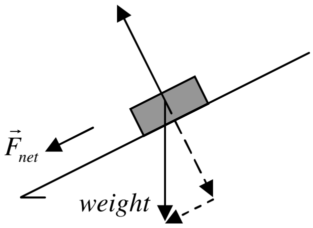
Free physics self-help revision

Object on an inclined plane

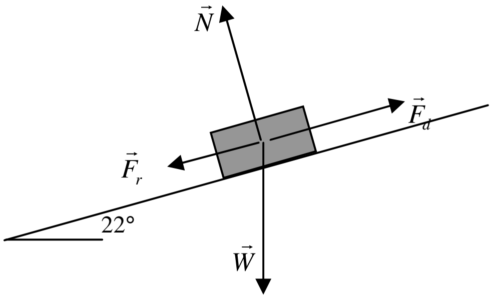
On an ***inclined plane*** *an object at rest has zero net force acting on it.*



If there is no friction (or very little friction), the vector sum of the normal reaction force and weight, (the net force) is not zero, and the object slides down the slope with increasing speed.



Example 1 A 1200-kg car travels uphill at *constant* velocity along a road which inclines at an angle of 22° with the horizontal. Air resistance and rolling friction total 50 N oppose its motion. Analyse the forces acting on the car and determine the driving force.

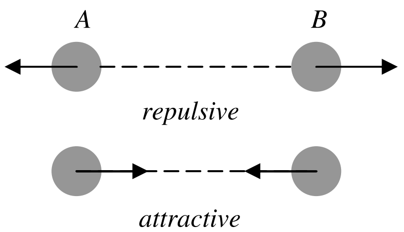


Since the car travels at constant velocity (zero acceleration), $\therefore \vec{F}_{net} = \vec{F}_d + \vec{F}_r + \vec{W} + \vec{N} = \vec{0}$, and therefore the component along the inclined plane (road) is zero. Choose uphill as the positive direction.

${}^{+}F_d + {}^{-}F_r + {}^{-}W\sin\theta = 0$, $F_d = F_r + W\sin\theta$,

$F_d = 50 + 1200 \times 9.8 \times \sin 22° \approx 4.5 \times 10^3$ N.

Newton's third law: *Two interacting objects, A and B, exert a force on each other, i.e. A exerts a force $\vec{F}_B$ on B and B exerts a force $\vec{F}_A$ on A. $\vec{F}_A$ and $\vec{F}_B$ are equal in magnitude but opposite in direction. Usually one is called action, the other reaction.*



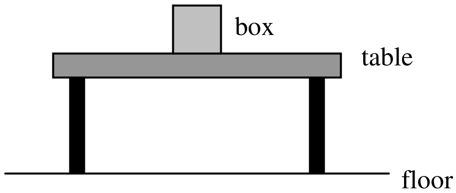
$\vec{F}_B = -\vec{F}_A$

In Newton's third law there are always two objects and two forces involved. One force is on one object and the second force on the other. In Newton's second law there can be one or more forces involved and they all act on the same object.

Only forces that act on the same object can be added to give the net force. It is meaningless to add the two forces in Newton's third law and say the net force is zero.

$\vec{F}_A + \vec{F}_B = \vec{0}$, *this addition is undefined.*

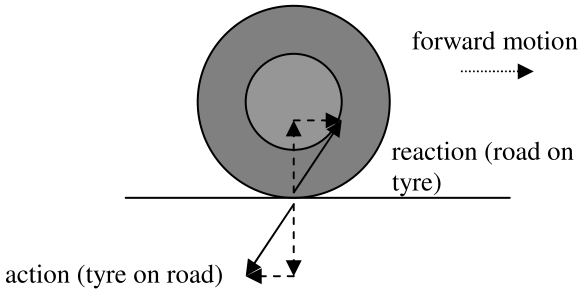
Example 2 In the following situation identify 5 pairs of forces that could be used to illustrate Newton's third law.



The box presses onto the table; the table exerts a reaction force on the box.
The table presses onto the floor; the floor exerts a reaction force on the table.
The earth attracts the box; the box attracts the earth.
The earth attracts the table; the table attracts the earth.
The box attracts the table; the table attracts the box.

