Physics Factsheet

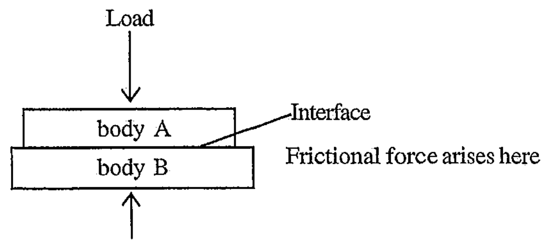
www.curriculum-press.co.uk Number 123

Understanding Frictional Forces

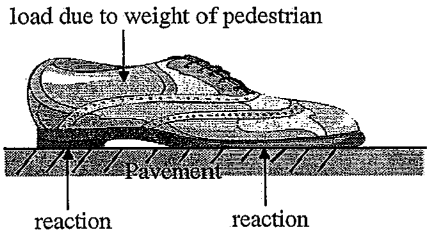
Significance of frictional forces in everyday life

Friction is a phenomenon which gives rise to forces which influence many activities in everyday life. Indeed, some activities depend on frictional forces, e.g. walking along a pavement, leaning a ladder against a wall, nailing two pieces of wood together. However, in other situations frictional forces are a burden to be overcome, e.g. energy loss in car engines.

Friction occurs at the interface between two bodies. No matter how smooth surfaces may appear, they are all "rough " on the microscopic scale. Frictional forces act along the plane of the interface.

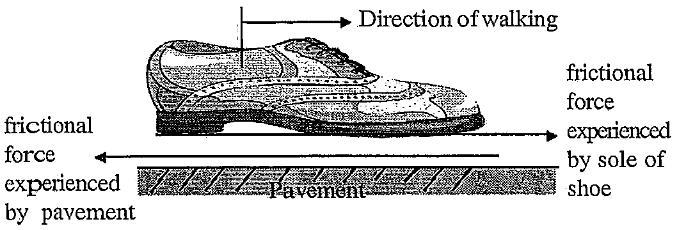


In the case of a person walking along a pavement, the interface is between the soles of the shoe and the pavement. The normal force is provided by the weight of the pedestrian.



The frictional force experienced by the shoe acts horizontally in the direction of walking. The force experienced by the pavement is in the opposite direction, but of equal magnitude *(Newton's Third Law of Motion.*

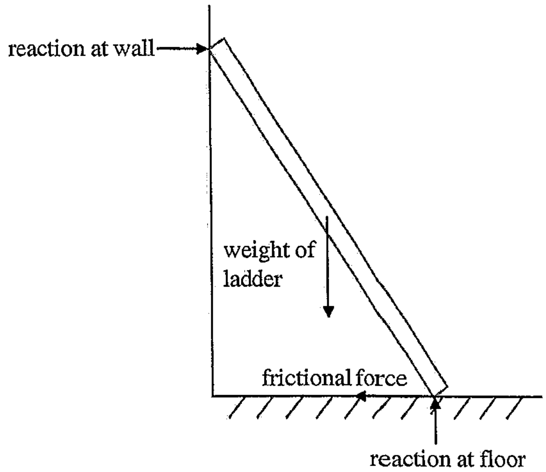
In these situations it is important to distinguish between the force exerted on a body, and that exerted by the body.



Walking depends on frictional forces. Indeed walking would be impossible if friction did not exist - try walking on ice.

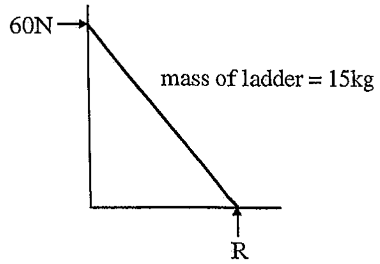
Notice that in the case of the shoe/pavement interface, frictional forces exist even when there is *no relative motion* between the two surfaces.

The simple act of leaning a ladder against a wall would be impossible without the existence of friction. An essential horizontal friction force acts at the interface between the floor and the bottom of the ladder, acting towards the wall. There may also be a friction force between the wall and ladder, but this is not essential.

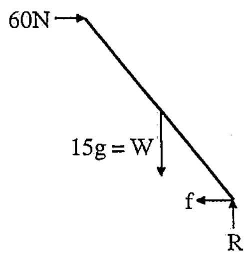


Exam Hint: Make sure you bring in the key points: there must be two bodies; frictional force acts along the interface; there may, or may not be, relative motion. Wording in exam questions, "rough" is code for ***include friction*** *"smooth" is code for* ***omit friction****.*

Example 1: A uniform ladder of mass 15kg rests with its upper end against a smooth vertical wall, and its lower end on a rough horizontal surface. If the magnitude of horizontal reaction at the wall is 60N, and g = 9.81ms^{-2}, then
(a) find the magnitude of the frictional force
(b) state its direction
(c) find the magnitude of the reaction R at the ground.



