Turning effect of a force

Physics

11

11.1 Moment

We have seen that by applying forces on objects, it is possible to push, pull or lift them. Similarly, it is possible to rotate objects by applying forces on them. That is, by applying a force we can rotate or turn an object around a given point. In this lesson, we will focus our attention on the ability of a force to rotate an object around a given point.

Let us do the following activity in order to investigate the factors affecting the rotation of an object.

Activity 1

Mark four points *A*, *B*, *C*, *D* on the same horizontal level of a door attached to its frame by two hinges. Attach a Newton balance to the point *A* with the aid of a rubber sucker clamp and apply a perpendicular force on the door to open it. Measure the force necessary to slightly move the door using the Newton balance. Repeat this procedure for the other three points *B*, *C* and *D* and record your measurements in Table1 11.1 given below.

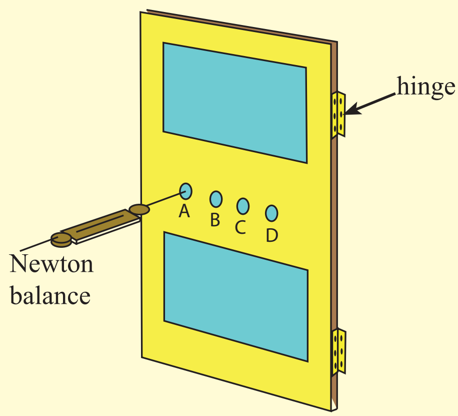


Figure 11.1 – Measuring the force necessary to open the door

Table 11.1

Point attached to the Newton balance	Perpendicular distance from the rotation axis to the force	Newton balance reading when the door just starts to move	Value of force × perpendicular distance (N m)
A *B* *C* *D*			

- At which point was the force required to rotate the door a maximum?
- At which point was the force required to rotate the door a minimum?

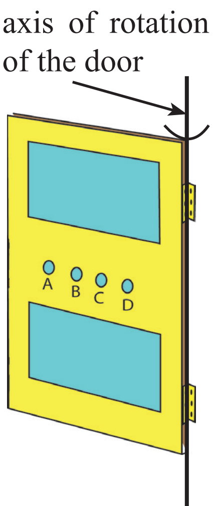


Figure 11.2 – Axis of rotation of the door

Here, the door rotates around an axis passing through the hinges as shown in Figure 11.2. This axis is known as the **axis of rotation** of the door.

It would be clear to you that the force required to rotate the door decreases when the perpendicular distance to the line of action of the force from the rotation axis is increased. It would also be clear to you from your measurements that the force required to rotate the door increases when the perpendicular distance to the line of action of the force from the rotation axis is decreased.

This means that it is easier to open the door when the applied force is further away from the rotation axis, while it is more difficult to open when the applied force is closer to the rotation axis.

It is clear from the above activity that the force required to rotate an object around an axis depends on the perpendicular distance to the force from the axis.

The product of the force and the perpendicular distance to the line of action of the force from the axis of rotation is known as the **moment of the force** around the axis.

In order to subject a body to a motion in a straight line, a force is required. In order to rotate an object around a given axis, what is required is not just a force but a moment. A moment required to rotate an object is created by applying a force at a certain distance from the rotation axis. This tendency for rotation due to the action of a force is known as the turning effect of the force.

Therefore, we can write an equation for the moment due to a force as defined below.

Moment due to a force	=	force N	×	perpendicular distance to the force from the rotation axis m

The unit of moment of a force is N m.

Since the moment is a tendency for rotation, depending on whether the rotation is clockwise or anticlockwise, the moment too has to be clockwise or anticlockwise.

• Investigation of the dependence of the moment on the magnitude of the force.

Let us carry out the following activity in order to investigate the dependence of the moment on the magnitude of the force.

