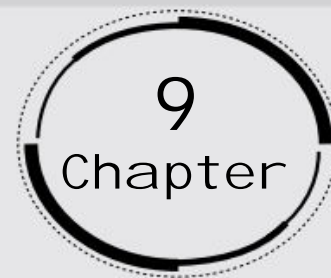


Mechanical Properties of Fluid



1. Explain why

a) The blood pressure in humans is greater at the feet than at the brain

Ans: The pressure of a liquid with density ρ , with the liquid column of h is given by the relation:

$$P = \rho hg$$

here g is the acceleration due to the gravity

It can be inferred that pressure is directly proportional to height. In the case of humans, the circulatory system can be considered as the liquid (blood)-column. The height of the column is the least at the head level and the maximum at the feet; hence, the pressure (blood pressure) in human vessels depends on this height. Thus, the blood pressure at the feet is more than what it is at the brain.

b) Atmospheric pressure at the height of about 6km decreases to nearly half of its value at the sea level, though the height of the atmosphere is more than 100km.

Ans. The density of a fluid depends on how much it has been pressed by the amount of fluid over it. This means that the density of air is the maximum near the sea level.

The density of air increases with a decrease in the height from the sea surface. At the height of about 6 km, the total mass squeezes the layer of air over here to nearly half of the pressure value at sea level.

In the case of just small changes in altitude, the atmospheric pressure is proportional to density. However, when larger height scales are considered, the density itself depends on the height, and the pressure isn't linearly dependent anymore.

Moreover, the pressure increases faster than the linear dependence expected in the case of small changes in altitudes.

c) Hydrostatic pressure is a scalar quantity even though pressure is force divided by area.

Ans: Mathematically, pressure is the perpendicular force per unit area. So, only the force component that is perpendicular to the surface or along the area vector

is used. The direction of this component and the direction of the area vector are the same.

Hence effectively, there is no direction involved anymore.

In other words, when force is applied to a liquid, the pressure in the liquid is transferred in all directions. Thus, the hydrostatic pressure does not have a fixed direction, and it is a scalar physical quantity.

2. Explain why

a) The angle of contact of mercury with glass is obtuse, while that of water with glass is acute

Ans: The angle between the surface inside the liquid and the tangent to the liquid surface at the point of contact is the angle of contact (θ), as shown in the following figure

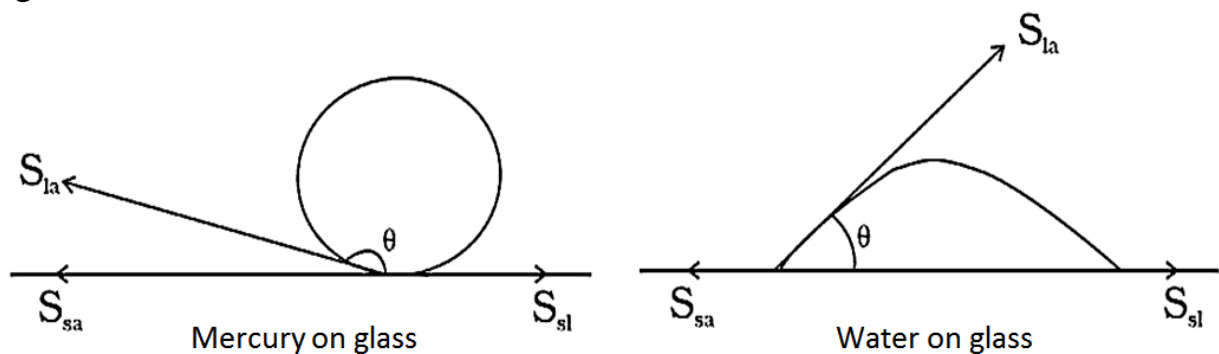


Image source: <https://goprep.co/the-angle-of-contact-of-mercury-with-glass-is-obtuse-while-i-1nk6rs>

Let S_{la} be the interfacial tension at the liquid-air interface, S_{sl} be at the solid-liquid interface, and S_{sa} be at the solid-air interface. At all the points of contact, the surface forces between the three media must be in equilibrium, i.e.,

$$\cos \theta = \frac{S_{sa} - S_{sl}}{S_{la}}$$

In the case of a mercury drop on glass, $S_{sl} > S_{sa}$, the angle of contact (θ) is obtuse.

