Chapter 3: Dynamics (Newton's Laws of Motion)

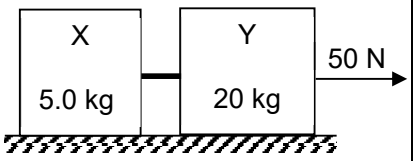
Newton's First Law of motion:
A body continues in its state of rest or uniform motion in a straight line, unless a resultant external force acts on it.

Newton's Second Law of motion:
The rate of change of momentum of a body is proportional to the resultant force acting on it and occurs in the direction of the force.

Newton's Third Law of motion:
If a body A exerts a force on body B, then body B exerts an equal and opposite force on body A.

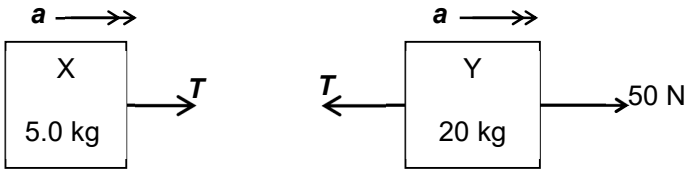
Worked Example 1 (Newton's Second Law)

A light string connects two blocks X and Y, of mass 5.0 kg and 20 kg respectively. A force of 50 N pulls them along a smooth horizontal surface.



Determine the force exerted on X by the string.

Draw FBD for each object:



Both X and Y experience the same acceleration a.

Consider the system as a whole (X and Y together),

$F = (m_x + m_y)\, a$

$50 = (5 + 20)\, a$

$a = 2.0 \text{ m s}^{-2}$

Next consider only block X,

$T = m_x\, a$

$= (5)(2.0)$

$= 10 \text{ N}$

Hence the force on X by the string is 10 N.

Worked Example 2

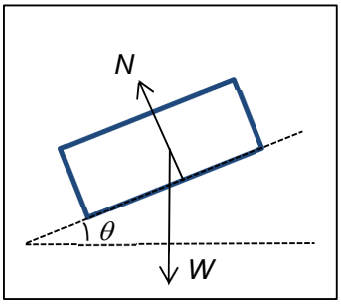
An object of mass 800 kg is sliding down a slope inclined at an angle of 30° to the horizontal. Sketch the forces acting on the object and calculate the acceleration of the object if:

(a) the slope is frictionless
(b) the frictional force acting on the object is 1000 N.

(a) Object on slope without friction

Taking downward along the slope as positive.

Consider forces acting along the slope:



Resolving the weight of the object in the direction along the slope (i.e. resultant force on the object along slope):

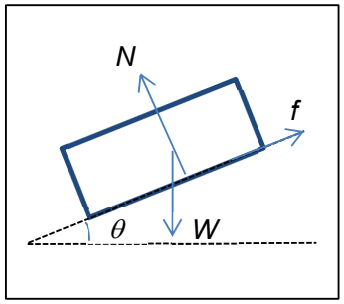
$$W_{//} = W \sin \theta$$

Using Newton's Second Law: $F = ma$

(i.e. resultant force on the object along the slope will cause the object to accelerate)

$$F = ma$$
$$mg \sin \theta = ma$$
$$a = g \sin \theta = 9.81 \sin 30°$$
$$= 4.9 \text{ m s}^{-2}$$

(b) Object on slope with friction



Taking downward along the slope as positive.

Consider forces acting along the slope:

Using Newton's Second Law:

$$F = ma$$
$$mg \sin \theta - f = ma$$
$$(800)(9.81) \sin 30° - 1000 = (800)\, a$$
$$a = 3.7 \text{ m s}^{-2}$$

Worked Example 3

A man of mass 65 kg stands on a weighing scale in an elevator going to the 25th storey. The elevator accelerates from the ground floor at 3.0 m s^{-2} from rest to speed *v*.

Once it reaches speed *v*, it continues moving at constant speed *v*. When approaching its destination, it decelerates at 2.0 m s^{-2} till rest.

Determine the reading, in newtons, on the weighing scale when it is

(a) accelerating,
(b) moving at constant speed and
(c) decelerating.