Activity 2

Items required : a fairly long stick of wood, two rubber washers, a screw, a drill, a Newton balance, a table or a plank of wood

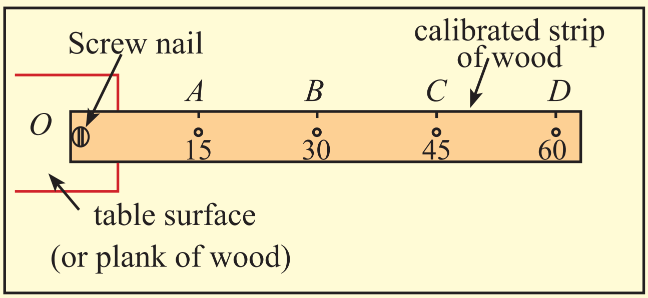


Figure 11.3 – Investigation of the dependence of the moment on the magnitude of the force

- Drill holes at the points *O*, *A*, *B*, *C* and *D* which are spaced 15 cm apart from the adjacent hole as shown in Figure 11.3.
- Next, clamp the stick to the table at the point *O* using the washers and the screw nail.

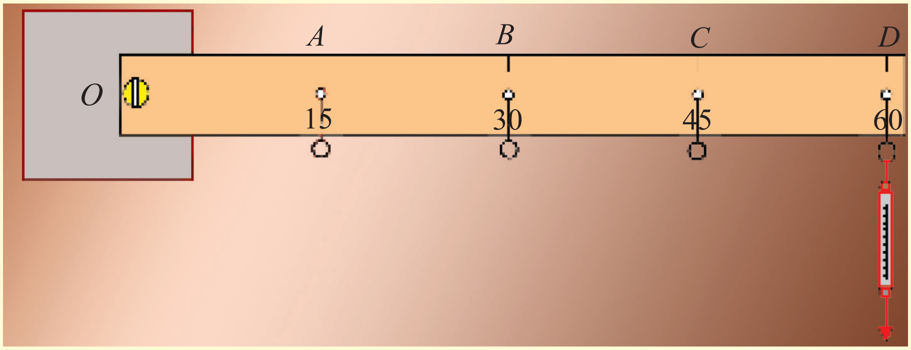


Figure 11.4 - Applying force perpendicular to the stick

- Now attach a loop formed with a piece of wire to each of the holes at *A*, *B*, *C* and *D* on the stick. Attach the Newton balance on the ring at *D* as shown in figure 11.4 and measure the minimum force necessary to bearly move the stick, keeping the balance perpendicular to the stick. The axis of rotation in this case is the axis passing from the centre of the nail head down through the nail.
- Next, rotate the nail half a turn to tighten the stick a little more and measure the force required to slightly move the stick.
- Again, rotate the nail half a turn to tighten the stick further and measure the force required to slightly move the stick.
- Tabulate your measurements. What is the result that you have expected ?

Suppose you obtained the results shown in the table below. (You may obtain values different to the values given depending on your set up.)

Table 11.2

Stage	Force
Initial set up	2 N
After tightening the screw by half a turn	5 N
After tightening the screw by a full turn	9 N

You will see that the force required to initiate the turning effect increases as the stick is tightened. Since the distance to the line of action of the force is maintained constant this confirms that the moment depends on the magnitude of the force.

Investigation of the dependence of the moment on the perpendicular distance to the force from the point of suspension.

In order to investigate how the moment depends on the perpendicular distance to the force from the point of suspension, let us do the following activity.

Activity 3

- As shown in Figure 11.5, insert a loop made from a piece of thread around the stick of wood used in Activity 2 near the point A and hook the balance on the loop. Rotate the screw by one turn to bring it back to its original position. Find the force required to initiate rotating the stick slightly. Suppose this force is F_1.

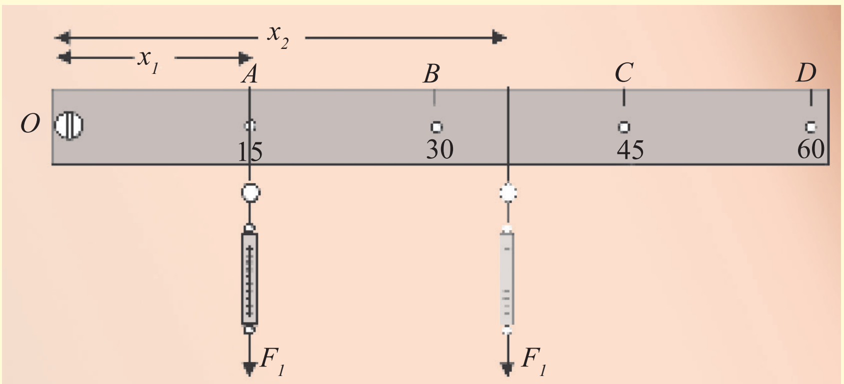


Figure 11.5 - Investigation of the dependance of the moment on the perpendicular distance