In the case of water on the glass, $S_{sl} < S_{sa}$, the angle of contact (θ) is acute.

b) Water on a clean glass surface tends to spread out, while mercury on the same surface tends to form drops. (Put differently, water wets glass while mercury does not.)

Ans: The Mercury molecules have a strong force of attraction between themselves and a weak force of attraction toward solids. Hence, the angle of contact tends to become obtuse, and the molecules come closer and tend to form a drop.

While in the case of water, the ratio of attraction between water molecules and the attraction between water molecules and the glass is lower. Hence the water molecules stay closer to glass molecules as well, keeping the glass surface wet.

c) The surface tension of a liquid is independent of the area of the surface

Ans: Surface tension can be defined as the force acting per unit length at the interface between the liquid and any other material.

There is no dependency of this force on the area of the surface.

Hence, surface tension is independent of the area of the surface of the liquid.

d) Water with detergent dissolved in it should have small angles of contact.

Ans: Detergent water has small angles of contact (θ) because the detergent molecules are sticky; in other words, they are significantly attracted to the water molecules and the solid which is in contact with the detergent water.

Therefore, the molecules of water can get closer to the solid.

In other words, $S_{sl} < S_{la}$ and the value of $\cos\theta = \frac{S_{sa} - S_{sl}}{S_{la}}$ increases, leading to a decrease in the value of θ making it acute or small.

e) A drop of liquid under no external forces is always spherical in shape

Ans: Surface tension pulls the surface together as much as possible.

This means that in the absence of any other external force/pressure. The surface tension will try to shrink the area as much as possible.

Beyond a certain extent, the volume cannot be shrunk, and the shape with minimum surface area for the unchanged volume is a sphere.

Hence a droplet will tend to become spherical.

3. Fill in the blanks using the word(s) from the list appended with each statement:

a) Surface tension of liquids generallywith temperatures (increases / decreases)

Ans: decreases.

The surface tension of a liquid surface is inversely proportional to the motion of the liquid molecules. An increase in the temperature leads to an increase in the random motion of the molecules, and hence the surface tension drops

b) Viscosity of gases..... with temperature, whereas viscosity of liquids with temperature (increases / decreases)

Ans: increases; decreases

All fluids experience resistance to their motion when they are made to flow. This resistance is known as viscosity.

The motion of the gas molecules becomes very random, and giving them a direction gets difficult.

The viscosity of gases increases with the increasing random motion of the molecules. The molecules of the liquid are more restricted than and not as free as those of gas. Increasing the temperature of liquids increases the motion of the molecules, making them more mobile and improves their ability to flow.

Hence the viscosity decreases with an increase in temperature.

c) For solids with elastic modulus of rigidity, the shearing force is proportional to....., while for fluids it is proportional to(shear strain / rate of shear strain)

Ans: Shear strain; Rate of shear strain

For elastic solids, shearing force is proportional to the shear strain. However, the shearing force is proportional to the rate of shear strain in the case of fluids.

d) For a fluid in a steady flow, the increase in flow speed at a constriction follows..... (conservation of mass / Bernoulli's principle)

Ans: Conservation of mass/Bernoulli's principle

Bernoulli's principle works in the conservation of mass and energy, which includes the effects of the continuity equation. Hence, Conservation of mass and Bernoulli's Equation is the correct options.

e) For the model of a plane in a wind tunnel, turbulence occurs at a speed for turbulence for an actual plane (greater / smaller)

Ans: Greater

As provided in the question, there is a model of a plane in a wind tunnel. Following Bernoulli's Principle and referring to the relevant Reynolds number it can be seen that the turbulence occurs at a greater speed.

4. Explain why

a) To keep a piece of paper horizontal, you should blow over, not under, it

Ans: As per Bernoulli's principle, the fluid pressure reduces if the velocity is increased.

