DEMONSTRATION 1

To demonstrate uniform motion in a straight line

It is rather difficult to demonstrate uniform motion of a freely moving body due to the inherent force of friction. However, it is possible to demonstrate uniform motion if a body of the forces acting on it are balanced.

(a) *Demonstration of uniform motion of a body in glycerine or caster oil in a glass or a plastic tube*

Take a glass or plastic tube one metre long and about 10 mm end diameter. Close one end of it with a cork. Fill the tube with glycerine (white) or castar oil upto the brim. Insert a steel ball or lead shot of three mm diameter in it and close it with a cork such that no air bubble is left in the tube. Take a wooden base 7.5 – 10.0 cm broad having metallic brackets near its ends. Paint the board with white paint or fix a sheet of white paper on it. Mount the tube on the wooden base with the help of metallic brackets (to rest the tube like the base of a fluorescent tube). Put marks on the base with black/blue paint or ink at regular intervals of 10 cm each [Fig. D 1.1(a)]. To demonstrate

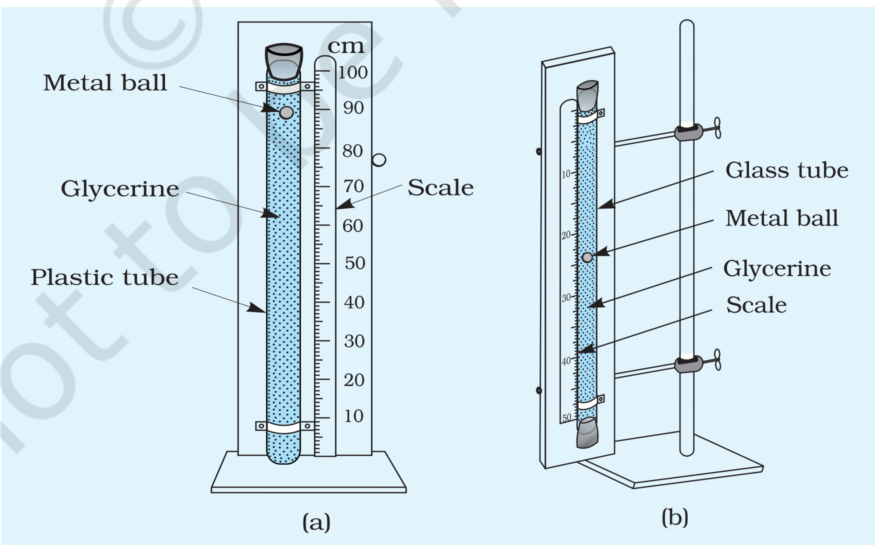


Fig. D 1.1: *Demonstration of uniform rectilinear motion of a ball under two balancing forces: (a) A demonstration apparatus* 1 m *long (b) A low cost apparatus* 50 cm *long* uniform motion keep the tube vertical and ask a student to note the time taken by the ball to travel successive segments of 10 cm. Repeat the experiment by inverting the tube a couple of times. It may be emphasised that if a 10 cm segment is further sub-divided into segments of 1 or 2 cm length, then the ball should travel successive smaller segments also is equal intervals of time*.

This demonstration can also be done with a half metre long glass tube and a half metre scale. It may be clamped vertical in a laboratory stand [Fig. D 1.1(b)]. In this case students can also be asked to note the time taken by the ball to travel successive segments of one cm.

The tube may be inclined slightly, say, at about 5° to the vertical. The advantages of this are:

(i) The ball moves closer to the scale which reduces the parallax error in observing its position on the scale.

(ii) The ball moving in contact with the wall of the tube is under identical conditions throughout its motion. If you wish it to move in the centre of the tube, i.e., along the axis of the tube, then the vertical adjustment of the tube has to done with greater precision.

In order to perform this demonstration with the half metre tube more effectively, students may be encouraged to devise their own mechanism to simultaneously record the distance moved by the ball and the time taken to do so. For example, let one student watch the falling ball at close distance and give signals by tapping the table as the ball passes successive equidistant marks at a pre-decided distance from each other.

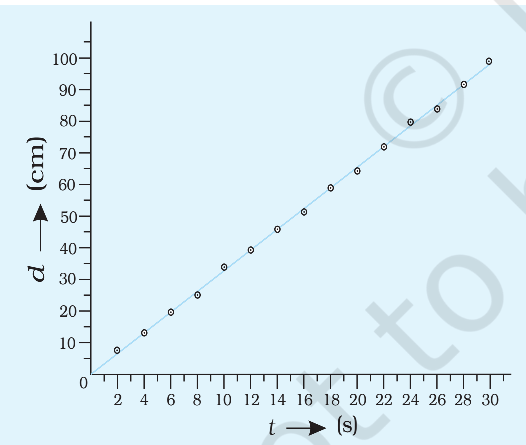


Fig. D 1.1(c): *Distance–time graph for motion of metal ball in glycerine*

A second student may start the stop-watch at the sound of any tap. Thereafter, he observes and speaks out the time shown by the watch at each successive tap, without stopping the watch. A third student may keep noting the data of distance covered by the ball and time elapsed since the measurement was started. Ask students to plot the distance versus time graph of the motion of the ball on the basis of this data and discuss the nature of this graph [Fig. D 1.1(c)].

In this coordinated activity of three students, it is likely that the first one may happen to miss giving signal at a mark when the ball passes it. He should only indicate this by saying "missed" and a few points less on the graph made with about 15 to 20 points are of no significance. Similarly, any tapping which he subsequently feels, was not made at the right instant, he may indicate

* In this experiment, the ball accelerates for some time initially and approaches the terminal velocity u_0 according to relation $u = u_0 = (1-e^{-t/T})$. For a typical terminal velocity $u_0 = 3\ cms^{-1}$, the time constant $T = 0.003s$. Thus, the duration of accelerated motion is so small that one may not at all bother for it.

by saying "wrong". Two students can also record this data, if there is sufficient time between successive readings, the second one taking over the task of the third. With some practice and by keeping the watch in the left hand close to the ball, even one student can record the data and take it up as an individual activity.

By mixing water with glycerine in a suitable ratio one can make adjust the speed of motion of the ball such that it is neither too slow as to cause boredom to the class nor so fast that the data is difficult to record.

(b) *By using a burette*

The above demonstration may also be performed by using a long burette. It has its own scale too. However, it may be difficult for students sitting at the back in the classroom to see the scale. Also, the upper end is open, which implies that several balls of the same size should be available. In fact, in the demonstration (a) above, the upper end of the tube may be kept open, if several balls of the same size are available, since the most tricky part of it is to close the upper end leaving no air bubbles inside the tube.

The demonstration with the burette can also be made more effective in the same manner as discussed above.

Note:

1. In the class discussion following the demonstration of a steel ball falling down with uniformed speed, an important question will be "what are the two balancing forces under which it moves with uniform velocity?" One is the net weight of the ball acting downwards due to which its speed increases in the beginning. As its speed increases, the resistance of liquid, acting upwards, to the motion increases till it balances the weight. Then onwards, the ball acquires terminal velocity and the speed remains nearly constant.

2. There are a number of situations in everyday life where an object falls down with uniform velocity in exactly the same manner as the ball in a liquid.

   (a) When a paratrooper descends from an aeroplane with the help of a parachute, resistance of air on the parachute often balances her/his weight. In such an event she/he moves vertically down with uniform speed, except for some horizontal drift due to the wind (Fig. D 1.2).

   (b) Many children play with a toy parachute which is first thrown up. Then it moves down in exactly the same manner as the paratrooper with a parachute.

   (c) A shuttle cock, which is used in the game of badminton, may be shot vertically upwards, when it comes down,

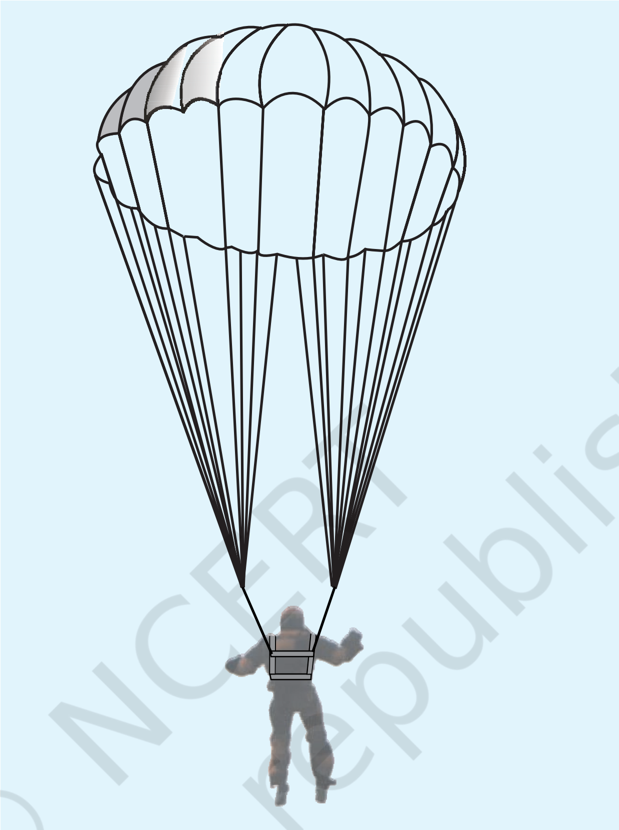


Fig. D 1.2: Discent of a parachute is nearly uniform

players often see that it is moving down with uniform downward speed (if there is no wind) after a small initial period of increasing speed.

3. This demonstration may also be done by the apparatus used for finding the viscosity of liquid by Stoke's law. However, for demonstrating uniform motion in a straight line, the demonstration is easier and better by: (a) using a scale to read the position of the ball, and (b) keeping the tube slightly inclined towards the horizontal.

DEMONSTRATION 2

To demonstrate the nature of motion of a ball on an inclined track

Make an inclined plane of about 50 cm length with 2 – 3 cm height at the raised end. Alternately, one can use a double inclined track apparatus and make the inclined plane by joining its two arms at the base strip so that these form a single plane. Give it a low inclination by raising one end of the base strip by about two cm with the help of a wooden block, or a book, etc. (Fig. D 2.1). Now let a metronome produce sound signals at intervals of ½ seconds. Keep the ball at the higher end of one of the inclined planes. Release it at any signal (which may be called 0th signal) and let students observe its position at 1st, 2nd, 3rd and 4th signals after the release. For this purpose, divide the class into four groups. Explain to them in advance, with the help of a diagram on the blackboard, that group I will observe the 1st position of the ball, group II the 2nd position of the ball, and so on.

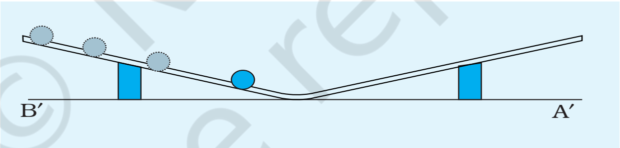


Fig. D 2.1: *Motion of a ball on a double inclined plane*

After the demonstration, there are as many observations for each position of the ball as the number of students in each group. Let one student in each group collect the observation in his/her group, calculate the mean value and record it on the blackboard. Then it can be shown that distances covered by the ball in successive intervals of ½ second go on increasing by equal amounts when the ball roll down the incline.

Note:

1. In the absence of a metronome, let a person tap on the table at a steady pace which synchronises with extreme positions of the pendulum of a clock, or a simple pendulum of 25 cm length on a laboratory stand.
2. If a strobe-light is available, use it illuminate the ball moving down the track. Then students can visually see successively longer distances moved by the ball in equal intervals of time.

DEMONSTRATION 3

To demonstrate that a centripetal force is necessary for moving a body with a uniform speed along a circle, and that magnitude of this force increases with angular speed

(a) *Using a glass tube and slotted weights*

Take a glass tube about 15 cm long and 10 mm outside diameter. Make its ends smooth by heating them over a flame. Now pass a strong silk or nylon thread about 1.5 m long through the tube. At one end of the thread tie a packet of sand or a rubber stopper and at the other a weight (*W*) (about three to 10 times the weight of the sand/cork). First, demonstrate that on lifting the glass tube, the weight stays on the table while the packet of sand or the stopper gets lifts up (Fig. D 3.1).