- Now rotate the screw by about ¼ th of a turn to tighten it.
- Then, move the loop together with the balance slowly towards *D*, keeping the force F_1 constant.
- When the stick begins to move around *O*, measure the distance x_2 from *O* to the balance.
- Repeat the procedure, tightening the screw by another ¼ th of a turn and sliding the loop towards *D*, keeping the force (F_1) constant and measure the distance x_3 from *O* to the balance when the stick begins to rotate around *O*.
- Tabulate your measurements.

What would you expect from your results?

Suppose you obtained the measurements shown in Table 11.3.

Table 11.3

Stage	Force	Distance to the balance (x)
Initial set up	1. 5 N	15 cm
After tightening the screw by quarter of a turn	1. 5 N	32 cm
After tightening the screw by half a turn	1. 5 N	55 cm

The above results show that when the force necessary to initiate the turning effect is kept constant, perpendicular distance to the Newton balance had to be increased as the strip is tightened

This confirms that the moment of force also depends on the perpendicular distance to the force from the point of suspension.

Direction of the moment of force and equilibrium of object under the action of the moments of force.

When a force acting on an object, depending on the direction of rotation, moments can be classified as clockwise or anti - clockwise.

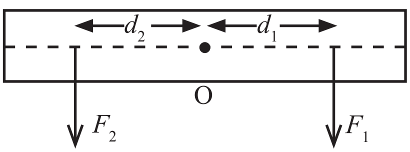


Figure 11.6 - Clockwise and anti - clockwise moments.

Consider two forces F_1 and F_2 exerted on a stick clamped at the point O as shown in the figure 11.6

clockwise moment $= F_1 \times d_1$

anti - clockwise moment $= F_2 \times d_2$

When the two forces are applied in the same time,

the resultant moment $= F_1 \times d_1 - F_2 \times d_2$

Here, colckwise moment is considered as positive.

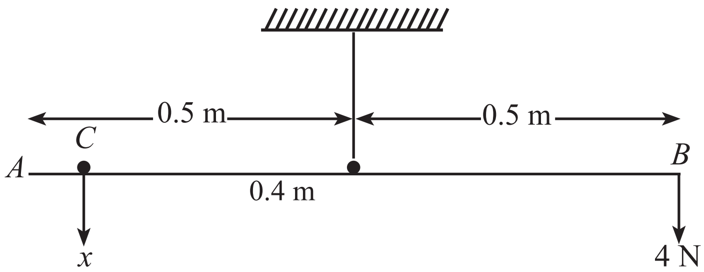
If the opposite moments are equal, (that is $F_1 \times d_1 = F_2 \times d_2$) the object will not rotate, and it will be in equillibrium.

Example 1

As shown in the following figure a uniform rod *AB* of length 1 m is suspended and balanced at its center.

(i) If a weight of 4 N is now suspended from *B*, find the initial (clockwise) moment.

(ii) If the 4 N weight is kept at *B*, what weight suspended from a point *C* situated 0.4 m from the center would balance the rod again?



(i) Clockwise moment = 4 N × 0.5 m = 2 N m

(ii) Assume that the weight suspended from *C* is *x*.

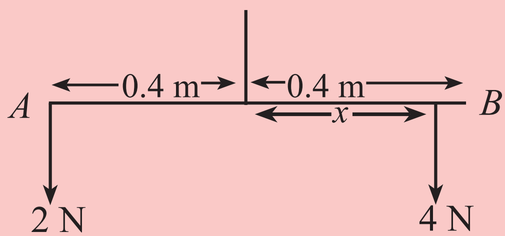
$$\therefore x \times 0.4 = 4 \times 0.5$$

$$x = \frac{4 \times 0.5}{0.4}$$

$$= \frac{4 \times 5}{4} = 5 \text{ N}$$

Exercise 11.1

(1) A uniform rod *AB* is 0.8 m long. It was balanced after being suspended from the centre and then a weight of 2 N held at one end. In order to bring the rod back into equilibrium, how far from the balance point on the other side of the rod should a weight of 4 N be held?