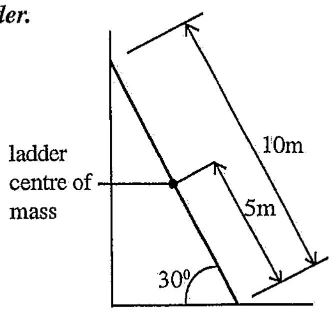
Answer:
Draw a free body diagram



Horizontal forces: 60 = f
Vertical forces: R = W = 15g

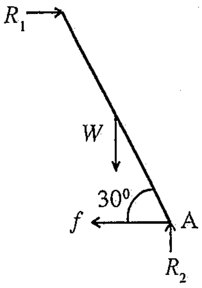
(a) f = 60N
(b) towards the wall
(c) R = 15g = 147.1N

Example 2: The top end of a uniform ladder, length 10m and mass 20kg, rests against a smooth vertical wall at an angle of 30° to the horizontal as shown. Assume g = 9.81ms^{-2}.
Find the clockwise and anticlockwise moments about the bottom of the ladder.



Answer

Draw a free body diagram



Moments about A: clockwise:
$R_1 \times 10\sin 30 = 5R_1$ Nm.
Moments about A: anticlockwise:
$W \times 5\cos 30 = 196.2 \times 4.33 = 850$ Nm.

(These could be equated to find R_1, which is equal and opposite to the friction at the bottom of the ladder.)

If relative motion does exist at the interface between the two bodies, as for example in a car engine, then energy is expended. A force is exerted through a distance. This "friction overcoming" energy is transferred to another form, usually heat, which has to be removed by the cooling system.

Three possible requirements for frictional forces have been identified:
1. Minimise the friction, e.g. sliding friction in piston engines
2. Control the friction, e.g situations where it is required that the friction force remains within certain values, as in a clutch or friction drives.
3. Maximise the friction, e.g. brake pads/disc, tyre/road interface.

We cannot eliminate frictional forces entirely. Nonetheless, engineers and designers devote a great deal of effort in *reducing* unwanted energy losses due to friction:

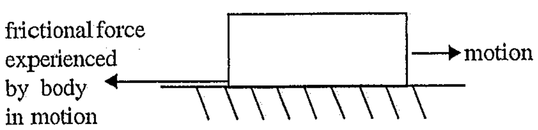
(a) Use low friction materials e.g. polymers
(b) Insert a rolling element into the interface e.g. ball bearings
(c) Use a lubricant between the two bodies e.g. oil.

Engineers *maximise* frictional forces by choosing materials with high friction e.g. in car brakes and clutches.

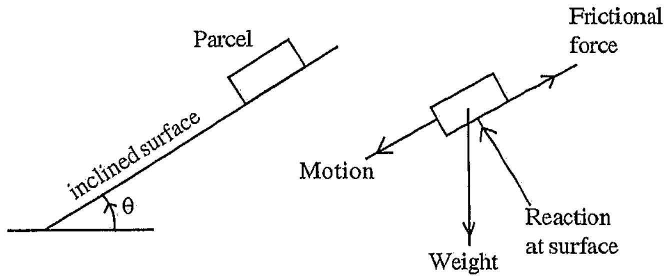
> *Frictional forces are essential for some everyday activities. In other activities, friction is a burden to be overcome*

In which direction does the friction force act?

If one of the bodies that are in contact has motion relative to the other, then the frictional force always acts in a direction to oppose the motion.

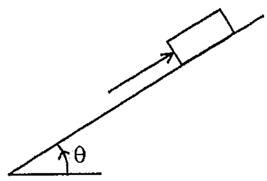


However, frictional forces can act when there is no relative motion between the two contacting bodies. In such cases it is necessary to examine each situation in order to decide the direction of the frictional force. Let us look at the case of a parcel on a slope inclined at an angle θ to the horizontal.



If the angle θ is sufficiently large then the parcel will slide down the slope, with the friction force experienced by the parcel acting up the slope, i.e. opposing motion.

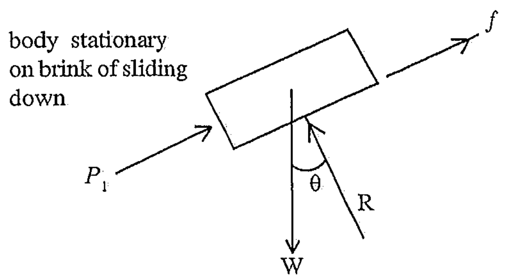
Suppose an additional force P is applied up the slope. If initially the force P is very small then the parcel will continue sliding (but more slowly) down the slope.



However force P can be increased until it just prevents the parcel from moving down and it remains stationary. If now the force P is further increased, it will reach a value at which the parcel is still stationary, but on the brink of sliding up the slope.