Now by holding the glass tube firmly in one hand and the weight (*W*) in the other, rotate the packet of sand in a horizontal circle. When the speed of motion is sufficiently fast, the weight (*W*) can hang freely without the support of your hand. Adjust the speed of rotation such that the position of the weight (*W*) does not change. In this situation, weight (*W*) provides the centripetal force necessary to keep the packet or stopper moving along a circular path (Fig. D 3.2). If the speed of motion is increased further, the weight (*W*) even moves up and vice versa. Why?

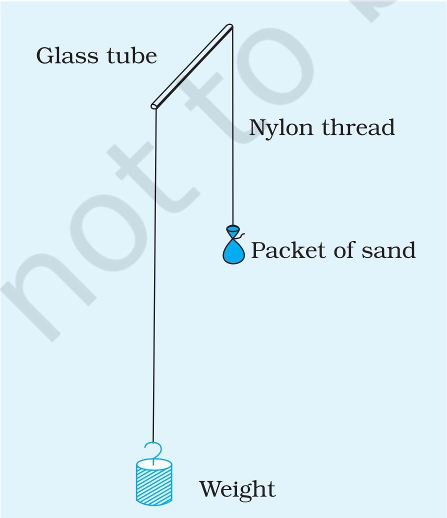


Fig. D 3.1: *The weight tied at the end passing down the glass tube is much heavier than the packet of sand*

As a safety precaution, in this demonstration, the packet to be rotated in a horizontal circle should be a packet of sand, or a packet of a few fine lead shots, or a rubber stopper, etc., lest it breaks off and strikes someone. Again, the glass tube should be wrapped with two layers of tape, lest it breaks and hurt the hand of the person demonstrating the experiment.

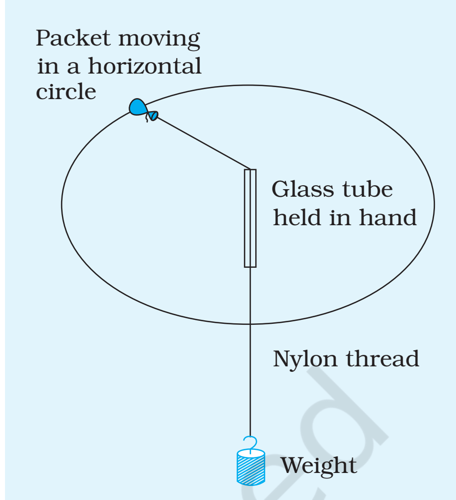


Fig. D 3.2: *On revolving the packet of sand at a suitable speed, the weight lifts off the table; its weight is just enough to provide the necessary centripetal force*

(b) *Using a roller and a turn table*

If a turn table (as you might have seen in a gramophone) or a potter's wheel is available, it can also be used to demonstrate centripetal force. A small roller is placed on the turn table and its frame is attached to the control peg by a rubber band (Fig. D 3.3). The roller is free to roll radially towards or away from the centre. The disc is set in motion first at the lowest speed of 16 revolution per minute. The stretching of the rubber band indicates that a force acts outwards along the radius. At higher speeds, 33 r.p.m., or 45 r.p.m., or 78 r.p.m., the stretching of the rubber band could seen to be larger and larger, showing that greater and greater centripetal force comes into play. Note that as the angular speed increases, the radius of circular motion of the roller also increases due to elongation of the rubber band.

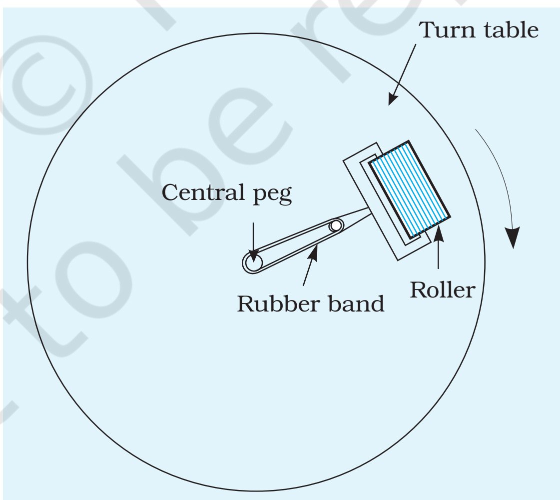


Fig. D 3.3: *Elongation of rubber band indicates that it is exerting a centripetal force on the roller*

DEMONSTRATION 4

To demonstrate the principle of centrifuge

Bend a glass tube (about 10 to 15 mm diameter) slightly at its middle to make an angle of, say, 160°. Fill it with coloured water leaving an air bubble in it and then close its both ends with rubber stoppers. Now mount it on the turn-table with both its arms inclined to horizontal say, at, 10° while keeping the turn-table horizontal. The lowest portion of the tube in the middle is attached to the central peg of the turn-table (Fig. D 4.1). The air bubble then stays at the top of one or both the arms of the glass tube.

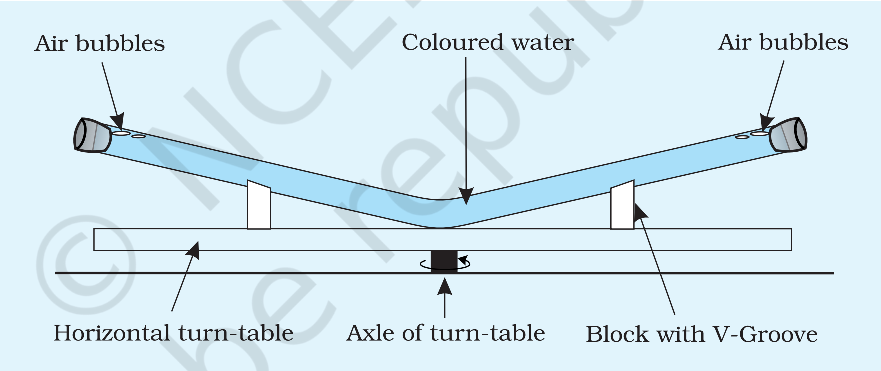


Fig. D 4.1: *A bent glass tube filled with a liquid but having an air bubble attached to the central peg of turn table at its middle*

Now rotate the turn-table and increase its speed in steps, 16 r.p.m., then 33 r.p.m., then 45 r.p.m. and then 78 r.p.m. As the speed of rotation increases, draw attention that the air bubble is moving towards the centre, the lowest part of the tube.

The rotating turn-table is an accelerated frame of reference. At every point on it, the acceleration is directed towards the centre. Thus, an object at rest in this frame of reference experiences an outward force. Every molecule of water in the tube experiences this force, just like the force of gravitation. Under the action of this force, denser matter moves outwards and the less dense inwards.

DEMONSTRATION 5

To demonstrate interconversion of potential and kinetic energy

Interconversion of kinetic and potential energies may be easily demonstrated by Maxwell's Wheel (Fig. D 5.1). It consists of a wheel rigidly fixed on a long axle passing through its centre. It is suspended by two threads of equal length, tied to the axle on two sides of the wheel. In the lowest position of the wheel, separation between the lower ends of the two threads is slightly more than that between them at the supporting at the top.

To set it in action the wheel is rotated and moved up so that both threads wind up on the axle. As the wheel moves up, it gains some potential energy. On releasing, it moves down and its P.E. is converted to K.E. of rotation of the wheel. At its lowest position when all the length of the two threads has unwound, all the energy of the wheel is kinetic due to which the threads start winding up in the opposite direction.

Thus, the wheel starts moving upwards, converting its K.E. into P.E.

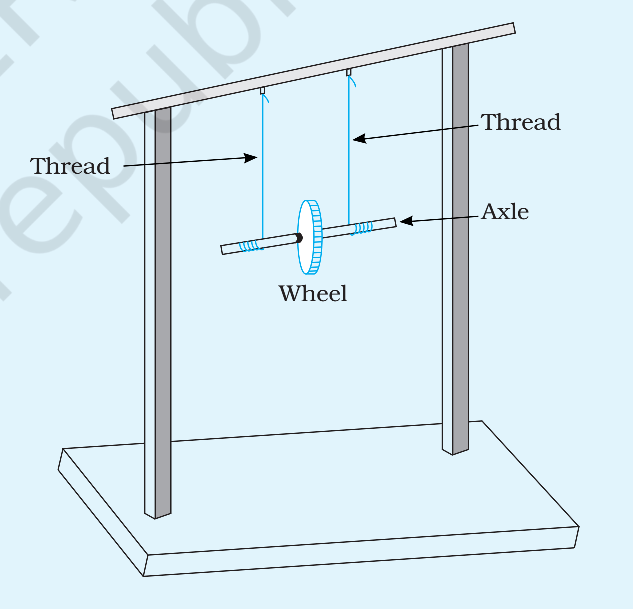


Fig. D 5.1: *The Maxwell's wheel*

Note: In order to ensure that loss of energy in successive up and down motions of the wheel be small, the threads should be quite flexible, inextensible and identical to each other.

DEMONSTRATION 6

To demonstrate conservation of momentum

The law of conservation of momentum can be demonstrated using two bifilar pendulums of the same length using bobs of different materials (Fig. D 6.1). The time period T for both pendulums is the same. Initially the two bobs A and B touch each other in their rest position. Also the suspension fibres of A and B are parallel to each other in their rest positions.

The bob A is displaced with the help of a wooden strip and allowed to touch the reference peg C and thus given a displacement, a, which is noted with the scale. The strip is then quickly removed, so that bob A moves smoothly towards the rest position and collides with the bob B. The maximum displacement a' and b' of the bobs A and B respectively after collision are noted simultaneously. On the right hand side of B, a rider is put on the scale, which is pushed by the ball B, as it undergoes the displacement b'. Then reading the displacement of A directly and of B from the displaced position of the rider becomes easier.

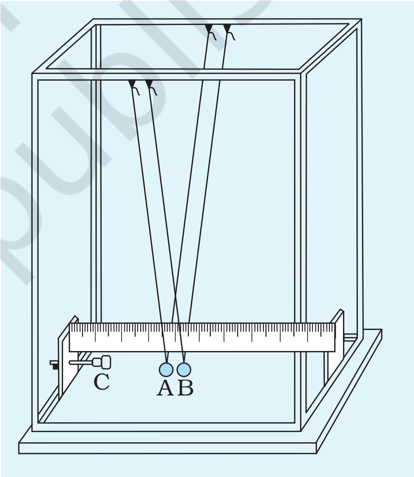


Fig. D 6.1: *The bifilar pendulums*

The masses m_A and m_B of the bobs are measured. The velocities of the bobs, just before and just after the collision are proportional to their displacements, since the time period, T, for both the pendulums is equal and the velocity of a simple pendulum in its central position is equal to (amplitude $\times 2\pi/T$). Therefore, the equality of total momentum of the two bobs before and after their collision implies

$$m_A a = m_A a' + m_B b'$$

Having measured a, a' and b', the above equality can be checked up (a' and b' are the displacements' after the impact).

DEMONSTRATION 7

To demonstrate the effect of angle of launch on range of a projectile

The variation in the range of a projectile with the angle of launch can be demonstrated using a ballistic pistol or toy-gun and mounting it suitably so that the angle of launch can be varied. While mounting the gun care must be taken to see that the axis of the gun passes through the centre of the circle graduated in degrees (Fig. D 7.1). If a toy-gun is used, whose maximum range is more than the length of the classroom, then this demonstration may be done in an open area such as the school play ground.

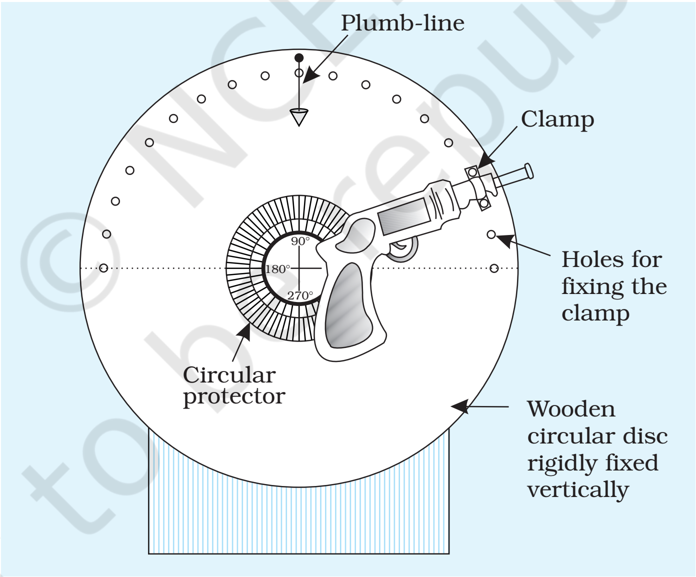


Fig. D 7.1: *A set up to study the range of a projectile fired with a toy pistol*

As the gun is fired at different angles ranging between 0° and 90°, the corresponding ranges are measured with care. A graph for the angle of projection versus the range may be drawn.