The paper falls under gravity, and to make it stay up and horizontal, we need to reduce the pressure on the top of it. For this reason. one should blow on the upper side of the paper.

b) When we try to close a water tap with our fingers, fast jets of water gush through the openings between our fingers

Ans: According to the continuity equation, for a flowing fluid, the rate of volume of fluid crossing any cross-section is constant. This means that the velocity of the flowing fluid is high if the cross-section of the passage is reduced. Covering the tap opening reduces the cross-section, and hence the water gushes out with a lot of speed.

c) The size of the needle of a syringe controls flow rate better than the thumb pressure exerted by a doctor while administering an injection

Ans: The liquid velocity at the needle is much higher than that inside the syringe. And higher velocity means much lower pressure.

Furthermore, the changes in the pressures at the different cross-sections are proportional to the pressures in the regions. A human thumb cannot constantly provide constant pressure. So the significant change in the pressures is carried to the needle end as well. The pressure over here changes proportionally.

But as mentioned before, the changes in the pressure at the needle end are proportional to the pressure at the needle end, which is very small.

Hence the absolute change in the pressure at the needle end is also minimal. Thus it can be said that the consistency of the pressure is controlled by the cross-section of the needle.

d) A fluid flowing out of a small hole in a vessel results in a backward thrust on the vessel

Ans: As the fluid flows out of a small orifice, its velocity is significantly high according to the continuity equation.

This outgoing liquid generates momentum.

Going by the law of conservation of momentum, a counter momentum is generated on the vessel, making it experience a backward thrust.

e) A spinning cricket ball in air does not follow a parabolic trajectory

Ans: A thrown spinning cricket ball has two motions – rotational and linear. The falling ball experiences viscosity in the upwards direction.

A rotating ball experiences viscosity due to the relative motion of the surface of the ball and the air in the vicinity. So at any instance, the face that is moving downwards faces an upwards viscosity force while the face going upwards faces a downwards viscosity force.

These viscous forces add up in such a way that the velocity of the air on one side of the ball is much higher than on their side, reducing the pressure on the side

which has a higher velocity.

This pressure imbalance causes a force directed towards the low-pressure region. Hence the ball deviates from the expected parabolic trajectory.

- 5. A 50kg girl wearing high heel shoes balances on a single heel. The heel is circular with a diameter 1.0cm . What is the pressure exerted by the heel on the horizontal floor?**

Ans: As provided, the mass of the girl, $m = 50 \text{ kg}$, the diameter of the heel

$$d = 1 \text{ cm} = 0.01 \text{ m}, \text{ the radius of the heel, } r = \frac{d}{2} = 0.005 \text{ m}$$

Therefore, the area of the heel, $A = \pi r^2$

$$\Rightarrow A = \pi \times 0.005^2$$

$$\Rightarrow A = 7.85 \times 10^{-5} \text{ m}^2$$

The force exerted by the heel on the floor is:

$$F = mg = 50 \times 9.8 = 490 \text{ N}$$

The pressure exerted on the floor by the heel:

$$P = \frac{F}{A} = \frac{490}{7.85 \times 10^{-5}} = 6.24 \times 10^6 \text{ Nm}^{-2}$$

Hence clearly, the pressure exerted by the heel on the horizontal floor is $6.24 \times 10^6 \text{ Nm}^{-2}$

- 6. Torricelli's barometer used mercury. Pascal duplicated it using French wine of density 984 kg / m^3 . Determine the height of the wine column for normal atmospheric pressure.**