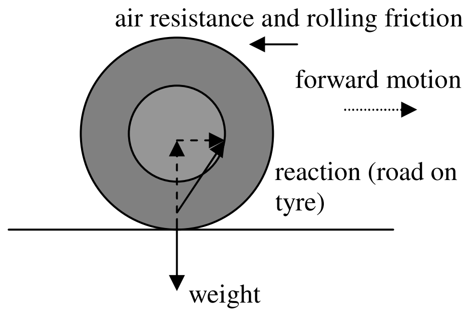
Example 3 A car experiencing some air resistance and rolling friction travels at constant velocity on a horizontal road. Analyse the forces in Newton's third law between the tyres and the road surface. Analyse the forces in Newton's second law in relation to the motion of the car.

Force diagram showing the forces in *Newton's third law*:

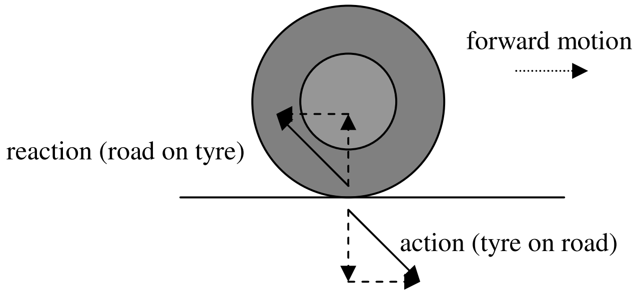


The reaction force has two components: the force of friction and the normal reaction of the road on the tyre.

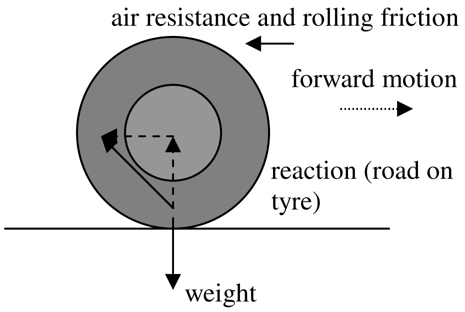
Force diagram showing the forces on the car (represented by the tyre) in *Newton's second law*:



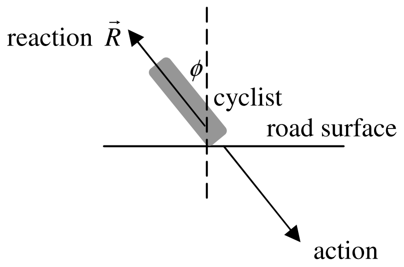
Example 4 A car slows down on a horizontal road whilst brakes are applied. Analyse the forces in Newton's third law between the tyres and the road surface. Analyse the forces in Newton's second law in relation to the motion of the car.
Force diagram showing the forces in *Newton's third law*:



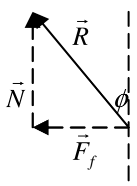
Force diagram showing the forces on the car (represented by the tyre) in *Newton's second law*:



Example 5 As a motorcyclist manoeuvres around a bend, she naturally slopes inwards instead of upright. The cyclist exerts a force (action) on the road and the road exerts a force (reaction) on the cyclist. These are the two forces in *Newton's third law*.

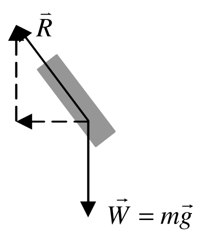


This reaction force $\vec{R}$ has two components. The vertical component is the normal reaction force $\vec{N}$, and the horizontal component is the force of friction $\vec{F}_f$.



$N = R\cos\phi$, $F_f = R\sin\phi$ and $\tan\phi = \dfrac{F_f}{N}$.

When the motion of the cyclist is analysed using *Newton's second law*, include only forces on the cyclist. They are weight $\vec{W}$ and reaction force $\vec{R}$. The action force is not involved because it is not on the cyclist.



The net force on the cyclist is given by the horizontal component $\vec{F}_f$ because $\vec{W}$ and the vertical component of $\vec{R}$ add to zero.
This net force changes the motion (direction) of the cyclist. The cyclist could not make the turn if there was no friction between the tyres and the road surface.

Example 6 Calculate the force of friction between the tyres and the road surface if the leaning angle with the vertical is 40°, and the total mass of the cycle and the rider is 250 kg.

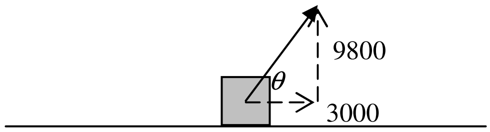
$$N = W = mg = 250\times 9.8 = 2450\ \text{N}$$

$$\tan\phi = \frac{F_f}{N},\ F_f = N\tan\phi = 2450\tan 40° \approx 2100\ \text{N}$$

Example 7 A 1-tonne car speeds up at 3.0 m s^{-2} in a straight road. Determine the reaction force (including direction) of the road on the car, assuming the resistive forces against the motion of the car are negligible.