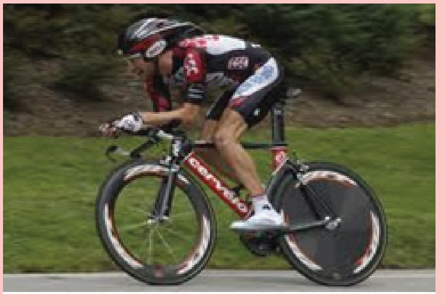


(2) Some examples of using the moment of a force in day to day life is given below.

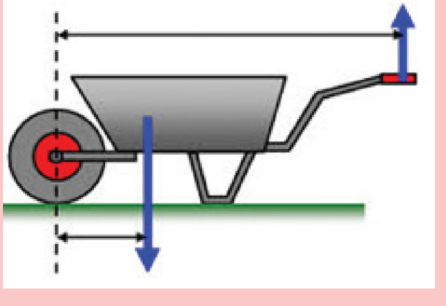
Describe how the moment acts in each one of them.

1. The use of a spanner to detach a nut.

2. Applying a force on the pedal of a bicycle



3. The use of a wheel barrow



11.2 The couple of forces

To rotate an object with a single force that object must be pivoted to a fixed point. It is possible to rotate an object that is not pivoted, with the use of two forces acting in opposite directions.

Consider the case of a strip of wood being pierced at the center and fixed with a screw to a table as shown in the figure. Attach a Newton balance as shown and measure the force (F) when the rod begins to rotate slightly.

Next, attach two Newton balances at both ends A and B and measure the force required to slightly rotate the rod. If the force required with one force had been F, the force required when two forces are applied in opposite direction would be $F/2$. Note that the two forces act on the same plane (coplaner).

From the above activity, it would be clear to you that when applying forces to rotate or turn an object around a certain axis it is easier to rotate by applying two equal forces in opposite directions.

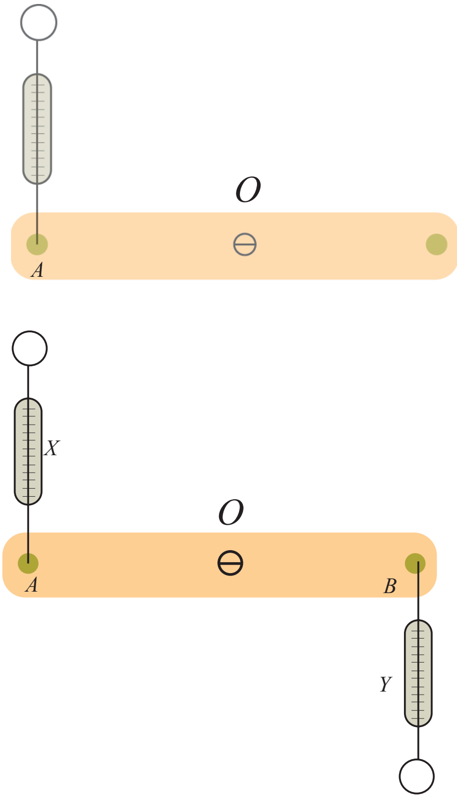


Figure 11.7 - Demonstration of couple of forces

Two coplaner forces of equal magnitudes acting in opposite directions, along two lines of action that are spaced apart are known as a couple of forces.

When a couple of forces is applied on an object, the resultant of the two forces is zero as the two forces of equal magnitude and act in opposite direction. Therefore, a couple of forces does not cause a linear displacement in an object. However, the object rotates around a point between the two forces.

The moment of a force couple is defined as the product between the magnitude of one force and the perpendicular distance between the lines of actions of the two forces.

Moment of a couple of forces = force × perpendicular distance between
(N) the lines of action of the two
forces (m)

The unit of the moment of a couple of forces is N m.