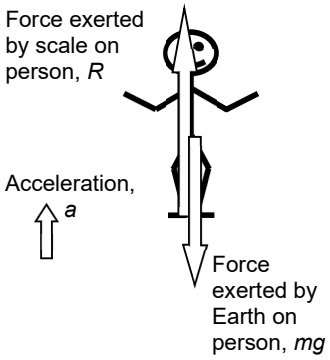
The reading shown on the weighing scale is a result of the force exerted by the man on the weighing plate. According to Newton's third law, an equal and opposite force is exerted by the scale on the man. Hence, the determination of the reaction force by the scale would help us find the reading of the scale.

(a) Taking upward as positive, and drawing a free body diagram:

During acceleration:

$$F_{net} = ma$$
$$R - mg = ma$$
$$R = ma + mg$$
$$= (65)(3.0) + (65)(9.81)$$
$$= 830 \text{ N}$$

Hence the reading on the weighing scale is 830 N when the elevator is accelerating upwards.



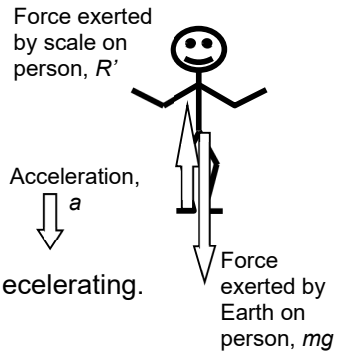
(b) During constant speed, acceleration is zero and therefore there is no resultant force exerted on the man. The force on the man by the scale is thus equal to the weight of the person i.e. 640 N.

$$F_{net} = 0$$
$$R - mg = 0$$
$$R = mg$$
$$= (65)(9.81)$$
$$= 640 \text{ N}$$

Hence the reading on the scale will be 640 N.

(c) When deceleration upwards, acceleration is downwards, hence taking <u>downward</u> as positive and drawing a FBD:

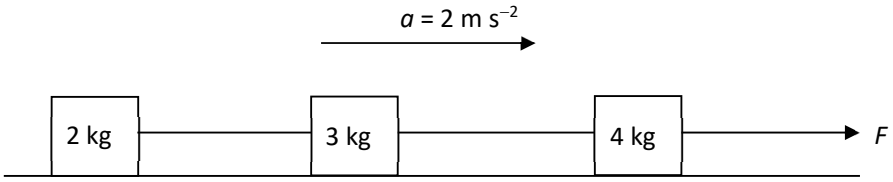
$F_{net} = ma$
$mg - R' = ma$
$R' = mg - ma$
$= (65)(9.81) - (65)(2.0)$
$= 510$ N



Hence the reading on the scale is 510 N when the elevator is decelerating.

MCQ

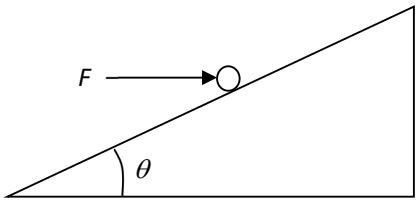
1 Three blocks of masses 2.0 kg, 3.0 kg and 4.0 kg are connected by an inextensible string on a horizontal frictionless table as shown. The blocks are pulled to the right with an acceleration of 2.0 m s^{-2} by an applied force *F*.



What is the value of the tension between the 4.0 kg and 3.0 kg masses?

A 4.0 N **B** 6.0 N **C** 10 N **D** 14 N

2 A horizontal force *F* is applied to a body of mass *m* to move it up a smooth plane inclined at an angle θ to the horizontal.



What is the magnitude of the resultant force on the mass *m*?

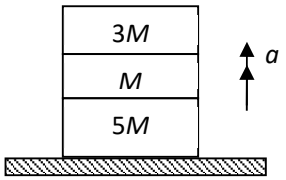
A $F\cos\theta - mg\sin\theta$

B $F\cos\theta + mg\sin\theta$

C $F\sin\theta - mg\cos\theta$

D $F\sin\theta + mg\cos\theta$

3 Three crates of masses 3*M*, *M* and 5*M* are stacked on top of one another on the floor of a lift as shown on the right. When the lift is accelerating upwards with an acceleration *a*, the magnitude of the force mass *M* exerts on the mass 5*M* is given by:



A $4Mg - 5Ma$

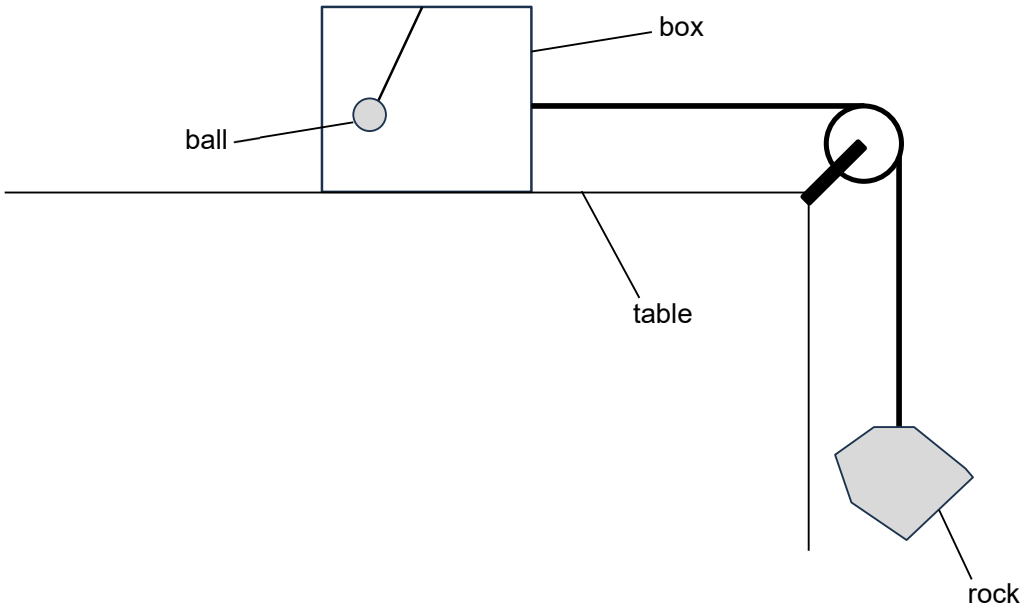
B $4Mg - 4Ma$

C $4Mg + 4Ma$

D $4Mg + 5Ma$

Structured questions

4 A 15.0 kg ball hangs by a string from the top of a 20.0 kg box that is attached to a 10.0 kg rock over a light frictionless pulley. There is negligible friction between the box and the table it rests on.

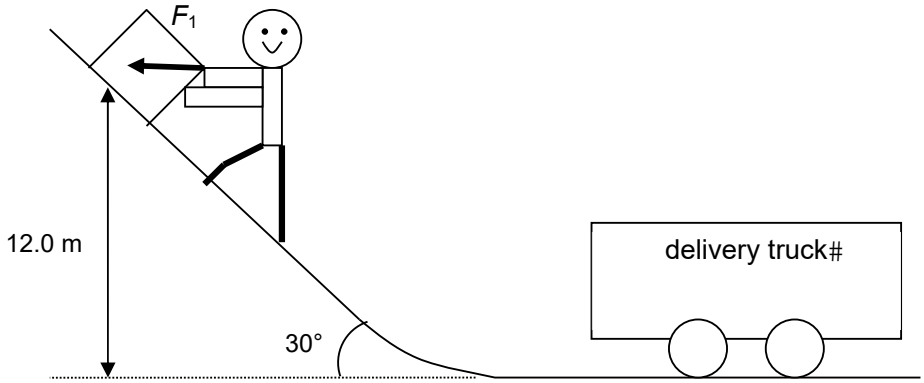


(a) Sketch a free-body diagram of the ball when the system is moving.

(b) Determine the angle the string inside the box makes with the vertical while motion is occurring.

(c) If you could vary the weight of the rock, determine the maximum angle the string can make with the vertical.

5 **(a)** A 40.0 kg television set is being lowered along a slope to be loaded into the delivery truck as shown in the figure below. Assume friction between the slope and television set is negligible.



If the delivery man takes a rest and pushes against the TV set by applying a horizontal force F_1 to stop the set from sliding down, calculate

(i) the magnitude of the force, F_1,

(ii) the normal reaction force acting on the TV set by the slope.

(b) The man suddenly slips and falls but he manages to jump off the slope before the TV set can crash into him.

Calculate the acceleration of the 40.0 kg TV set along the slope.

(c) Explain briefly, how the force F_1, required to keep the set stationary on the slope, will change (if at all) if the friction between the slope and set is *not* negligible.