Ans: Provided that,

Density of mercury, $\rho_1 = 13.6 \times 10^3 \text{ kg / m}^3$

The height of the mercury column,

$$h_1 = 0.76 \text{ m}$$

Provided density of French wine,

$$\rho_2 = 0.984 \times 10^3 \text{ kg / m}^3$$

Let the height of the column of wine = h_2

The acceleration due to gravity = $g = 9.8 \text{ ms}^{-2}$

The pressure in both the columns (given by ρhg) is equal at equal altitudes of the same liquid, which means:

$$\rho_1 h_1 g_1 = \rho_2 h_2 g_2$$

$$\Rightarrow h_2 = \frac{\rho_1 h_1 g_1}{\rho_2 g_2} = 10.5 \text{ m}$$

Thus, the height of the column of wine at normal atmospheric pressure is 10.5m

- 7. A vertical off-shore structure is built to withstand a maximum stress of 10^9 Pa . Is the structure suitable for putting up on top of an oil well in the ocean? Take the depth of the ocean to be roughly 3km, and ignore ocean currents**

Ans: Yes

As provided, the maximum allowable stress for the structure, $P = 10^9 \text{ Pa}$

Depth of the ocean, $d = 3 \times 10^3 \text{ m}$

The density of water, $\rho = 10^3 \text{ kg / m}^3$

The acceleration due to gravity, $g = 9.8 \text{ m / s}^2$

The pressure exerted because of water at depth,

$$P = \rho dg = 3 \times 10^3 \times 10^3 \times 9.8 = 2.94 \times 10^7 \text{ Pa}$$

Hence it has been calculated that the maximum allowable stress for the structure is significantly greater than the pressure of the water and hence can be used safely.

- 8. A hydraulic automobile lift is designed to lift cars with a maximum mass of 3000kg. The area of cross-section of the piston carrying the load is 425 cm^2 . What maximum pressure would the smaller piston have to bear?**

Ans: As provided, the mass limit on the mass of a car that can be lifted,
 $m = 3000 \text{ kg}$

The area of cross-section of the load-carrying piston, $A = 0.0425 \text{ m}^2$

The maximum force exerted by the load, $F = mg = 3000 \times 9.8 = 29400 \text{ N}$

The maximum pressure experienced by the piston that is carrying the load is,

$$P = \frac{F}{A} = \frac{29400}{425 \times 10^{-4}} = 6.917 \times 10^4 \text{ Pa}$$

Since the pressure is transferred/transmitted equally in all directions in a liquid, the maximum pressure on the smaller piston would be $6.917 \times 10^4 \text{ Pa}$.

- 9. A U -tube contains water and methylated spirit separated by mercury. The mercury columns in the two arms are in level with 10.0cm of water in one arm and 12.5cm of spirit in the other. What is the specific gravity of spirit?**

Ans: The provided system of water, mercury, and methylated spirit can be shown as follows:

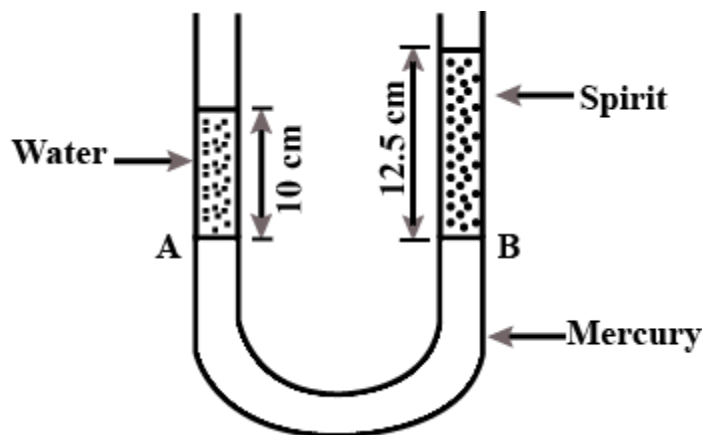


Image source: <https://www.toppr.com/ask/question/a-u-tube-contains-water-and-methylated-spirit-separated-by-mercury-the-mercury-columns-in/>

The height of the spirit column, $h_1 = 12.5\text{cm} = 0.125\text{m}$

The height of the water column is: $h_2 = 10\text{cm} = 0.1\text{m}$

P_0 = Atmospheric pressure, . Density of spirit, ρ_2 = Density of water

Pressure at point A, $P_0 + \rho_1 h_1 g$

Pressure at point B, $P_0 + \rho_2 h_2 g$

The values of pressures at points A and B are equal

$$P_0 + \rho_1 h_1 g = P_0 + \rho_2 h_2 g$$

$$\Rightarrow \frac{\rho_1}{\rho_2} = \frac{h_2}{h_1} = 0.8$$

Hence, clearly, the specific gravity of spirit is 0.8.