Alternately one can also study the range of water jet projected at different angles provided it is assured that water will be released at same pressure.

DEMONSTRATION 8

To demonstrate that the moment of inertia of a rod changes with the change of position of a pair of equal weights attached to the rod

Take a glass rod and hang it horizontally from its centre of gravity with the help of a light, thin wire. Take two lumps of equal mass of plasticine, roll both of them separately to get discs of same size and uniform thickness. Now attach them near the two ends of the rod (like rings) so that the rod is again horizontal [Fig. D 8.1(a)]. Make sure that the plasticine cylinders easily move along the rod. Give a small angular displacement to the rod and note the time for 10 oscillations. Find the time period for one oscillation. Now, move the rings of plasticine by equal distances towards the centre of the rod so that it remains horizontal [Fig. D 8.1(b)]. Give a small displacement to the rod and again note the time period for 10 oscillations. Find the time period for one oscillation. Are the two time periods the same or different? If you

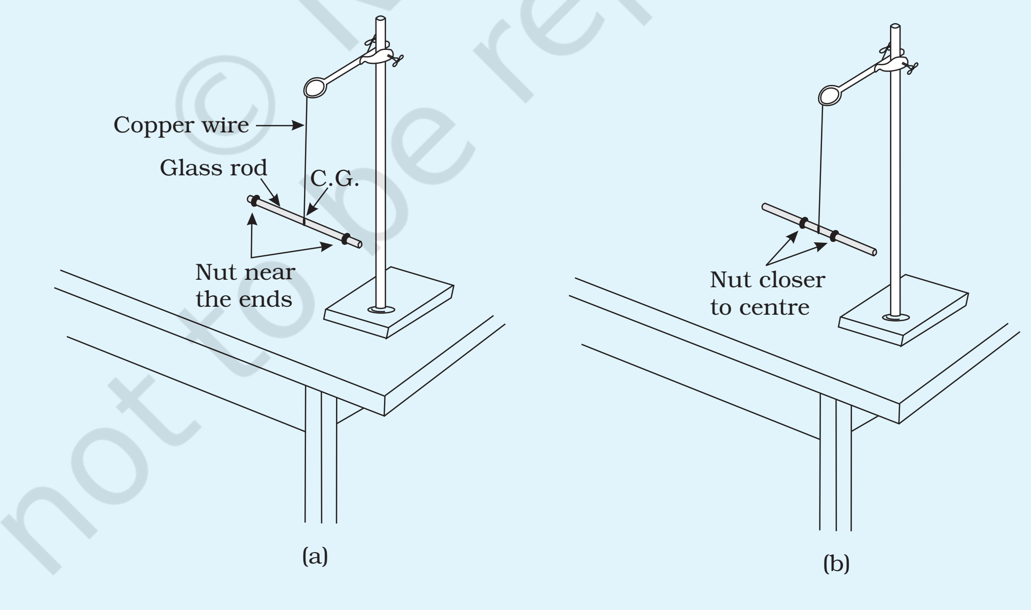


Fig. D 8.1: *Setup to demonstrate that total mass remaining constant, the moment of inertia depends upon distribution of mass. Here nuts have replaced the plasticine balls: (a) the movable mass are far apart, (b) the masses are closer to the C.G. of the rod* find that the time periods in both the situations are different, it shows that the moment of inertia changes with the distribution of the mass of a body even if the total mass remains the same.

An important caution for a convincing demonstration is that the point where a thin metal wire is attached to the glass rod (the point about which the glass rod makes rotatory oscillations) should remain fixed. The metal wire should be so tied that the rod hangs horizontally from it. It ensures that the axis of rotation passes through its C.G. The wire can be fixed tightly by using a strong adhesive. Therefore, the position of plasticine discs have to be adjusted so that the glass rod hangs horizontally.

DEMONSTRATION 9

To demonstrate the shape of capillary rise in a wedge-shaped gap between two glass sheets

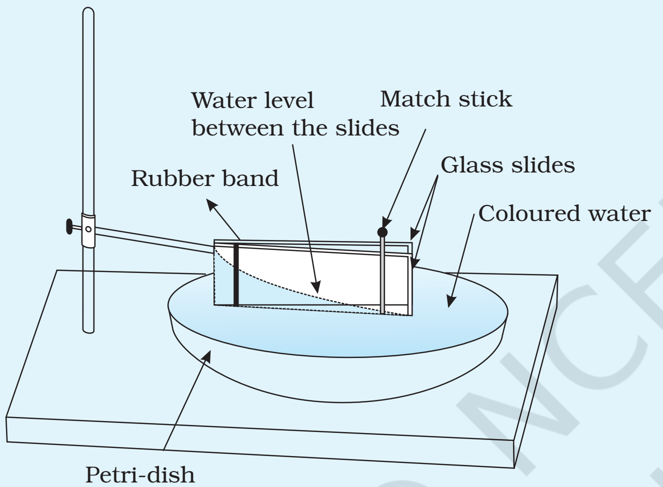


Fig. D 9.1: *Capillary rise of water is higher at the end tied by rubber band in the wedge-shaped gap between the glass slides*

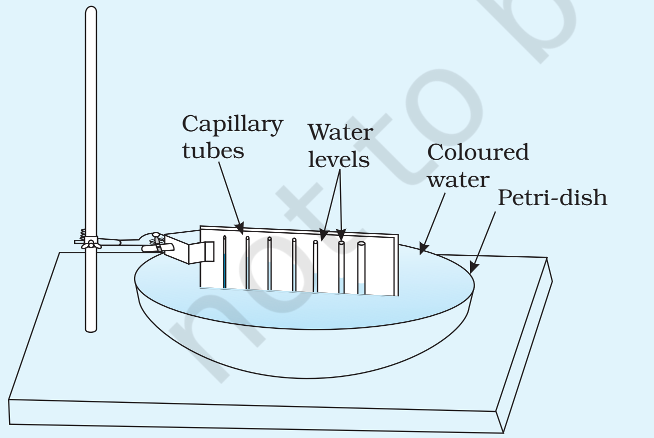


Fig. D 9.2: *Rise of water in capillary tubes of different diameters*

You would require two plane glass slides, a thick rubber band, a match stick, a petri-dish, some potassium permanganate granules and a felt-tip glass marking pen.

Clean the two slides and the petri-dish thoroughly with soap and water and rinse with distilled water. Ensure that no soap film remains on them. Fill the dish about half with distilled water coloured by potassium permangnate. Tie one end of the pair of slides together with a rubber band and put a match stick between their free ends (Fig. D 9.1). Dip this arrangement in the coloured water in the petri-dish. Water rises more at the tied end as compared to that at the match stick end because the separation between the glass slides increases linearly from the tied end to the match stick end.

Note

1. The same effect could be demonstrated by using a number of capillary tubes of different diameters arranged side by side in increasing order of diameter, as shown in Fig. D 9.2.

2. Students may take up this experiment as an activity or project work.

DEMONSTRATION 10

To demonstrate affect of atmospheric pressure by making partial vacuum by condensing steam

To perform this demonstration you will need a round-bottom flask, a glass tubing, a cork, cork borer, a long piece of pressure rubber tube just fitting the glass tubing, a pinch cock, burner, tripot stand, laboratory stand with a clamp and large water container.

Take some water in a round bottom flask. Close its mouth tightly with a rubber cork, in which a short glass tube is fitted. Attach a pressure rubber tube, about 1.5 m long, in the open end of the glass tube. Heat the water, as shown in Fig. D 10.1(a). The steam produced in the flask expels the air from the flask, the glass tube and the rubber tube. Stop heating after some time and tightly close the mouth of the rubber tube with a pinch cock immediately.

Invert the flask and clamp it as high as possible in a tall stand placed on the table [Fig. D 10.1(b)]. Dip the free end of the rubber tube in coloured water kept in the large container on the ground and release the pinch cock. As the flask cools, water from the container rushes through the glass tube into the flask. The students will naturally

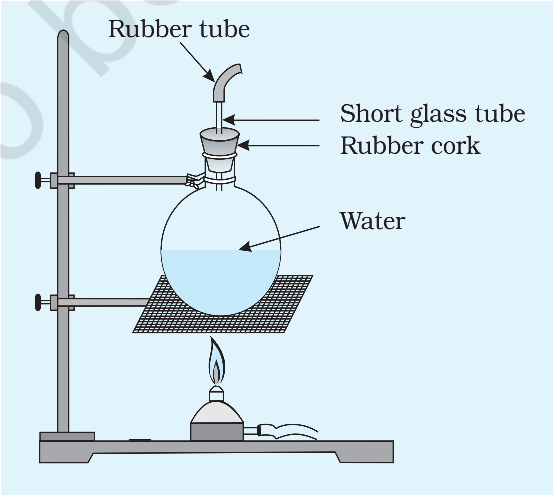


Fig. D 10.1 (a): *On heating the water in flask, steam drives air out from it*

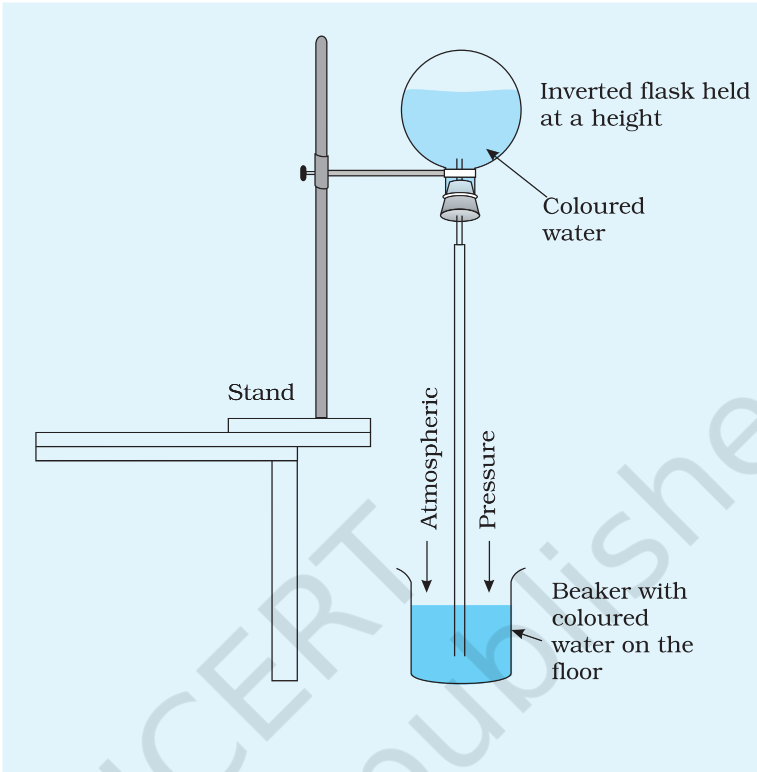


Fig. D 10.1 (b): *Atmospheric pressure pushes coloured water up into the flask as steam in the flask condenses*

become curious to know the reason why water rises through the height. It may be explained in terms of difference in pressure of air on the surface of the water in the container and inside the flask.

Note

To make this experiment more spectacular, a student may climb on the table and raise the stand by another 2 m. Then the pressure rubber tube may also have to be longer.

DEMONSTRATION 11

To study variation of volume of a gas with its pressure at constant temperature with a doctor's syringe

This demonstration can be given with the help of a large (50 mL or more) doctor's syringe (disposable type), laboratory stand, grease or thick lubricating oil, 200 gram to 1 kg weights which fit over one another, cycle value-tube, rubber band, a wooden block and a laboratory stand.

Make the piston in the syringe air tight by applying a drop of thick lubricating oil or grease into the syringe. Draw out the piston in the syringe so that the volume of air enclosed by it is equal to its full capacity. Next close the outlet tube of the syringe by fixing a piece of cycle value-tube on it and folding the valve-tube. Hold the syringe vertically with a laboratory stand with its base resting on a wooden block (Fig. D 11.1).