Moment of a couple of forces = F x d
Where F = force
d = perpendicular distance between the lines of action of the two forces

If we want to rotate an object by a single force as done by attaching one Newton balance to the point *A* and pulling the object as in the example above, then the object has to be pivoted at a certain point. (What happens here is the formation of a force couple due to the action force we apply and the reaction force generated at the pivot according to Newton's third law.) However, it is possible to rotate even a free object by applying a force couple as done in the example of applying two forces at points *A* and *B* with two Newton balances

Applications of couple of forces

When opening or closing a tap, a couple of forces acts on the tap head.

Figure 11.8 - tap

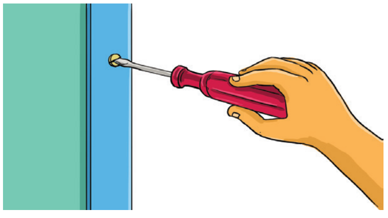


Figure 11.9 – Unscrewing a nail with a screw driver

When unscrewing or tightening nails with a screw driver as shown in Figure 11.9 we apply a couple of forces on the handle of the screw driver.

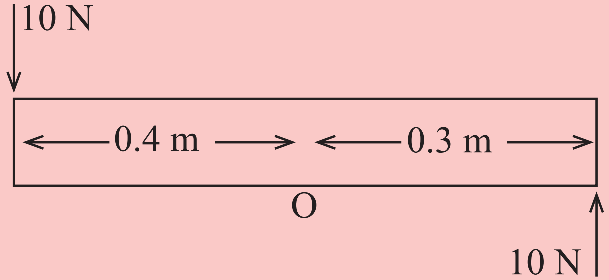
A steering wheel can be rotated more easily by applying a couple of forces with both hands instead of trying to turn it with only one hand.

Figure 11.10 - rotating the steering wheel

Exercise 11.2

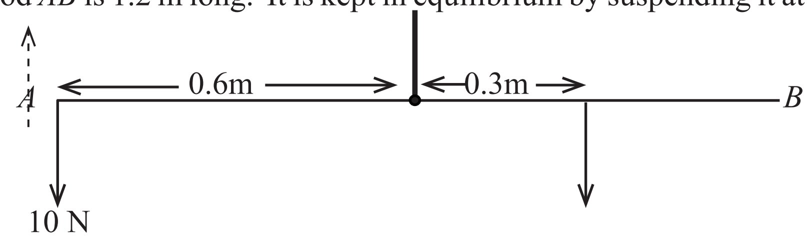
(1) (i) Give two examples where force couples are acting.

(ii) A thin plank of timber which is pivoted at O is shown in the figure. If two forces are applied as shown in the figure, find the moment of the couple of forces.



Miscellaneous exercises

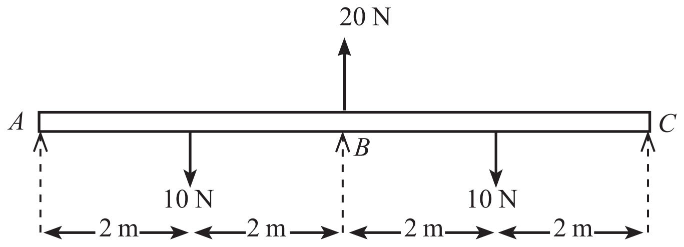
(1) The rod AB is 1.2 m long. It is kept in equilibrium by suspending it at the center.



Now, if a weight of 10 N is held at the end A, what force held at a point 0.3 m away from the center of the rod would bring it back to equilibrium?

(2) Determine the sum of moments of the three forces about,

(a) point A, (b) point B, (c) point C



Summary

- What is meant by the moment of a force is the tendency of an object to rotate as a result of a force acting on it.

- The moment of a force is given by the product between the force and the perpendicular distance to the line of action of the force from a selected axis.

  That is,

Moment due to a force = force x perpendicular distance to the line of action of the force from a selected axis.

- A couple of forces is a pair of two equal forces that are parallel to one another and acting in opposite directions on an object so as to turn or rotate it.

- A couple of forces can rotate an object without causing a linear motion in the object.

Technical terms

Moment of force	බලයෙහි ඝූර්ණය	உந்தம்
Turning effect of a force	බලයේ භ්‍රමණ ආචරණය	விசையின் திரும்பல் விளைவு
Couple of forces	බල යුග්මය	விசையிணை