Theme 4: Force and Laws of Motion

Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Force - inertia, role of force in causing acceleration, relation of mass with force
- Multiple forces - resultant force, direction of force
- Newton's laws of motion - action & reaction

Life without Force

Imagine how life would have been if there was no movement around us. It would be like a static picture. In fact, look at a static picture and imagine how you would find it if you knew there was no motion in the Universe. Fig. 4.1 has one for your quick reference.

Fig. 4.1, Ram and Lakshman arrive at Pampa Sarovar; Image by Ms Sarah Welch via Wikimedia Commons

Fig. 4.1 is the picture from the *Kishkindha Kand* chapter of the Indian epic, *Ramayan*. Ram and Lakshman arrive at this place called *Pampa Sarovar*. Imagine if they were unable to move the bow and arrow, which they are seen holding in their hands. Imagine they could not move their lips, and hence not talk. Imagine the monkeys on the tree permanently stationed there and imagine Hanuman seeing Ram and Lakshman but being unable to move towards them.

Imagine there was no movement of air and hence the trees being fully stationary, ditto as in the picture!

We appreciate many static pictures because we build stories and emotions around them, none of which would exist if there was no motion. Now imagine the other extreme where everything around was moving and there was no way to stop any of them. The way the first situation may remind us of a static picture, the second may remind us of a chaotic movie. Thankfully, neither of the two situations are true. Not only does motion exist but we also have a way to control it. We can make a stationary object move or a moving object stop or slow down. We humans have given a nice name to this control - *force*. The two situations we just imagined have one thing in common. Both are about life without force.

Interesting situations arise when there is more than one force, and they influence the effect of each other. It can easily get converted from interesting to complicated to *"I can never understand it"* if we did not have clearly stated laws explaining how exactly force influences motion. Way back in the 17th century, Sir Isaac Newton published the three laws of motion, which help us understand this relationship between force and motion. Let us look at a few situations where we see the interplay of multiple forces and their effect on the movement of objects.

Case Study A - Parachutist

A parachutist who weighs 60 kg, jumps from an aeroplane. Her fall can be described in terms of four main phases:

Phase 1: The initial vertical speed is zero but she is immediately acted upon by her weight acting downwards. The air resistance has less effect at this stage. She starts accelerating (downwards).

Phase 2: After some time as the air resistance balances her weight, she starts falling down at a constant speed. The parachute is not open yet.

Phase 3: Now she opens the parachute, which slows her down further.

Phase 4: After some time she starts falling down at a constant speed which is less than the speed she was falling with in Phase 2.

Fig. 4.2, Skydiving; Image by MaxPixel.net

Question 1

If we round off acceleration due to gravity to 10 m/s^2, the parachutist's weight would be 600 N. If the air resistance is greater than her weight, the resultant force will be upwards and her speed will reduce. If it is less, then the resultant force will be downwards and her speed will increase.

Fill the empty spaces in Table 4.1 with the value of air resistance and value + direction of resultant force in each phase. The value of air resistance and resultant force can be one of the following:

A. 0 N
B. > 600 N
C. < 600 N
D. = 600 N

The direction of resultant force can be

A. Upwards
B. Downwards
C. None

Phase	Value of Air Resistance	Value of Resultant Force	Direction of Resultant Force
Phase 1			
Phase 2			
Phase 3			
Phase 4			

Table 4.1, Air resistance and resultant force in each phase of the parachutist's falll

Question 2

Name any one phase in which the parachutist experiences an upward acceleration. Write your answer in the space provided. Write 'none' if you think she does not decelerate in any of the phases.

Answer

Question 3

The speed of the parachutist is plotted against time (see Fig. 4.3). Seven points have been marked on the graph. Identify the point which represents the event of the opening of the parachute. Write your answer in the space provided.