The driving force (due to friction) on the car
$= ma = 1000\times 3.0 = 3000$ N
The normal reaction force on the car
$= mg = 1000\times 9.8 = 9800$ N

$$R = \sqrt{3000^2 + 9800^2} \approx 1.02\times 10^4\ \text{N}$$



$$\tan\theta = \frac{9800}{3000},\ \theta \approx 73° \text{ with the road surface}$$

Questions: Next page

Q1 A 5-kg box slides down a plane inclined at 30° to the horizontal at constant speed. Calculate the force of friction on the box.

Q2 A 5-kg box slides down a plane inclined at 30° to the horizontal with its speed increasing at 0.5 m s^{-1} in a second. Calculate the force of friction on the box.

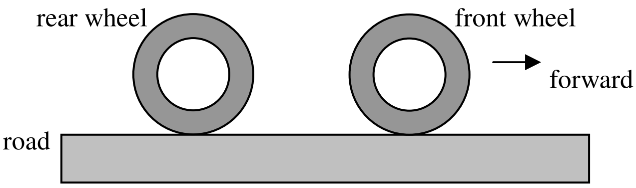
Q3 A 5-kg box rests on a horizontal floor. Name 2 pairs of forces that you can use to illustrate Newton's third law.

Q4 An apple falls to the ground through the air. Name 2 pairs of forces that you can use to illustrate Newton's third law.

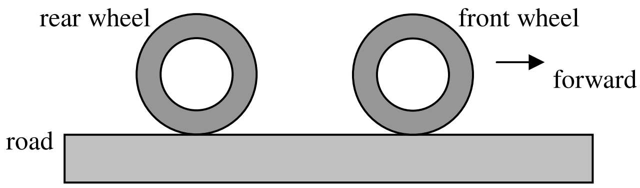
Q5 Your bike naturally slopes inwards instead of upright when you ride it at a roundabout. Why?

Q6 Is it true that friction always slows you down?

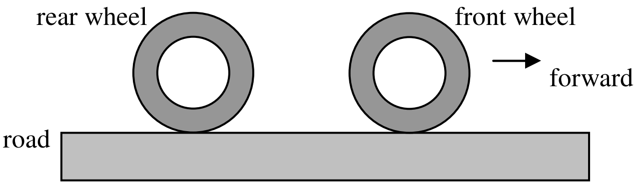
Q7 Draw an arrow to show the force exerted by each tyre on the road due to friction when a motorcycle *slows* down by braking the rear wheel.



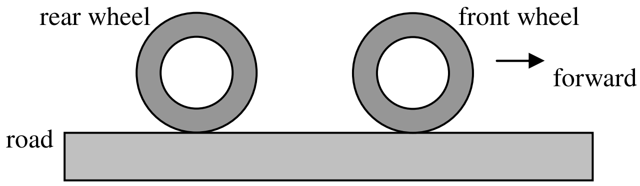
Q8 Draw an arrow to show the force exerted by the road on each tyre due to friction when a motorcycle *slows* down by braking the rear wheel.



Q9 Draw an arrow to show the force exerted by each tyre on the road due to friction when a motorcycle *speeds* up.



Q10 Draw an arrow to show the force exerted by the road on each tyre due to friction when a motorcycle *speeds* up.



Q11 A 800 kg car slows down at 2.0 m s^{-2} in a straight road. Determine the reaction force (including direction) of the road on the car, assuming air resistance is negligible.

Numerical, algebraic and worded answers:
1. 24.5 N 2. 22 N 3. The box presses onto the floor; the floor supports the box. The earth attracts the box; the box attracts the earth.
4. The apple pushes the air; the air pushes the apple. The earth attracts the apple; the apple attracts the earth.
5. So the ground could provide a force on the bike (due to friction) towards the centre of the roundabout to enable the bike to make the turn.
6. No, you need friction to speed up or to turn.
7. Forward arrow (rear wheel); much smaller forward arrow (front wheel).
8. Backward arrow (rear wheel); much smaller backward arrow (front wheel). 9. Backward arrow (rear wheel); much smaller forward arrow (front wheel). 10. Forward arrow (rear wheel); much smaller backward arrow (front wheel). 11. 8000 N approx., backward 78 deg with the vertical.