Press the piston downward with the hand to compress the air inside. Release the piston and observe, whether the air inside regains its initial volume by pushing the piston up. Since, the friction between the piston and the inner surface of the syringe is quite large, both

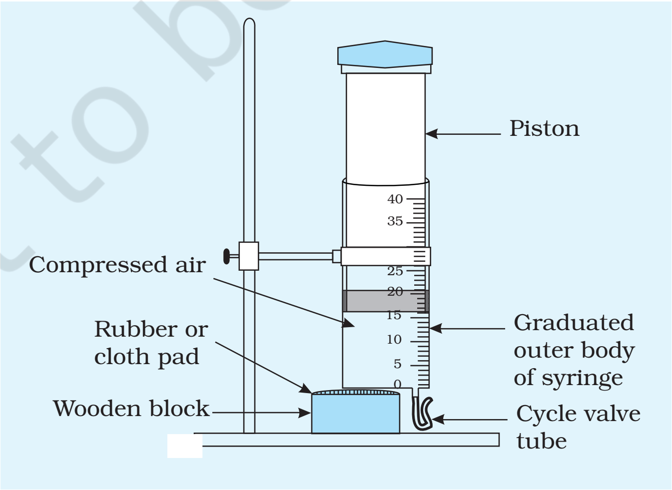


Fig. D 11.1: *The load is kept on the piston of the syringe to apply the force of its weight along the axis of the piston* being of plastic, the air inside is unable to push the piston upto its original position. When the piston comes to rest, the thrust of atmospheric pressure plus limiting friction is acting on it downwards. Note the volume of enclosed air in this position of the piston.

Next, pull the piston up a little and release. Again it does not reach quite upto its original position. This time the thrust of atmospheric pressure minus limiting friction is acting on it downwards. Note this volume of air also and check that the mean of the two volumes so measured is equal to the original volume of air at atmospheric pressure.

Now balance a 1 kg weight on the handle of the piston. Note the two volumes of enclosed air, (i) piston slowly moving up and coming to rest, and (ii) piston slowly moving down and coming to rest and find their mean. In this manner note volume, V, of air for at least two different loads, say 1 kg and 1.8 kg, balanced turn by turn on the piston. Check up, in the end that volume for no load is same as that at the beginning to ensure that no air leaks out during the experiment. Draw a graph between $1/V$ and load W for the three observations, W = 0 kg, 1 kg and 1.8 kg if a graph black-board is available. Alternately, it may be given as an assignment to students.

DEMONSTRATION 12

To demonstrate Bernoulli's theorem with simple illustrations

(a) Suspend two simple pendulums from a horizontal rod clamped to a laboratory stand (Fig. D 12.1). Use paper balls or table tennis balls as bobs. Their bobs should be close to each other and at the same height but not touching each other. Ask the students what would happen if you strongly blow into the space between the bobs. A person/ student not thinking in terms of Bernoulli's theorem would conclude that air pushed into this space will push the bobs away from each other. Now blow air between the two bobs suspended close to each other and ask them to observe what happens. The speed of air passing between them gets increased due to less space available and so the pressure there, gets decreased. Thus, the pressure of air on their outer faces of the bobs pushes them closer. That is why one observes the bobs to actually move closer.

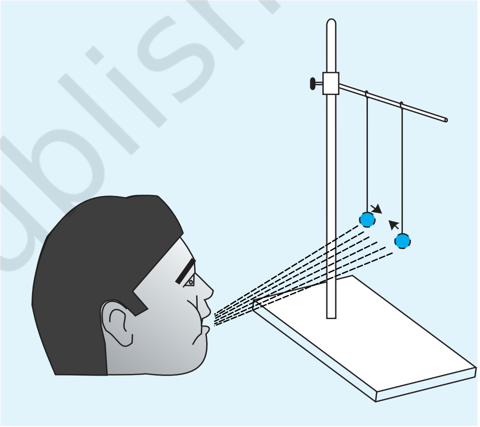


Fig. D 12.1

(b) Place a sheet of paper supported by two books in the form of a bridge. Let the books be slightly converging (Fig. D 12.2) i.e., their separation is larger on the side facing you. Now, you blow under the \`bridge', the paper \`bridge' is pushed down.

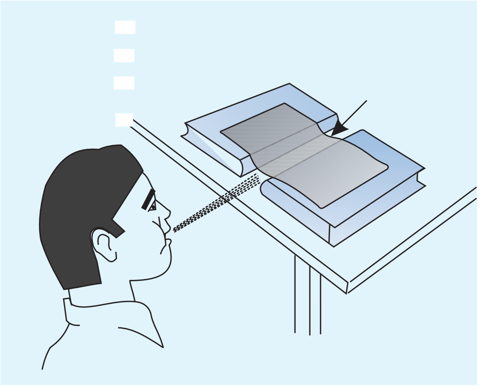


Fig. D 12.2

(c) Hold the shorter edge of a sheet of paper horizontally, so that its length curves down by its weight [Fig. D 12.3(a)]. If you press down lightly on the horizontal part of the curve with your finger the paper curves down more. Now, instead of touching with the hand hold the horizontal edge of the sheet of paper close to your mouth. Blow over the paper along the horizontal. Does the hanging sheet of paper get pushed down or

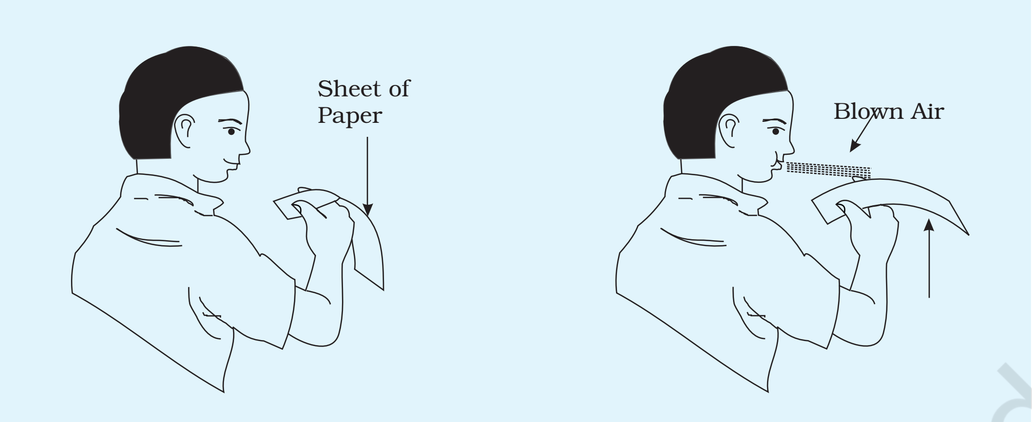


Fig. D 12.3 (a) *Fig. D 12.3 (b)*

lifts up [Fig. D 12.3(b)]? The curved shape of paper makes the tubes of flow of the wind narrower as the wind moves ahead as shown in [Fig. D 12.3(c)]. Thereby its speed increases and pressure on the upper side of the paper decreases.

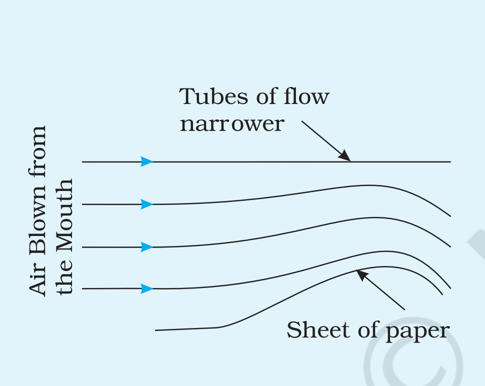


Fig. D 12.3 (c)

(d) Fill coloured water in an insecticide/pesticide spray pump. Spray the water on a white sheet of paper. Coloured drops deposit on the paper. It is evident that water from the tank rises up in the tube attached to it and is then forced ahead in the form of tiny droplets. But what makes it rise up in the tube? As the pump forces air out of a fine hole, the speed of air in the region immediately above the open end of the tube in the tank becomes high (Fig. D 12.4). Thus, the pressure of air in the region is lower than the surrounding still air (which is equal to atmospheric pressure). Right in this region, just below the hole in the pump is the upper end of the fine tube through which water rises up, due to atmospheric pressure acting on the surface of water outside the tube.

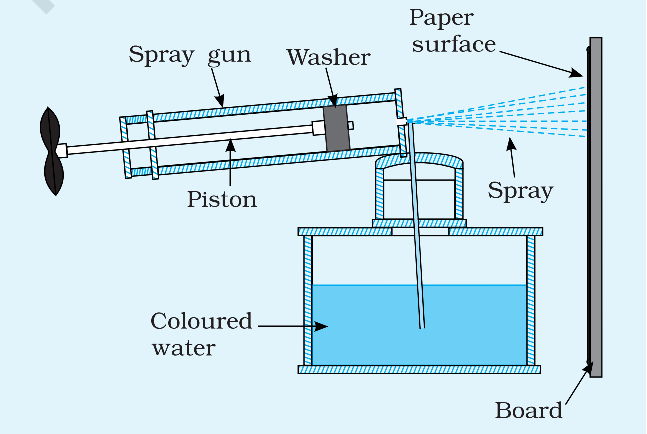


Fig. D 12.4

(e) Fig. D 12.5 shows the construction of a Bunsen burner. The fuel gas issues out of the jet J in the centre of the vertical tube. Due to the high speed of gas, its pressure gets lowered. So, through a wide opening in the side of the vertical tube air rushes in, mixes up with fuel gas and the gas burns with a hot and blue flame. If the air does not get mixed with fuel gas at this stage and comes into contact with it only at the flame level, the flame will be bright yellow-orange like that of a candle, due to incomplete combustion of the gas which gives off comparatively less heat than when it burns with a blue flame.

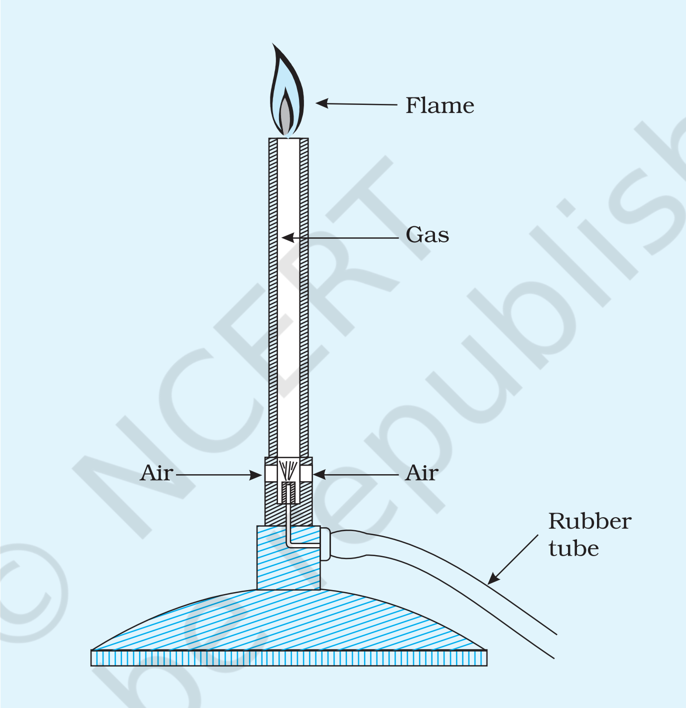


Fig. D 12.5

DEMONSTRATION 13

To demonstrate the expansion of a metal wire on heating

Stretch a length of any metal wire firmly between two laboratory stands, which are fixed rigidly on the table by G-clamps (Fig. D 13.1). Suspend a small weight at the centre of the wire and stretch the wire as tightly as possible, without significantly bending the iron stands. However, the wire cannot be made straight and some sagging is inevitable due to the weight suspended at the centre. Place a pointer on the hind side of the upper edge of the weight to serve as reference.

Heat the wire along its entire length by a spirit lamp or a candle. The wire is seen to sag more and the weight moves down. Remove the flame to let the wire cool. As the wire gradually cools, the weight ascends to its original position.