- 10. In problem 10.9, if 15.0cm of water and spirit each are further poured into the respective arms of the tube, what is the difference in the levels of mercury in the two arms? (Specific gravity of mercury = 13.6)**

Ans: Provided that,

Height of the water column, $h_1 = 10 + 15 = 25\text{cm}$

Height of the spirit column, $h_2 = 12.5 + 15 = 27.5\text{cm}$

The density of water, $\rho_1 = 1\text{g cm}^{-3}$; that of spirit, $\rho_2 = 0.8\text{g cm}^{-3}$ and that of mercury is 13.6g cm^{-3}

Now, let h be the difference between the levels of mercury in the two arms. The pressure exerted by the height h of the mercury column: $= \rho h g = h \times 13.6$

The difference between the pressures exerted by water and spirit:

$$\rho_1 h_1 g - \rho_2 h_2 g = g(25 \times 1 - 27.5 \times 0.8) = 3g$$

Equating the pressures, we get:

$$13.6 h g = 3g$$

$$\Rightarrow h = 0.220588 \approx 0.221 \text{ cm}$$

The difference between the levels of mercury in the two arms is 0.221 cm.

11. Can Bernoulli's equation be used to describe the flow of water through a rapid in a river? Explain.

Ans: Bernoulli's equation cannot describe the turbulent flow of fluids like that in a rapid river.

Water flow in a river is chaotic. Bernoulli's equation suggests that an increase in a fluid's velocity occurs concurrently with a decrease in static pressure or simultaneously with a reduction in potential energy throughout the water flow. This theory is only applicable to isentropic flows, wherein turbulence and other disturbances are ignored.

There are various versions of Bernoulli's equation with respect to various flow kinds. For instance, incompressible flows obey the simple form of Bernoulli's equation whereas compressible flows obey an advanced form of the equation. Bernoulli's theory is in accordance with the principle of energy conservation. Clearly, at each point on the flowing water in the river, the sum of any and all sources of energy is equal to that as in a steady flow. The sum for kinetic energy, internal energy and potential energy should also maintain stability. Thus, Bernoulli's equation cannot describe the flow of water through a rapid in a river.

12. Does it matter if one uses gauge instead of absolute pressures in applying Bernoulli's equation? Explain.

Ans: Gauge pressure gives us the pressure difference in the fluid under consideration and some standard pressure. Using gauge pressure will only tell us about the pressure difference.

Bernoulli's principle assumes that the pressures under consideration are linearly proportional to the square of the velocity and the height of the fluid.

However, the difference in pressure cannot be directly shown to have this proportionality. Hence, we need to convert the gauge pressure to absolute pressure before plugging it into Bernoulli's equation.

So yes, it matters if we use gauge instead of absolute pressures in applying Bernoulli's equation.

- 13. Glycerin flows steadily through a horizontal tube of length 1.5m and radius 1.0cm. If the amount of glycerin collected per second at one end is $4.0 \times 10^{-3} \text{ kg/s}$, what is the pressure difference between the two ends of the tube? (Density of glycerin $1.3 \times 10^3 \text{ kg/m}^3$ and viscosity of glycerin $= 0.83 \text{ Pa s}$). [You may also like to check if the assumption of laminar flow in the tube is correct].**

Ans: Provided that,

Length of the horizontal tube, $l = 1.5 \text{ m}$

The radius of the tube, $r = 1 \text{ cm} = 0.01 \text{ m}$

Thus, the diameter of the tube, $\therefore d = 0.02 \text{ m}$

As given in the question, Glycerine is flowing at a rate of $M = 4.0 \times 10^{-3} \text{ kg s}^{-1}$