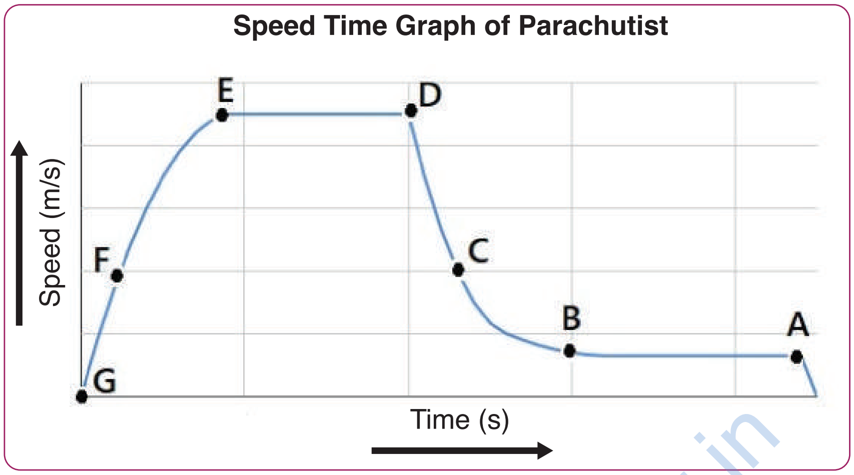


Fig. 4.3, Speed time graph of the parachutist

Answer

Question 4

In Fig. 4.3, which point represents the start of Phase 4? Write your answer in the space provided.

Answer

Question 5

i. Another parachutist, who is 10 kg heavier than the first, also jumps at the same time. He also carries an additional bag which has a mass of 5 kg. Who will accelerate at a higher rate immediately after jumping? At this stage, there is no impact of air resistance yet. We will refer to the first parachutist by her name - Bela - and the one with the additional bag as Ravi.

a. Ravi

b. Bela

c. Same acceleration

Answer

ii. After the jump, both of them experience an air resistance of 300 N. At what rate would Ravi and Bela accelerate after this? Specify the direction of acceleration as downwards/upwards while writing your answer in the space provided.

Bela

Ravi

Case Study B - Straw Propeller

Fig. 4.4 to 4.11 show the design of a simple model of the machine called *Aeolipile* (also known as *Hero's Engine*). This model uses two cylindrical plastic straws of different diameters to make the model. Thanks to the simplicity of the model, plenty of explorations are possible. Since the fat straw rotates like a propeller, the model has been named as *straw propeller.*

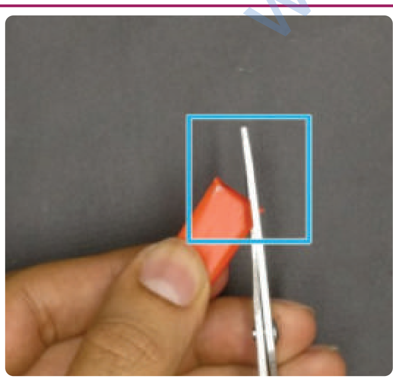


Fig. 4.4, Take a 10 cm fat straw and bend it in half. Nip the two corners at the centre-fold using scissors.

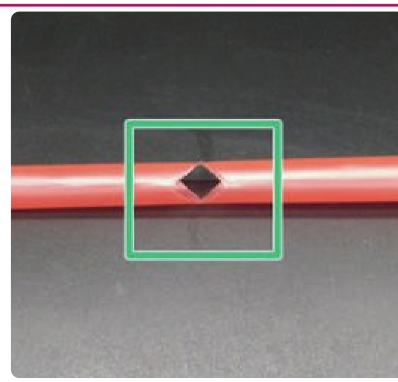


Fig. 4.5, You get two diamond shaped holes in the middle.

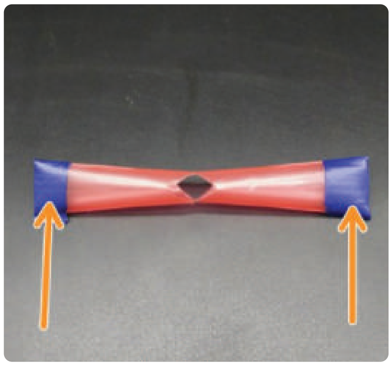


Fig. 4.6, Press down each end of the fat straw and seal them with tape.

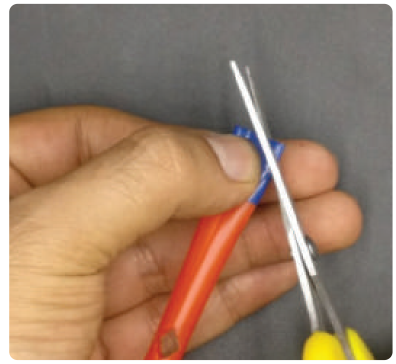


Fig. 4.7, Nip any two diagonally opposite corners of the fat straw.