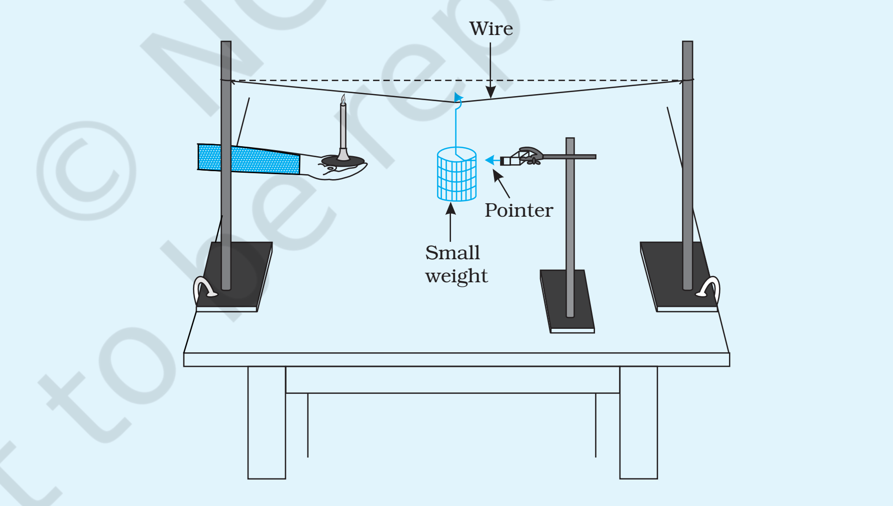


Fig. D 13.1: *A taut wire sags on heating due to its thermal expansion*

Note:

The wire can also be heated electrically, if so desired. Use a step-down transformer which gives various voltages in steps from 2 volt to 12 volt. The advantage is that heating of the wire for a certain voltage applied across it will be uniform along its whole length and the observed sagging by this heating will be repeatable.

DEMONSTRATION 14

To demonstrate that heat capacities of equal masses of aluminium, iron, copper and lead are different

This demonstration can be performed with four cylinders of aluminium, iron, copper and lead having equal mass and cross-sectional area, a rectangular blocks of paraffin wax, beaker/metallic vessel, thread, water and a heating device.

Since the four solid cylinders are having equal mass and equal cross-sectional area, their lengths are inversely proportional to their densities. Take water in a beaker or a metallic vessel and boil it. Suspend the four cylinders, tied with threads, fully inside boiling water (cautiously, if a beaker is being used). After a few minutes all have attained the temperature of boiling water [Fig. D 14.1(a)].

Take out the cylinders in quick succession and place them side by side on a thick block of paraffin wax [Fig. D 14.1(b)]. The cylinders sink to different depths in the paraffin wax. They all cool from temperature of boiling water to melting point of wax during the process of sinking. Although all the cylinders have the same mass, but the amount of heat they give out are different.

An alternative (and more convenient to do) method is to have a wooden board with semi cylindrical grooves resting against a block. Equal length of each groove is initially filled with wax. Hot cylinders are placed on this wax in the grooves, instead of on the wax block.

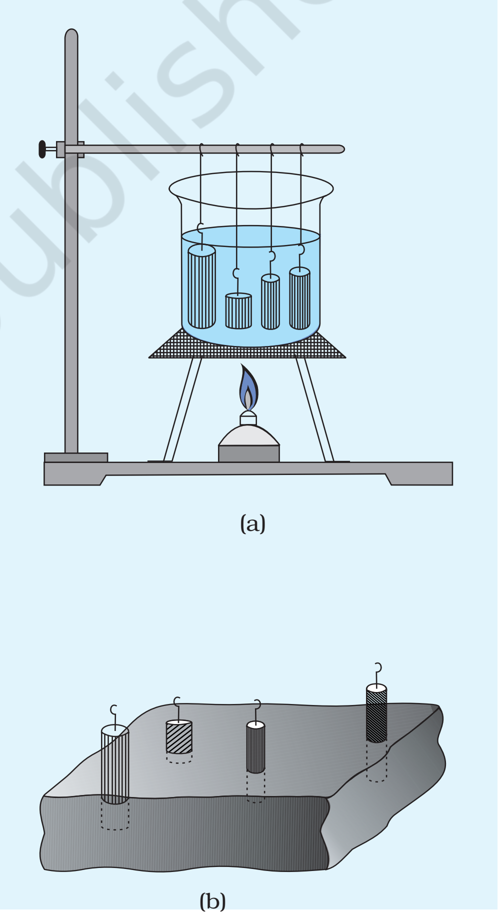


Fig. D 14.1: *Qualitative comparison of heat capacities of different metals*

Note

A substantial portion of heat given out by each cylinder is radiated into the atmosphere. Moreover, they radiate at different rates because of the difference in their surface areas. Therefore, by this experiment we only get a qualitative comparison of the heat capacities of these solids.

DEMONSTRATION 15

To demonstrate free oscillations of different vibrating systems

A number of demonstrations involving vibrating systems are presented through (a) to (j). Demonstrate as many vibrating systems as possible and discuss the following in each case:

(i) What are the energy changes that occur during vibrations?

(ii) How can the frequency of vibration be altered?

(iii) Can the damping of the system be reduced? If so, how?

(iv) How does the force acting on the oscillating body vary with its displacement from the mean position?

(a) *Simple pendulum*: Make a rather long and heavy simple pendulum following the steps described in Experiment 6. One may tie a brick or a 1kg weight at one end of a strong thread about 1.5 m in length. Suspend the pendulum from a stand having a heavy base so that it does not topple over. The base can be made heavy by putting a heavy load on it, say a few bricks. Alternatively, the stand may be clamped on the table with a G-clamp. The vertical rod of the stand may be further supported by tying it to three G-clamps fixed on the table (Fig. D 15.1). A sturdy stand will help in keeping the pendulum oscillating for quite a long time with very small damping.

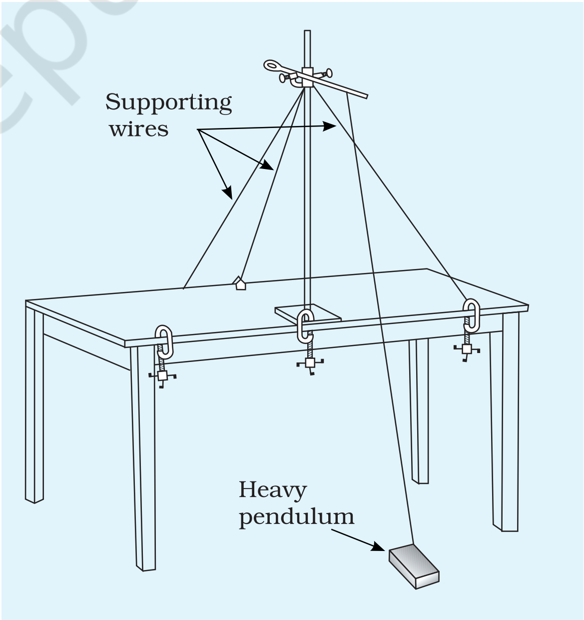


Fig. D 15.1: *Set up to study oscillations of a heavy pendulum*

(b) *Vibrating hacksaw blade*: Clamp a hacksaw blade (or a thin metal strip) with its flat surface horizontal at the edge of the table by a

G-clamp (Fig. D 15.2). Load the free end by about 20 g of plasticine or by putting a 20 g weight on the flat free end and fastening it to the blade with a thread. Let the free end of the blade vibrate up and down. Repeat the demonstration with a smaller load and then with no load on the blade. Compare the oscillations with different loads.

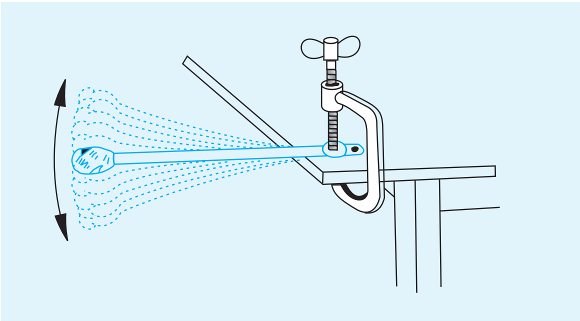


Fig. D 15.2: *A hacksaw blade clamped at one end vibrates up and down*

(c) *Oscillating liquid column:* Fix a U-tube of large diameter (about 2cm) on a stand with its arms vertical. Fill liquid of low viscosity e.g., water or kerosene or methylated spirit in it. Let the liquid column oscillate up and down in the tube (Fig. D 15.3). For this purpose blow repeatedly into one arm of the U-tube with your mouth as soon as the liquid column in the arm you are blowing attains maximum height so as to generate a small air pressure in it each time so as to oscillate the liquid column by resonance. Another method is to slightly tilt the stand to one side repeatedly, with the U-tube fixed on it so as to oscillate the liquid column by resonance.

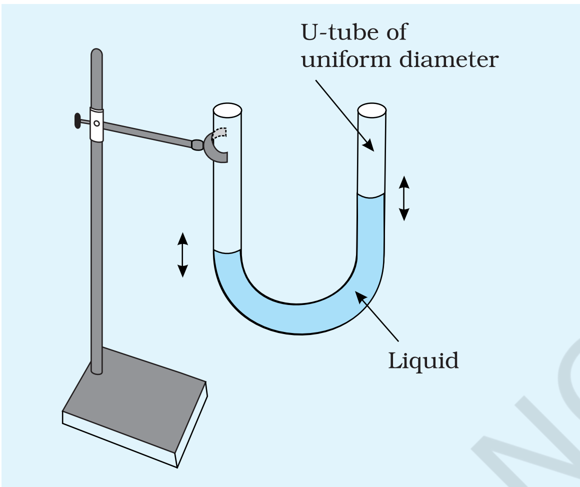


Fig. D 15.3: *Set up to demonstrate oscillations of liquid column in a U-tube*

A low cost U-tube can be improvised with two straight tubes of about 3.5 cm to 4 cm diameter and each of length about 50 cm. Fix the tubes vertically on a wooden board about 20 cm to 30 cm apart. Join their lower ends with a piece of a rubber tube, or a piece of hose pipe made of plastic. A plastic hose pipe is better because it bends to the U-shape easily. Fill this U-tube with coloured water upto about 10 cm below the two open ends. Oscillate the liquid in the tube by either of the two methods described above.

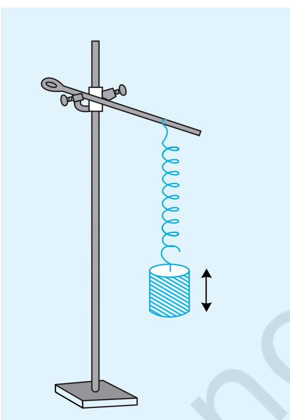


Fig. D 15.4: *A load attached to the lower end of a helical spring oscillates up and down*

(d) *Helical spring :* Attach a suitable mass, say 1kg, at one end of a helical spring (Fig. D 15.4). Suspend the spring vertically. Pull the weight down through a small distance and let it go. Observe and study the vertical oscillations of the mass suspended by the lower end of the spring.

(e) *Oscillations of a floating test-tube :* Take a test tube and fill at its bottom about 10 g of lead shots or iron filings or sand. Float the tube in water and adjust the load (lead shots or iron filings or sand) in the tube till it floats vertically. Keeping the tube vertical push it a little downwards and release it so that it begins to oscillates up and down on the surface of the water (Fig. D 15.5).

(f) *Oscillations of a ball along a curve* : Take about 30 cm length of aluminium curtain channel and bend it into an arc of a circle. Put it on a table and provide it proper support by two rectangular pieces of thick card board or plywood to keep it standing in a vertical plane. Let a ball–bearing or a glass marble oscillate in its groove (Fig. D 15.6). Alternatively place a concave mirror (10 cm or 15 cm aperture) or a bowl or a *karahi* on a table with its concave side facing up. Let a ball bearing or a glass marble oscillate in it along an arc passing through its lowest point as shown by point P in Fig. D 15.6.

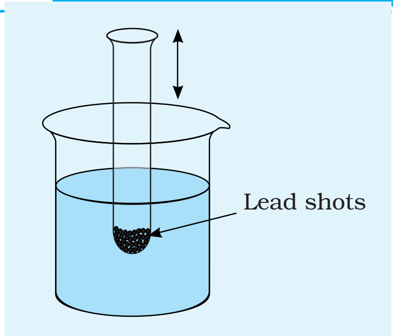


Fig. D 15.5: *A test tube floating in vertical position due to a load in it, oscillates up and down, when it is pushed a little and then released*

(g) *Oscillations of a ball on the double inclined track:* Adjust a double inclined track on a table with its arms equally inclined to the horizontal (Fig. D 15.7). Release a steel ball–bearing (2.5 cm diameter) from the upper end of one of the arms and let it oscillate to and fro between the two arms of the double inclined plane.