Now look in more detail at these two extreme cases where the parcel is stationary but on the brink of moving. To do so, it is necessary to draw Free Body Diagrams. These show all the external forces acting on a body

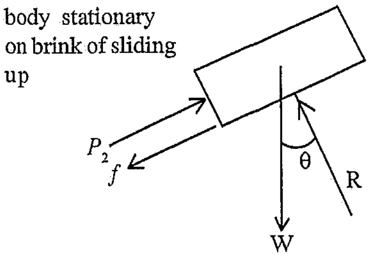
(a) Force P to just prevent the parcel sliding down the slope



Parcel is not moving, but on the brink of sliding down
Forces acting in the plane of the slope are:
(i) force P_1 up the slope
(ii) component of weight (W sin θ) down the slope
(iii) frictional force f acting up the slope

In this case the frictional force aids the force P in preventing sliding down. And then the other extreme situation:

(b) Force P is just less than that which will cause the parcel to move up the slope



Parcel is not moving but on the brink of sliding up.

Forces acting in the plane of the slope are;
(i) force P_2 up the slope
(ii) component of weight (W sinθ) down the slope,
(iii) frictional force f acting down the slope

In this case, friction acts down the slope, making it more difficult for the larger force P to move the body up the slope.

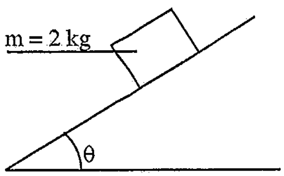
> ***Exam Hint:*** *Exam questions are often framed around this type of example. They may ask for the range of values a force P can take without the body moving.*

In the above cases the range of force is $(P_2 - P_1)$.

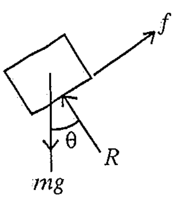
Analysing forces is much simpler if you draw a free body diagram. This comprises just the body together with **all** the forces experienced by the body. Use this free body diagram to write the equations of motion. Then solve the equations for the required quantity.

> ***Exam Hint:*** *Remember that a free body diagram should only show forces acting on on the body, not forces exerted by the body.*

Example 3: A body of mass 2kg is stationary on a rough surface which is inclined at θ° to the horizontal. The maximum frictional force between the body and the surface is 10N. The angle θ° is increased until the body is on the brink of sliding down. Calculate the value of θ at which this occurs. Take g as 9.81ms⁻².



Answer
Draw a free body diagram



body is on the brink of sliding down
friction acts up the slope
mg = weight of body
f = frictional force
R = reaction from surface

Forces parallel to slope: f = mgsinθ
$\sin\theta = f / mg = 10 / (2 \times 9.81) = 0.51$
so θ = 30.6°

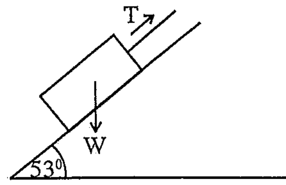
> *If motion exists, then the friction force acts in the opposite direction, i.e. to oppose the motion.*

> *Frictional forces can exist even when there is no relative motion between the two bodies*

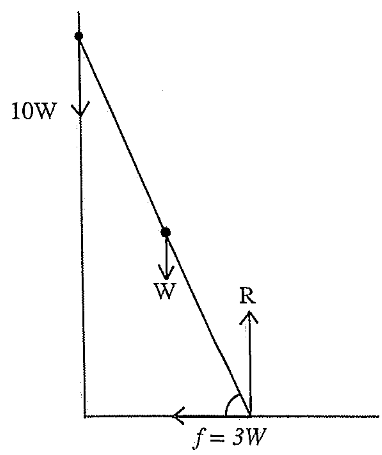
> *Always draw a free body diagram*

Practice Questions

1. A box of mass 5 kg is held at rest on a rough slope by a tensioned rope. The slope makes an angle of 53° with the horizontal. The frictional force at the interface between box and slope is 12 N.
   (a) Find the component of the weight acting down the slope. Take $g = 9.81\ \text{ms}^{-2}$
   (b) Find the smallest value of T (the tension in the rope) which would stop the box from sliding down the slope. (Friction acts up the slope).
   (c) Find the largest value of T which could be applied without pulling the box up the slope. (Friction now acts down the slope.)



2. A ladder of weight W newtons leans against a smooth vertical wall and rests on a rough horizontal surface. A man weighing 10W newtons stands on the top of the ladder (just where it touches the wall). The frictional force at the ladder/ground interface is 3W newtons. Use moments about the top of the ladder (where the man is standing) to calculate the angle between the ladder and the ground. (Notice that in questions of this type any value can be used for the length of the ladder and for the weight, W.)



Answers

1. (a) 39.2N (b) $T_{min} = 27.2$ N. 9(c) $T_{max} = 51.2$ N
2. 74°

Acknowledgements:
This Physics Factsheet was researched and written by D. W. Parkins.
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