The density of Glycerine, $\rho = 1.3 \times 10^3 \text{ kg m}^{-3}$

Viscosity of Glycerine $\eta = 0.83 \text{ Pa s}$

The volume of Glycerine flowing per sec:

$$V = M / \rho = \frac{4.0 \times 10^{-3}}{1.3 \times 10^3} = 3.08 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$$

According to Poiseuille's Law, we have the expression for the rate of flow:

$$V = \frac{\pi P r^4}{8 \eta l}$$

here, P is the pressure difference between the two ends of the tube

$$P = \frac{V 8 \eta l}{\pi r^4} = 9.8 \times 10^2 \text{ Pa}$$

Reynolds' number is given by the following expression:

$$\frac{4 \rho V}{\pi d \eta} = \frac{4(1.3 \times 10^3)(3.08 \times 10^{-6})}{\pi(0.02)0.83} = 0.3$$

Reynolds' number is about 0.3; therefore, the flow is laminar.

- 14. In a test experiment on a model aero plane in a wind tunnel, the flow speeds on the upper and lower surfaces of the wing are 70 m/s and 63 m/s respectively. What is the lift on the wing if its area is 2.5 m^2 ? Take the density of air to be 1.3 kg m^{-3} .**

Ans: The given speed of wind on the wing's upper surface, and the speed of wind relative to the wing's lower surface $v_2 = 63 \text{ m s}^{-1}$.

The area of the wing, $A = 2.5 \text{ m}^2$

The density of air, $\rho = 1.3 \text{ kg/m}^3$

Now, according to Bernoulli's theorem, we have the relation:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

In the current case, let P_2 be the pressure on the lower side of the wing and P_1 be the pressure on the upper side, and the v -s are the velocities mentioned initially. The required lift is the force that comes from the pressure difference in the lower and the upper surface.

This can be obtained as:

$$\text{Lift} = (P_1 - P_2)A = \left(\frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2 \right) A$$

$$\text{Lift} = \frac{1}{2}\rho(v_2^2 - v_1^2)A = \frac{1}{2}1.3(70^2 - 63^2)2.5 = 1.51 \times 10^3 \text{ N}$$

Hence, $1.51 \times 10^3 \text{ N}$ is the lift on the wing of the airplane.

15. Figures (a) and (b) refer to the steady flow of a (non-viscous) liquid. Which of the two figures is incorrect? Why?

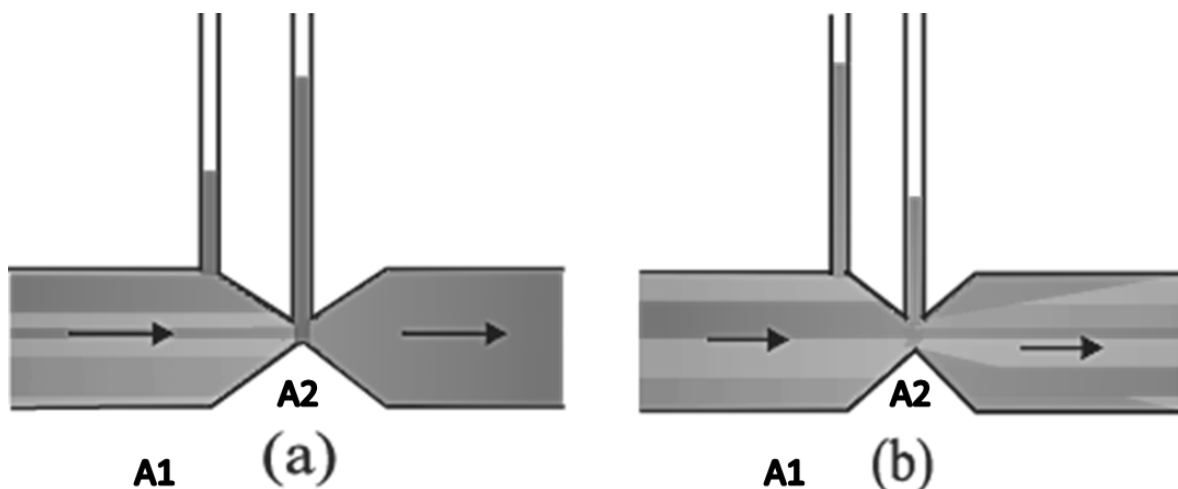


Image source: <https://www.meritnation.com/ask-answer/question/in-this-ncert-answer-the-figure-is-drawn-wrong-pls-exp/mechanical-properties-of-fluids/6861344>