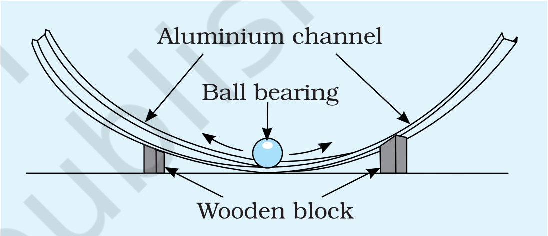


Fig. D 15.6: *Arrangement to demonstrate the to-and-fro motion of a steel ball in a channel in the form of an arc of a circle*

(h) *Oscillations of a trolley held between two springs on a table:* Take a trolley and attach two identical helical springs at each of its ends such that the springs are along a straight line. Place the trolley on a table and fix the free ends of the springs to two rigid supports on opposite ends of the table so that the springs are under tension along the same straight line [Fig. D 15.8(a)]. Displace the trolley slightly to one side keeping both springs under tension. Release the trolley and observe its to and fro motion along the length of the springs. Find the time period of oscillations and also make a note of damping.

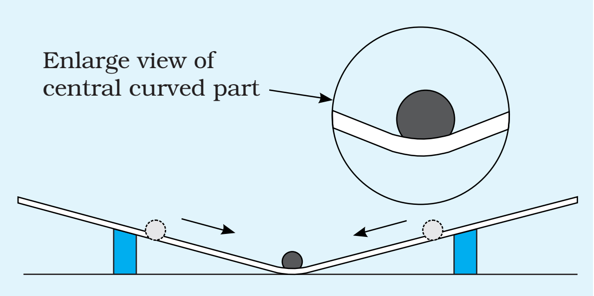


Fig. D 15.7: *Arrangement to demonstrate the to-and-fro motion of a ball along a double inclined track*

(i) *Oscillations of a trolley attached to a spring:* Remove one of the springs from the set up arranged for demonstration (h) shown in Fig D 15.8 (a). Displace the trolley to one side and release it. Compare the time period of oscillations affect of damping with the earlier case.

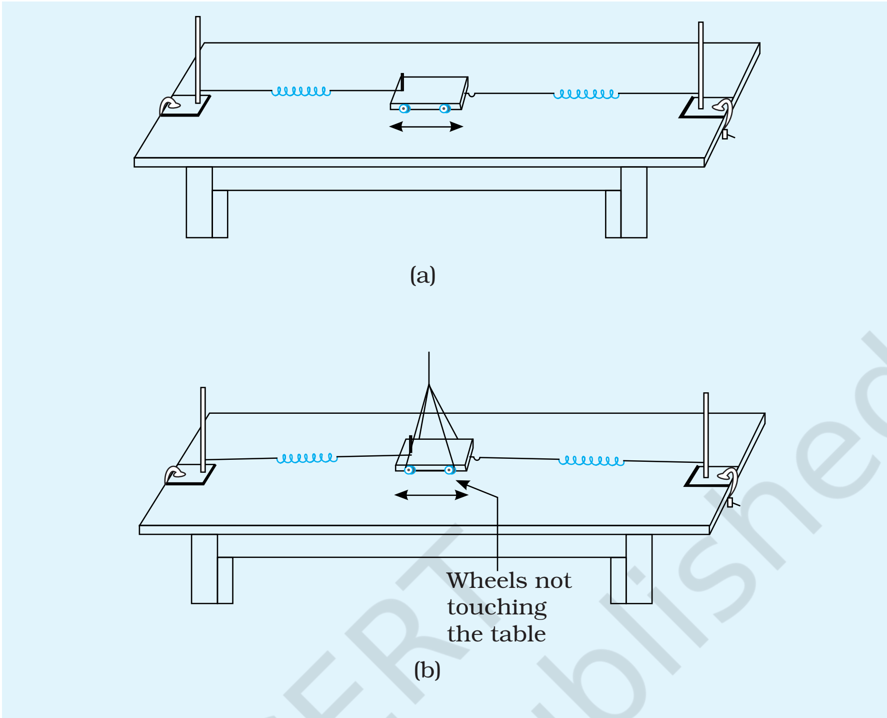


Fig. D 15.8: *(a) Set up for demonstrating the to-and-fro motion of a trolley held between two identical springs (b) Arrangement to demonstrate the to-and-fro motion of a trolley suspended from a high support while it is held between two springs on either side*

(j) *Oscillations of a trolley suspended from a point and held between two springs:* Set up the trolley with two springs on a table as described in demonstration (h) above. Attach an inflexible string to the trolley as shown in Fig. D 15.8(b). Fix the other end of the string to a stand kept on a stool placed on the table or to a hook on the ceiling such that the trolley remains suspended just above the table. Set the trolley in oscillation by displacing it slightly to one side. Study how the time period of oscillations and damping get affected as compared to the case when the trolley was placed on the table, as in demonstration (h).

DEMONSTRATION 16

To demonstrate resonance with a set of coupled pendulums

Take two iron stands and keep them on the table at about 40 cm from each other. Tie a half metre scale (or still better a straight strip of wood about 1.5 cm wide) between them so that it is horizontal with its face vertical and free to rotate about its upper edge (Fig. D 16.1). Near one edge of the scale suspend a pendulum with a heavy bob (say, approximately 200 g). Also suspend four or five pendulums of different lenghts with bobs of relatively lower masses. However, one of them should be exactly of the same length as the one with the heavy bob, as described.

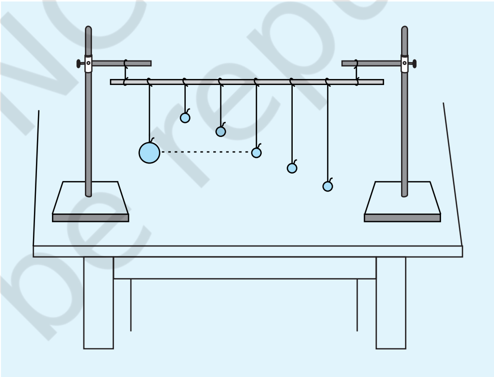


Fig. D 16.1: *A set up to demonstrate resonance*

Let all the pendulums come to a rest after setting up the arrangement described above. Gently pull the bob of the heavy pendulum and release it so that it starts oscillating. Make sure that other pendulums are not disturbed in the process. Observe the motion of other pendulums. Which of the pendulums oscillates with the same frequency as that of the heavy pendulum? How does the amplitude of vibrations of different pendulums differ?

DEMONSTRATION 17

To demonstrate damping of a pendulum due to resistance of the medium

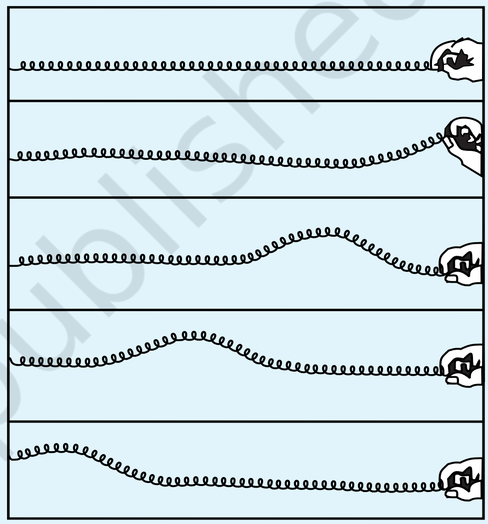
(a) *Damping of two pendulums of equal mass due to air:* Set up two simple pendulums of equal length. The bob of one should be small in size say made of solid brass. The bob of the other should be of the same mass but larger in size — either of a lighter material like thermocole or a hollow sphere. Give them the same initial displacement and release simultaneously. Observe that in the pendulum with the larger bob the amplitude decreases more rapidly. Due to its larger area, air offers more resistance to its motion. Though both pendulums had the same energy to start with, the larger bob looses more energy in each oscillation.

(b) *Alternative demonstration by comparing damping due to air and water:* Set up a simple pendulum about half metre long with a metal bob of 25 mm or more diameter. In its vertical position the bob should be about 4 cm to 5 cm above the table. First, let the pendulum oscillate in air and observe its damping. Now place a trough below the bob containing water just enough to immerse the bob in water. Let the pendulum oscillate with the bob immersed in water and note the effect of changing the medium on damping.

DEMONSTRATION 18

To demonstrate longitudinal and transverse waves

A few characteristic properties of transverse and longitudinal waves can be demonstrated with the help of a slinky, which is a soft spring made of a thin flat strip of steel (about 150 to 200 turns) having a diameter of about 6 cm and width 8 cm to 10 cm. Nowadays slinky shaped spirings made of plastics are also available. Let two students hold each end of the slinky and stretch it to its full length (at least 5 metres) on a smooth floor. Give a sharp transverse jerk at one end and let the student observe the pulse as it moves along the spring [Fig. D 18.1(a)].

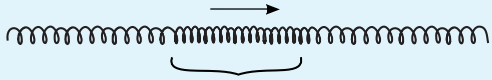


(a)

Fig. D 18.1(a): *Motion of a pulse through a slinky*

Find the speed of the pulse by measuring the time taken by it to move from one end to the other along the stretched length of the spring. For more accuracy, instead of measuring time taken by the pulse to move from one end to the other, measure the time taken by it to make three to four journeys along the entire length of the spring. This would be possible because each pulse moves back and forth along the spring a few times before it dies.

Repeat the experiment by decreasing the tension in the spring (by stretching it to a smaller length) and find the speed of the pulse. Does the speed depend on tension?



(b)

Fig. D 18.1(b): *A compression moving along the length of a slinky*

The slinky can also be used to demonstrate propagation of longitudinal waves. To do so, give a longitudinal jerk at one end of the slinky, keeping the slinkly stretched on the floor to about half the length (2.5 m) than while demonstrating movement of a transverse pulse [Fig. D 18.1(b)]. Ask the students to observe the motion of the pulse in the form of compression of the spring.

The damping may be too high if the floor is not very smooth. In that case the experiment may be performed by suspending the slinky from a steel wire stretched between two pegs firmly fixed on opposite walls of the room. In order to minimise the effect of sagging of the spring in the middle, support the spring by tying it to the wire with pieces of thread spaced at about 25 cm from each other. All pieces of thread must be equal in length.

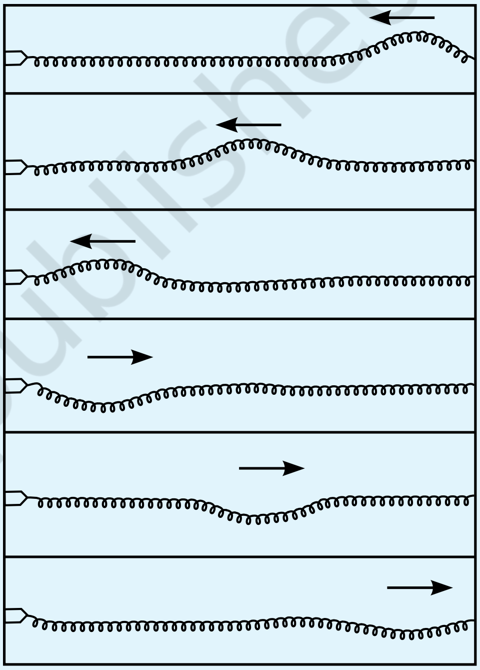
The transverse waves may also be demonstrated with the help of a flexible clothes line or a rubber tubing or a rope instead of a slinky. Tie one end of the rubber tubing or the clothes line to the knob of a door and give it a jerk at the other end while keeping it stretched. If the rubber tube is heavy (fill water in it) and is held loosely, the pulse would move slowly to make better observation.

Instead of a single pulse, a series of pulses one after the other creating an impression of a continuous wave propagation may also be demonstrated. This can be done by using a slinky or a flexible clothes line. Stretch the slinky on the ground and ask one of the students to hold one end firmly. Instead of giving just one jerk at the other end, move the hand to and fro continuously to make waves of wavelength about 0.5m which can be seen to move continuously along the spring.

DEMONSTRATION 19

To demonstrate reflection and transmission of waves at the boundary of two media

Stretch the slinky on a smooth floor or suspend it from a stretched steel wire as described in Demonstration 18.1. Keeping one end fixed, send a pulse from the other end. Note the size and direction of displacement of pulse before and after it gets reflected at the fixed end. Note that the reflected pulse is upside down with little change in its size in comparison to the incident pulse [Fig. D 19.1(a)].