Fig. 4.8, The nipped corners are denoted by red boxes.

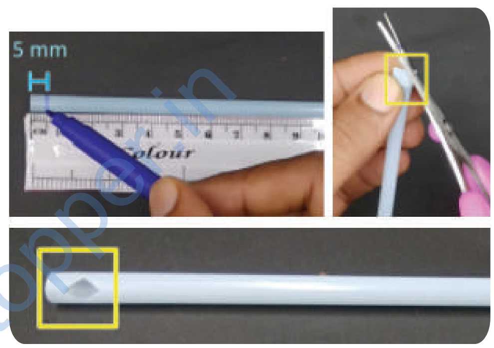


Fig. 4.9, Take the thin straw and make one diamond shaped hole around 0.5 mm away from one of its ends.

Fig. 4.10, Insert the thin straw into the diamond holes of the fat straw such that the hole in the thin straw lies within the fat straw.

Fig. 4.11, Shut the hole-end of the thin straw with your finger and blow through the other end of the thin straw.

Fig. 4.12, Fat straw rotates as you blow air.

When air is blown through the thin straw, it enters the fat straw and exits through the cuts at the corners of the fat straw. This movement of air makes the fat straw rotate.

Question 6

The fat straw in the straw propeller is held in two different ways depending on the position of the corner holes (see Fig. 4.13 & Fig. 4.14). In which direction will the fat straw rotate in each case?

Note that  is clockwise and  is anticlockwise direction.

	
Fig. 4.13, Case A	**Fig. 4.14**, Case B

a. Case A - Clockwise, Case B - Anticlockwise
b. Case A - Anticlockwise, Case B - Anticlockwise
c. Case A - Anticlockwise, Case B - Clockwise
d. Case A - Clockwise, Case B - Clockwise

Answer

Question 7

Which direction will the propeller rotate in, if all the four corners are cut? Assume that the size of all the four holes is the same.

Fig. 4.15, Straw propeller with all four corners cut

a. Clockwise
b. Anticlockwise
c. Will not rotate
d. Sometimes clockwise, sometimes anticlockwise

Answer

Question 8

Two people conducted an experiment with the straw propeller. 30 year old David made a propeller using an 18 cm long fat straw while 8 year old Bunty used a 6 cm long fat straw. David blew air and measured the speed of rotation of his propeller as 25 rotations per minute. Bunty blew air in his propeller and found the speed as 15 rotations per minute. They concluded that a longer straw would rotate faster.

Should David and Bunty have made any changes to the way the experiment was conducted? If yes, specify the change and the reason. If no, state why no change is required. Note that both of them measured the maximum speed the propeller could achieve in one deep exhale.

Answer

Question 9

i. According to Newton's third law of motion, each ***action*** is accompanied by another force called the ***reaction***, which is equal to the action but in the opposite direction. The pictures in Fig. 4.16 to Fig. 4.19 show the possible action-reaction pair in the straw propeller. Identify the picture which correctly represents the correct pair.

Note that in the pictures

- The length of the arrow indicates the value of the force, i.e. longer the arrow, more is the force.
- The direction of the arrow indicates the direction of the force, i.e. an arrow from Air pointing towards Fat Straw means that the force is from air on the fat straw.
- Air here is the air exiting from the fat straw.

A.

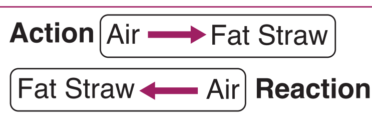


Fig. 4.16

B.

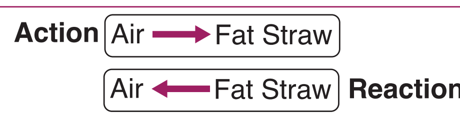


Fig. 4.17

C.

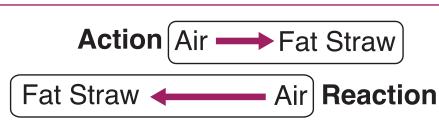


Fig. 4.18

D.