Ans: Considering the second figure:

Let us say A_1 and A_2 are the cross-section areas of the pipe and the narrow region, respectively and V_1 and V_2 are the speeds of the fluid in the normal region of the pipe and at the narrow region, respectively

According to the law of continuity: $A_1 \times V_1 = A_2 \times V_2$

Hence it can be noted that the velocity of the liquid at the narrow region is higher than that in the normal region.

Now using Bernoulli's theorem, it can be said that the pressure is high in a region where the velocity is low. Hence the pressure at the normally thick (at A1) will be higher than that at A2.

Hence the column connected at this place will also have higher pressure at the point of contact. This is why the liquid column will also rise higher than the column connected at the narrow junction. Therefore, figure (b) is possible.

- 16. The cylindrical tube of a spray pump has a cross -section of 8.0cm^2 one end of which has 40 fine holes each of diameter 1.0mm . If the liquid flow inside the tube is 1.5mmin^{-1} , what is the speed of ejection of the liquid through the holes?**

Ans: Provided that,

Area of the cross-section of the spray pump $A_1 = 8 \times 10^{-4} \text{m}^2$

Number of holes, $n = 40$

Diameter of each hole, $d = 10^{-3} \text{m}$

The radius of each hole, $r = 0.5 \times 10^{-3} \text{m}$

Area of the cross-section of each hole, $a = \pi r^2 = \pi(0.5 \times 10^{-3})^2$

The total area of 40 holes, $A = n a = n\pi r^2 = 31.41 \times 10^{-6} \text{m}^2$

The speed of flow of liquid inside the tube, $v_1 = 1.5 \text{m} / \text{min} = 0.025 \text{m} / \text{s}$

The liquid is ejected through the holes at the speed of v_2

According to the continuity equation, we have $v_2 = \frac{A_1 v_1}{A_2} = 0.633 \text{ m/s}$

Therefore, it has been calculated that the speed of ejection of the liquid through the holes is 0.633 m/s .

- 17. A U -shaped wire is dipped in a soap solution, and removed. The thin soap film formed between the wire and the light slider supports a weight of $1.5 \times 10^{-2} \text{N}$. (Which includes the small weight of the slider). The length of the slider is 30cm . What is the surface tension of the film?**

Ans: The weight that the soap film supports, $W = 1.5 \times 10^{-2} \text{N}$

Length of the slider, $l = 0.3\text{m}$

A soap film has two free surfaces.

Therefore, the total length $= 2l = 0.6\text{m}$

Hence the surface tension is obtained as

$$S = \frac{\text{Force}}{2l} = \frac{1.5 \times 10^{-2} \text{N}}{0.6\text{m}} = 2.5 \times 10^{-2} \text{N} / \text{m}$$

Therefore, the surface tension of the film is obtained as $2.5 \times 10^{-2} \text{ N / m}$.

18. Figure 10.24 (a) shows a thin liquid film supporting a small weight $4.5 \times 10^{-2} \text{ N}$. What is the weight supported by a film of the same liquid at the same temperature in Fig. (b) and (c)? Explain your answer physically

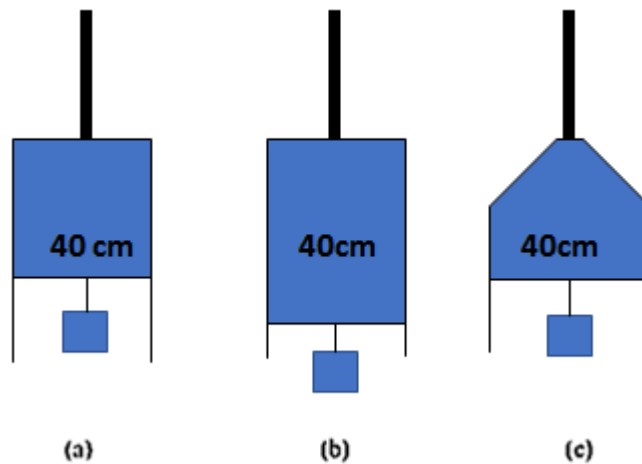


Image source: self-made

Ans: For case (a):

The length of the liquid film is supported by the weight $l = 40 \text{ cm} = 0.4 \text{ m}$.