(a)

Fig. D 19.1 (a): *A pulse reflected at a fixed end undergoes phase change of π*

Next join the coil spring (slinky) with another long helical spring of heavier mass end to end [Fig. D 19.1(b)]. Stretch them by holding the free end of each spring and produce a pulse at the free end of the lighter spring (slinky). Observe what happens when the pulse arrives at the joint of two springs. In what way (i.e., with respect to size and direction of displacement) does the reflected pulse undergo a change? Does the pulse transmitted to the heavier spring also undergo any change?

Repeat the demonstration by sending the pulse from the end of the heavier spring. Note how the reflected and transmitted pulse undergo a change at the boundary of the two springs as compared to the incident pulse [Fig. D 19.1(c)].

How do these changes differ from those in case of incident pulse going from lighter to heavier spring?

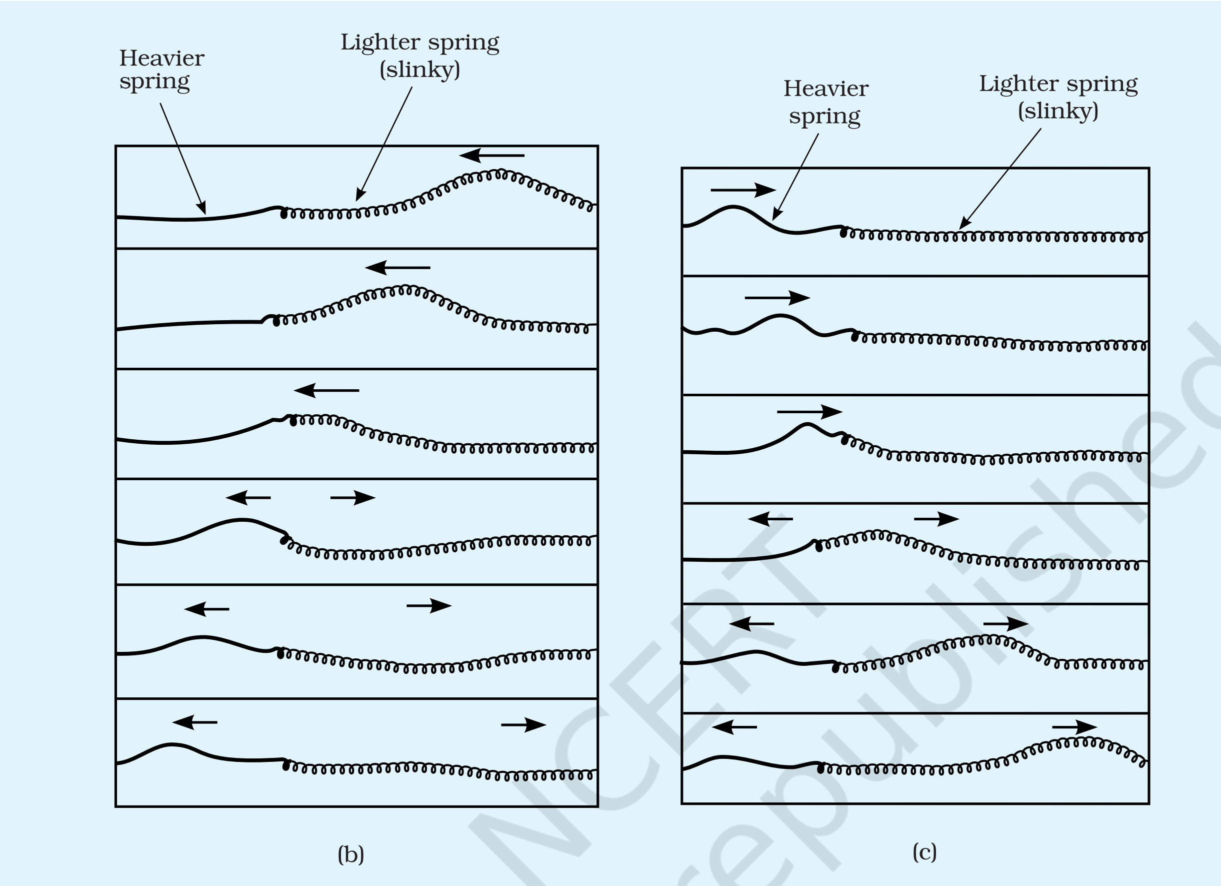


Fig. D 19.1 (b): *Reflection and transmission of a pulse moving from a rarer medium to a denser medium*

Fig. D 19.1 (c): *Reflection and transmission of a pulse moving from a denser medium to a rarer medium*

Now join the slinky (coil spring) to a fine thread instead of a heavier spring. Stretch the spring and the thread and produce a pulse at the free end of the spring. Note what happens to the pulse at the boundary of the spring and the thread.

DEMONSTRATION 20

To demonstrate the phenomenon of beats due to superposition of waves produced by two tuning forks of slightly different frequencies

Take two tuning forks of identical frequency. Attach a small piece of plasticine or wax to the prongs of one of the tuning forks. This will slightly lower the frequency of the tuning fork. Now holding them one in each hand strike both the tuning forks simultaneously on two rubber pads. Place them close to each other.

Carefully listen to the combined sound produced by the two tuning forks. Gradual increase and decrease in the intensity of sound will be heard. It is due to beats produced by the superposition of waves of slightly different frequencies. You can also count the number of beats produced per second if their frequency does not exceed two or three beats per second. The person who is listening to the beats, gives a silent signal at each minimum intensity or maximum intensity, e.g., by shaking his head in the manner we say 'yes'. Then a second person with a stop-watch, either finds the time taken by 10 beats or counts the number of beats in 5 seconds. The person with the stop-watch will also listen to the beats, though less loudly and may measure the frequency without the aid of a signal by the first person.

If two tall tuning forks of the same frequency mounted on resonating wooden boxes are available, all the students in a classroom may be able to listen to the beats. Place them on a desk in the centre of the classroom. Let there be pin-drop silence in the classroom. Then strike the tuning forks with a rubber hammer in quick succession, with roughly equal force. Make their frequencies slightly different by loading one with plasticine or wax or by tightly attaching a small load with adhesive tape. Both tuning forks must be of rather good quality and must give audible sound for about 8 to 10 seconds in spite of dissipation of energy in the resonating box.

DEMONSTRATION 21

To demonstrate standing waves with a spring

Stretch the wire spring (heavier one and not the slinky) to a length of 6 m to 7 m, by tying its one end to a door handle. It may sag in the middle but that will not affect the demonstration. Give a transverse horizontal jerk at the free end, a pulse will travel along the spring, and get reflected back and forth. If instead of stretching the spring in air it is stretched along the ground, then due to large damping, the results will not be so clear and convincing.

Now generate a continuous transverse wave in the spring by giving series of jerks to the spring at fixed time intervals. Change the frequency of the waves by changing the time period of oscillating your hand till stationary waves are set up. You will find that stationary waves are produced only when an integral number of loops, i.e., 1,2,3 etc. are accommodated in the entire length of the spring. In other words, stationary waves are produced corresponding to only some definite time periods.

Ask one of the students to measure the time period of standing waves when one loop, two loops, three loops, and so on are formed in a given length of stretched spring. For the same extension of the spring, and thus for the same tension in the spring, how are the time periods of stationary waves of one loop, two loops, and three loops related to each other?

While producing stationary waves, suddenly stop moving your hand to and fro and thus stop supplying energy to the spring. This is best done by taking the help of a stool on which your hand rests while producing the waves as well as when you stop your hand. Observe that the spring continues to vibrate for some time with the same time period and the same number of loops. Thus, it can be demonstrated that the stretched spring is capable of making free oscillations in several modes—with one loop, two loops, three loops, etc. The various time periods with which you can produce stationary waves in it, are also the natural time periods of the spring.

Thus, when you are producing and observing stationary waves in the stretched spring, you can consider it as a resonance phenomenon. However, in this case, the object being subjected to forced oscillations (i.e., the stretched spring), is capable of oscillating freely with one of the several time periods, unlike the simple pendulums with which you experimented earlier to study the phenomenon of resonance.

One can also demonstrate stationary waves with a spring when its both ends are free to move. Tie a thread, 3 – 4 m in length, at one end of the spring. Tie other end of the thread to a hook on the wall or a door handle. Stretch the spring by holding it at its free end and send a continuous transverse wave in the spring by moving the end in your hand. Do you observe that the stationary waves now produced are somewhat different than those produced when one end of the spring was fixed. Note the difference in the pattern of stationary waves in the two situations and discuss the reason for the difference. Also ask to note the number of loops produced when a stationary wave is set in the spring.

Change the time period of the wave by adjusting to and fro motion of your hand to produce ½ loop, 1½ loop, 2½ loop and so on for same extension of the spring.

How are these time periods related to the various time periods of vibration when the end not in your hand was kept fixed and extension of the spring was the same?

Note

Mathematically, it can be shown that superposition of two waves of the same frequency (and thus moving with same velocity) travelling in opposite directions in an infinite medium, produce stationary waves. In this mathematical treatment, there is no need of specific frequencies at which the stationary waves are produced. However, it is not possible to translate that mathematical result into a simple experimental demonstration. In an experiment we have to take a finite medium, like the stretched spring of finite length. A finite medium with boundaries has its natural frequencies and thus experiment is done at those frequencies. In the above demonstrations one wave is produced by hand and the other (travelling in the opposite direction) is the reflected wave and their superposition produces stationary waves, exemplifying the above referred mathematical result.

APPENDICES

APPENDIX A-1
SOME IMPORTANT CONSTANTS

Name	Symbol	Value
Speed of light in vacuum	c	2.9979×10^{8} m s^{-1}
Charge of electron	e	1.602×10^{-19} C
Gravitational constant	G	6.673×10^{-11} N m^{2} kg^{-2}
Planck constant	h	6.626×10^{-34} J s
Boltzmann constant	k	1.381×10^{-23} J K^{-1}
Avogadro number	N_A	6.022×10^{23} mol^{-1}
Universal gas constant	R	8.314 J mol^{-1} K^{-1}
Mass of electron	m_e	9.110×10^{-31} kg
Mass of neutron	m_n	1.675×10^{-27} kg
Mass of proton	m_p	1.673×10^{-27} kg
Electron-charge to mass ratio	e/m_e	1.759×10^{11} C/kg
Faraday constant	F	9.648×10^{4} C/mol
Rydberg constant	R	1.097×10^{7} m^{-1}
Bohr radius	a_0	5.292×10^{-11} m
Stefan-Boltzmann constant	σ	5.670×10^{-8} W m^{-2} K^{-4}
Wien's constant	b	2.898×10^{-3} m K
Permittivity of free space	ε_0	8.854×10^{-12} C^{2} N^{-1} m^{-2}
	$1/4\pi\varepsilon_0$	8.987×10^{9} N m^{-2} C^{-2}
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T m A^{-1}
		$\cong 1.257 \times 10^{-6}$ Wb A^{-1}m^{-1}

Other Useful Constants

Name	Symbol	Value
Mechanical equivalent of heat	J	4.186 J cal^{-1}
Standard atmospheric pressure	1 atm	1.013×10^{5} Pa
Absolute zero	0 K	– 273.15 °C
Electron volt	1 eV	1.602×10^{-19} J
Unified Atomic mass unit	1 u	1.661×10^{-27} kg
Electron rest energy	mc^{2}	0.511 MeV
Energy equivalent of 1 u	1 uc^{2}	931.5 MeV
Volume of ideal gas (0 °C and 1 atm)	V	22.4 L mol^{-1}
Acceleration due to gravity (sea level, at equator)	g	9.78049 m s^{-2}

APPENDIX A-2
Densities of substances (20 °C)

Substance	Density (10^3 kgm^{-3})	Substance	Density (10^3 kgm^{-3})
Alcohol (methyl)	0.81	Olive oil	0.9
Alcohol (ethyl)	0.79	Quartz (crystal)	2.6
Asbestos	2.4	Sea water 1.03	
Brass (60.40)	8.4	Stainless steel	7.8
Brass (70.30)	8.5	Turpentine	0.85
Cast iron	7.0	Wrought iron	7.8
Caster Oil	0.95	Zinc	7.1
Charcoal	0.4	Water 0 °C	0.99987
Coal	1.6 – 1.4	4 °C	1.00000
Copper	8.9	20 °C	0.99823
Constantan	8.9	100 °C	0.9584
Cork	0.24	Water, heavy	
Diamond	3.5	(D_2O) at max. density	
German Silver	8.4	temperature, 11 °C	1.106
Glass	2.5		
Glycerine	1.3	Petrol	0.70
Gold (pure)	19.3	Kerosene 0.80	
Gold (22 carat)	17.5	Common salt sol.	1.189
Gold (9 carat)	11.3	(20% by wt.)	
Graphite	2.3	Air (STP)	0.00129
Ice	0.92	Carbon dioxide (STP)	0.00198
Manganin	8.5	Hydrogen (STP)	0.00009
Mild Steel	7.9	Oxygen (STP)	0.00143
Milk	1.03	Nitrogen (STP)	0.00125
Mercury	13.56		