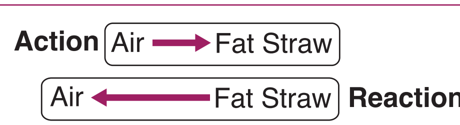


Fig. 4.19

Answer

ii. If the reaction force is equal and opposite to the action, why don't the two forces cancel each other? When a ball hits a bat, if we consider the force of the ball on the bat as the action, identify the reaction force.

a. From ball on ball but in the direction opposite to the action force
b. From bat on bat in the same direction as the action force
c. From bat on bat in the direction opposite to the action force
d. From bat on ball in the direction opposite to the action force

Answer

Question 10

i. Imagine the rowing of a boat using oars. As the first step, the oars are placed in water and pushed in the forward direction. Which direction will this make the boat move in?

a. Forward	b. Backward
c. Sideways left	d. Sideways right

Answer

ii. So as to repeat the action of moving the oars forward, they have to be brought back. Step 2 would be to move the oars backward. Which direction will this make the boat move in? Assume that the oars are not taken out of water before they are brought back.

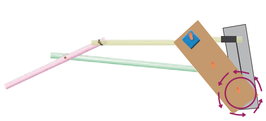
a. Boat won't move	b. Forward
c. Backward	d. Sideways (left or right)

Answer

iii. If the intent is to cause a net movement of the boat in the backward direction, what should be done between steps 1 and 2? Write your answer in the space provided.

Answer

Exploration Pathway



Body Joints - Wing Folding

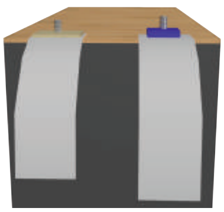
It may look simple to the eye, as most beautiful things do, but the functioning of a bird's wings is quite complex indeed. Here, using everyday materials, like straws and skewers, we make a lovely model to demonstrate the movements of a bird's wings, which allow it to move upwards (and propel forwards) when the wings flap downwards. However, when the wings flap upwards, a bird doesn't need the reverse to happen! And this model shows exactly how ingenious evolution has been in designing the flying gait of birds and other airborne creatures!

Straw Propeller

Newton's Third Law of Motion is one of the most beautifully succinct laws. So much so, that it seems obvious to most who read it. However, few really understand the law and this TACtivity - made by inserting a thin straw through holes made in the middle of a fat straw - goes a long way in addressing many of those misconceptions and clarifying several other fundamental concepts in physics.

Straw Spinner

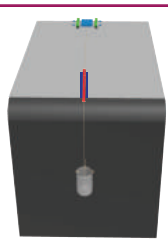
Newton's Third Law of Motion is one of the most beautifully succinct laws. So much so, that it seems obvious to most who read it. However, few really understand the law. This TACtivity - made using a couple of bendable straws and a bead or tube - demonstrates the law lucidly and also shows what causes rotational motion.



Inertia - Nut Tower

Inertia is the property of any object to remain in uniform motion or stay at rest unless acted upon by a net external force. This is also nothing but Newton's First Law of Motion. In simpler terms, the mass of an object is nothing but a measure of its inertia.

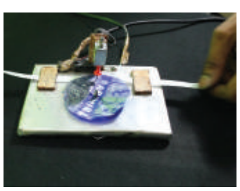
In this adaptation of a classic inertia experiment, we make `towers' with varying numbers of identical nuts, place them on a strip of paper, and pull out the paper from underneath the `tower' at varying speeds to see if our `tower' still remains standing!



Trolley Model

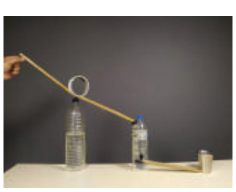
Newton's Second Law of Motion talks about how the net force acting on a body is directly proportional to the mass of the body and acceleration it experiences.

In this ingenious TACtivity, we use our own Hand Cart to conduct a series of experiments to discover for yourself the relationship between mass and acceleration.



Ticker Timer - Acceleration

Any mass experiencing a net force is accelerated. Acceleration is nothing but the rate of change of speed and/or direction. In this TACtivity, ticker tape is pulled through the ticker timer and analysed to measure linear acceleration, i.e. change of speed. This is done by making strips of "10-tick" length, and placed sequentially as a histogram. Acceleration measurements may be made by analysing the velocity measurements.



Measure Speed - Sound

Any object in motion is said to have a "speed", i.e. the rate of change of its position. In this TACtivity, a marble moves on a track with a distinct sound to mark the beginning and the end of the journey. This sound is captured by the Science Journal app which gives us the time taken for the journey.