The weight supported by the film, $W = 4.5 \times 10^{-2} \text{ N}$

Every liquid film has two free surfaces. Hence the surface tension can be calculated as

$$S = \frac{\text{Force}}{2l} = \frac{4.5 \times 10^{-2} \text{ N}}{2 \times 0.4 \text{ m}} = 5.625 \times 10^{-2} \text{ N / m}$$

Since the properties of the liquid are the same in all the cases., the surface tension in all three cases is equal. And the weight supported is also the same in all three cases, i.e., $= 5.625 \times 10^{-2} \text{ N / m}$.

19. What is the pressure inside the drop of mercury of radius 3.0mm at room temperature? Surface tension of mercury at that temperature (20°C) is $4.65 \times 10^{-1} \text{ Nm}^{-1}$. The atmospheric pressure $1.01 \times 10^5 \text{ Pa}$. Also give the excess pressure inside the drop.

Ans: As provided, the radius of the mercury drop, $r = 3 \times 10^{-3} \text{ m}$

The surface tension of mercury, $S = 4.65 \times 10^{-1} \text{ N / m}$

The atmospheric pressure, $P_0 = 1.01 \times 10^5 \text{ Pa}$

Total pressure inside the mercury drop = Excess pressure inside mercury + Atmospheric pressure

$$\text{Total pressure} = \frac{2S}{r} + P_0 = \frac{2 \times 4.65 \times 10^{-1}}{3 \times 10^{-3}} + 1.01 \times 10^5 = 1.013 \times 10^5 \text{ Pa}$$

Hence the excess pressure is obtained as $= \frac{2S}{r} = 310 \text{ Pa}$.

- 20. What is the excess pressure inside a bubble of soap solution of radius 5.0mm, given that the surface tension of soap solution at the temperature (20°C) is $4.65 \times 10^{-1} \text{ Nm}^{-1}$. If an air bubble of the same dimension were formed at the depth of 40.0cm inside a container containing the soap solution (of relative density 1.20), what would be the pressure inside the bubble? (1 atmospheric pressure is $1.01 \times 10^5 \text{ Pa}$).**

Ans: As provided in the question, the excess pressure inside the soap bubble is 20 Pa;

The pressure inside the air bubble is $= 1.06 \times 10^5 \text{ Pa}$

A soap bubble is of radius, $r = 5 \times 10^{-3} \text{ m}$

The surface tension of the soap solution, $S = 2.5 \times 10^{-2} \text{ N / m}$

Also, the relative density of the soap solution = 1.20

Thus, the density of the soap solution, $\rho = 1.2 \times \rho_{\text{air}} = 1.2 \times 10^3 \text{ kg / m}^3$

It is given that the air bubble is formed at a depth, $h = 40 \text{ cm} = 0.4 \text{ m}$

The radius of the air bubble, $r = 5 \times 10^{-3} \text{ m}$

Acceleration due to gravity, $g = 9.8 \text{ m / s}^2$

Therefore, it can be noted that the excess pressure inside the soap bubble is given by:

$$P = \frac{4S}{r} = 20 \text{ Pa}$$

The excess pressure inside the air bubble can be written as:

$$P = \frac{2S}{r} = 10 \text{ Pa}.$$

The total pressure inside the air bubble under consideration is the sum of the atmospheric pressure, the pressure due to the column of the liquid and the excess pressure:

$$P_{\text{total}} = P_0 + h\rho g + P = 1.057 \times 10^5 \text{ Pa}$$

Hence, the pressure inside the air bubble is $1.057 \times 10^5 \text{ Pa}$.