APPENDIX A-3
Variation of atmospheric temperature and pressure with altitude
(At sea level, pressure = Standard atmosphere and temperature = 15 °C assumed)

Altitude (metres) (1)	Pressure (millibars) (2)	Temperature (°C) (3)
0	1013.25	15.0
250	983.58	13.4
500	854.61	11.8
750	926.34	10.1
1000	898.75	8.5
1500	825.56	5.2
2000	794.25	2.0
2500	746.82	1.2
3000	701.08	– 4.5
3500	657.64	– 7.8
4000	616.40	–11.0
4500	577.28	–14.2
5000	540.20	–17.5
6000	471.81	–29.0
7000	410.61	–30.5
8000	356.00	–37.0
9000	307.42	–43.5
10000	246.36	–50.0

APPENDIX A-4

Acceleration due to gravity at different places in India along with their Latitude, Longitude and Elevation

Place	g(m/s²)	Latitude (*N*)	Longitude (*E*)	Elevation (*m*)
Agra	9.7905	27°12’	78°02’	158
Aligarh	9.7908	27°54’	78°05’	187
Allahabad	9.7894	25°27’	81°51’	94
Varanasi	9.7893	25°20’	83°00’	81
Mumbai	9.7863	18°54’	72°49’	10
Kolkata	9.7880	22°35’	88°20’	6
Delhi	9.7914	28°40’	77°14’	216
Equator	9.7805	00°00’	n.a.	0
Jaipur	9.7900	26°55’	75°47’	433
Udaipur	9.7881	24°35’	73°44’	563
Srinagar	9.7909	34°05’	74°50’	159
North Pole	9.8322	90°00’	n.a.	0
Chennai	9.7828	13°04’	80°15’	6
Thruanatapuram	9.7812	8°28’	76°58’	27
Tirupati	9.7822	13°38’	79°24’	169
Madurai	9.7810	9°55’	78°7’	133
Bangaluru	9.7803	12°57	77°37’	915
Guwahati	9.7899	26°12’	91°45’	52
Bhubaneswar	9.7866	20°28’	85°54’	23

APPENDIX A-5

Surface tension of liquids

Substance	In contact with	Temp (°C)	Surface Tension(10^{-3} Nm^{-1})
Water	Air	10	74.22
	Air	20	72.55
	Air	30	71.18
	Air	40	69.56
	Air	50	67.91
Acetic acid	Vapour	10	28.8
	Vapour	20	27.8
	Vapour	50	24.8
Ethyl Alcohol	Air	0	24.05
	Vapour	10	23.61
	Vapour	20	22.75
	Vapour	30	21.89
Glycerol	Air	20	63.04
	Vapour	90	58.6
Methyl Alcohol	Air	0	24.49
	Air	20	22.61
	Vapour	50	20.14
Mercury	Vapour	20	470
	Vapour	100	456
Oleic acid	Air	20	32.5
Kerosene	Air	20	24
Turpentine	Air	20	27

APPENDIX A-6
Coefficient of viscosity of liquids

Substance	Temp (°C)	Coefficient of viscosity (cP)
(1) Water	0	1.787
	20	1.002
	50	0.5468
	100	0.2818
(2) Acetic Acid	15	1.31
	30	1.04
	60	0.70
	100	0.43
(3) Ethyl Alcohol	0	1.773
	20	1.200
	50	0.834
	70	0.504
(4) Mercury	0	1.685
	20	1.554
	50	1.407
	100	1.240
	200	1.052
(5) Methyl Alcohol	0	0.82
	20	0.597
	30	0.510
	50	0.403
(6) Glycerine	20	1495
	25	942
	30	622
(7) Carbon disulphide	0	0.436
	20	0.4375
	40	0.329
(8) Castor oil	10	2420
	30	451
	50	125
(9) Carbon tetrachloride	0	1.348
	20	0.972
	40	0.744

APPENDIX A-7
Elastic properties of solids

Substance	Young's Modulus (10^{10} Nm^{-2})	Modulus of rigidity (10^{10} Nm^{-2})	Bulk Modulus (10^{10} Nm^{-2})
Aluminium	7.03	2.61	7.55
Brass (70/30)	10.06	3.73	11.18
Copper	12.98	9.83	13.78
Gold	7.8	2.7	21.7
Iron (soft)	21.14	8.16	16.98
Silver	8.27	3.03	10.36
Steel (mild)	21.19	8.22	17.92
Rubber	0.05	0.00015	-
Wood (oak)	1.3	-	-
Wook (teak)	1.7	-	-
Glass	5.1-7.1	3.1	3.75
Quartz	5.4	3.4	-

APPENDIX A-8
Velocity of sound

Substance	Temperature (0 °C)	Velocity of longitudinal wave (ms^{-1})	Substance	Temperature (0 °C)	Velocity of longitudinal wave (ms^{-1})
Alcohol	20	1177	Hydrogen	0	1284
*Aluminium	20	5240	*Iron	20	5170
Air	0	331.45	Mercury	20	1451
*Brass	20	3130-3450	Nitrogen	0	334
*Copper (annealed)	20	3790	*Steel (tool)	20	5150
Carbon dioxide	0	259	Water	20	1484
*Glass, crown	20	4710-5300	Water vapour	100	405
*Glass, flint	20	3490-4550	Oxygen	0	316

*In case of solids, velocities of longitudinal waves in thin rods are quoted.
For the gases for which v_0, the velocity of sound at 0 °C is quoted here, v_t the velocity at t °C with fair degree of accuracy, is $v_t = v_0 \left(\frac{273.15+t}{273.15}\right)^{\frac{1}{2}}$

APPENDIX A-9
Average speed of some selected objects

S.No.	Object	Speed
1.	Slug or snail	1.6 mm/s
2.	Tortoise	10 to 15 cm/s
3.	Man walking	80 to 160 cm/s
4.	Man riding a bicycle	2.5 to 5 m/s
5.	100 m race (International men's)	~10 m/s
6.	Railway train (fastest in India in 1988 - Shatabdi Express)	38.9 m/s
7.	Cheetah (the fastest land animal)	29 m/s
8.	Surjit (the fastest bird)	100 m/s
9.	Jumbo jet aeroplane	267 m/s
10.	Sound in air	331 m/s
11.	Near earth satellite	7.7 km/s
12.	Earth moving round Sun	29.9 km/s
13.	Light	300,000 km/s

APPENDIX A-10
Coefficient of friction between some common surfaces

Surfaces in contact	Condition	Coefficient of dynamic friction
Glass on glass	Clean and dry	0.18
Wood on glass	Clean and dry	0.2 to 0.3
Wood on wood	Clean and dry	0.25 to 0.5
Wood on steel	Clean and dry	0.20 to 0.25
Steel on steel	Clean and dry	0.17 - 0.23
Steel on steel	Greased	0.05
Stone on concrete	Dry	0.45
Car tyre on concrete	Moderate speed	0.40

APPENDIX A-11
Standard wire gauge

Size (S.W.G)	Diameter (mm)	Size (S.W.G.)	Diameter (mm)
1	7.62	21	0.813
2	7.01	22	0.711
3	6.40	23	0.610
4	5.89	24	0.559
5	5.38	25	0.508
6	4.88	26	0.457
7	4.47	27	0.417
8	4.06	28	0.376
9	3.66	29	0.345
10	3.25	30	0.315
11	2.95	31	0.295
12	2.64	32	0.274
13	2.34	33	0.254
14	2.03	34	0.234
15	1.83	35	0.213
16	1.63	36	0.193
17	1.42	37	0.173
18	1.22	38	0.152
19	1.02	39	0.132
20	0.914	40	0.122

APPENDIX A-12
Coefficient of expansion

Solids	Coefficient of linear expansion (10^{-6} K^{-1})	Liquids	Coefficient of volume expansion (10^{-4} K^{-1})
Aluminium	24	Alcohol (ethyl)	11.2
Brass	18 to 19	Alcohol (methyl)	12.2
Copper	16.7	Benzene	12.4
Constantan	18	Ether (ethyl)	16.3
Glass (Pyrex)	3	Glycerine	5.3
Glass (soft soda)	8.5		
Iron (cast)	10.0	Mercury	1.8
Iron (wrought)	12.0	Water (15 °C)	1.5
Ice	51.0	Water (99 °C)	7
Steel	11.0	Kerosene oil	10.0
Lead	23.0		
Zinc	28.0		

APPENDIX A-13
Specific heat of substances

Substance	Specific heat, $Jkg^{-1}K^{-1}$	Substance	Specific heat, $Jkg^{-1}K^{-1}$
Solids		*Liquids*	
Aluminium (0 °C)	877	Ethyl Alcohol	2436
Copper (0 °C)	380	Methyl alcohol	2562
Copper (50 °C)	390	Benzene	1680
Ice	2100	Ether	2352
Iron (cast)	500	Glycerine	2478
Iron (wrought)	483	Mercury	140
Steel	470	Water (15 °C)	4185.5
Lead	130	Brine (0 °C)	2970
Brass	380	Sea water (17 °C)	3930
Constantan	412		
Zinc (0 °C)	384		
Glass (crown)	670		
Glass (flint)	500		
Sand	1000 to 800		

APPENDIX A-14
Latent heat of fusion and vaporisation

Substance	10^4 Jkg^{-1}
(i) Latent heat of fusion	
Aluminium	40.2
Calcium	23.0
Copper	20.5
Gold	6.3
Iron	26.8
Lead	2.5
Mercury	1.17
Magnesium	37.7
Platinum	11.3
Silver	10.5
Sodium	11.3
Tin	5.8
Zinc	10.0
Water	33.4
(ii) Latent heat of vaporisation	
Acetic acid	40.5
Benzene	39.4
Carbon disulphide	35.1
Ether	35.1
Water (100 °C)	226.0
Water (30 °C)	243.0

APPENDIX A-15
Boiling point of distilled water

Pressure (10^5 Pa)	Boiling point (°C)
0.784	93.0
0.88	96.2
0.98	99.1
1.013	100.0
1.209	105.0
1.76	116.3
1.96	119.6

APPENDIX A-16
International practical temperature scale 1968

		K	°C
1.	Triple point of water	13.81	– 259.34
2.	Boiling point of hydrogen at pressure of 25 cm of mercury	17.042	– 256.108
3.	Boiling point of hydrogen	20.28	– 252.87
4.	Boiling point of neon	27.102	– 246.048
5.	Triple point of oxygen	54.361	– 218.789
6.	Triple point of argon	83.798	– 189.352
7.	Condensation point of oxygen	90.188	– 182.962
8.	Triple point of water	273.16	0.01
9.	Boiling point of water	373.15	100
10.	Freezing point of tia	505.1181	231.9681
11.	Freezing point of zinc	692.73	419.58
12.	Freezing point of silver	1235.08	961.93
13.	Freezing point of gold	1337.58	1064.43

Notes :

1. The regulations on the IPTS-68 were adopted by the International Committee on Weights and Measures in 1968.
2. Boiling points (condensation points) and freezing points, unless otherwise stated are at standard atmospheric pressure (i.e., 760 mm of mercury at 0°C or 101325 Pa).

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DATA SECTION

TABLE I

LOGARITHMS

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						5	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	12	16	20	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	29	33
12	0792	0828	0864	0899	0934						3	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	6	10	13	16	19	23	26	29
						1303	1335	1367	1399	1430	3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584						3	6	9	12	15	19	22	25	28
						1614	1644	1673	1703	1732	3	6	9	12	14	17	20	23	26
15	1761	1790	1818	1847	1875						3	6	9	11	14	17	20	23	26
						1903	1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	6	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405						3	5	8	10	13	15	18	20	23
						2430	2455	2480	2504	2529	3	5	8	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	17	19	21
						2672	2695	2718	2742	2765	2	4	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6471	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8

LOGARITHMS

TABLE 1 (*Continued*)

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7768	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9997	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS

TABLE II

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	3	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	3	4	5	6	6

ANTILOGARITHMS

TABLE II (*Continued*)

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	42S6	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	1314	
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20