Surface Tension

1991 A/L

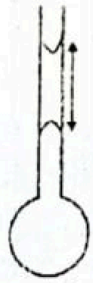
1) Define surface tension. Describe briefly a laboratory method to determine the surface tension of water using capillary rise.
A glass tube of internal radius 12 mm wall thickness 0.4 mm and open at both ends, is suspended vertically from a sensitive spring balance. A beaker containing a liquid is now brought slowly so that the surface of the liquid just touches the lower end of the suspended glass tube. What happens to the reading of the balance? Explain your answer.
The beaker of liquid is then raised until the original reading is seen again on the balance. If the depth of immersion of the tube is 3.67 cm, calculate the surface tension of the liquid assuming that the angle of contact of the liquid with glass is zero. Density of liquid is 1000 kgm^{-3}.

1993 A/L

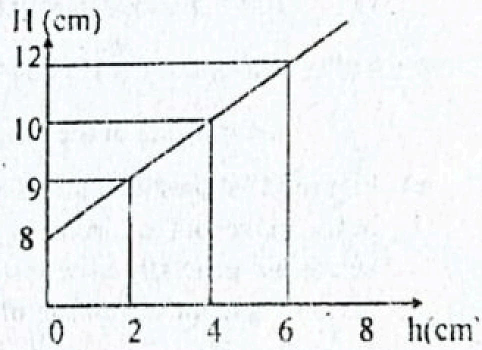
2) Draw a labeled diagram of the apparatus used to determine the surface tension of a liquid using the Jaeger's method. Give the essential steps of this experiment. Write down the equation which would enable you to determine the surface tension, indicating clearly the quantities involved. What are the advantages of this method?
A bucket with a flat base has a small circular hole of radius 0.1 mm at its base and contains 5 cm of oil of density 800 kg m^{-3} and surface tension 0.03 Nm^{-1}. Show that the oil will not flow out of the hole.
If this bucket without any oil is now pushed vertically down into water, at what depth will the water start to flow into the bucket through the hole. The surface tension of water is 0.075 Nm^{-1} and its density is 10^3 kgm^{-3}

1996 A/L

3) A vertical narrow tube carries a soap bubble of radius 0.1 cm at its lower end, and the air inside the bubble is trapped by a column of the soap solution of length 1 cm as shown in the figure.
Take density of the soap solution as 1000 kg m^{-3}



(i) If the angle of contact at both menisci of the liquid column is zero, calculate the surface tension of the soap solution.
(ii) When the soap bubble is broken it was found that the maximum length of the column of the soap solution that can be kept inside the vertical tube without falling is 3 cm. Calculate the internal radius of the tube.
(iii) Now the soap column is removed and the tube is partially dipped in a liquid so that its lower end is at a depth h below the liquid surface. When the air pressure inside the tube is then gradually increased, and measured with a manometer it is found that the maximum level difference of the manometer liquid, that can be achieved is H. If the variation of H with h is as shown in the figure, calculate the surface tension of the liquid.
Density of the manometer liquid = 6.0×10^2 kgm^{-3}



1999 A/L

4) A soap film is formed on a wire frame. A loop made with and elastic string of unstretched length 10 cm is kept on the surface of the film and the film inside the loop is broken. The cross-sectional area of the string is 1.25×10^{-9} m^2 and the Young's modulus of the material of the string is 7.0×10^6 Nm^{-2}. Surface tension of the soap solution is 2.5×10^{-2} Nm^{-1}
(i) Calculate the diameter of the loop
(ii) What is the change in surface energy of the film?
(iii) Calculate the energy stored in the string.
(iv) If one half of the length of the string was made with an inextensible string, draw the shape of the loop when the film inside is broken

2003 A/L

5) (i) Three glass capillary tubes are immersed partially in three liquids A, B and C, in which the angles of contact with glass are 30^0, 90^0 and 130^0, respectively. If the tubes are immersed vertically, in each of the above cases, draw the liquid level outside the tube, liquid level inside the tube and the shape of the liquid meniscus in the tube. Clearly indicate the directions of surface tension forces acting on the liquid in the tube and mark the angles of contact.

(ii) A glass tube of inner radius (r) 0.5 mm is immersed vertically in a container of mercury such that the lower end of the tube remains 10 cm below the surface of mercury in the container. The surface tension (T) and the density of mercury (ρ) are $0.465\ Nm^{-1}$ and $13.6 \times 10^3\ kg\ m^{-3}$ respectively and the angle of contact (θ) between mercury and glass is 140^0. The atmospheric pressure is $1.0 \times 10^5\ N\ m^{-2}$. Gravitational acceleration (g) is $10\ ms^{-2}$

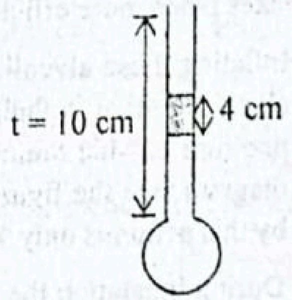
(a) Derive an expression of the difference (h) between mercury levels of the tube and the container in terms of r, T, ρ, θ and g. Hence calculate h [$\cos 40^0 = 0.766$]

(b) What must be the pressure of air in the tube in order to form a hemispherical meniscus at the lower end of the tube?

(iii) Oil in a hot cup of soup floats in little oil bubbles on the surface of the soup, but when the soup cools the oil spreads over the surface of the soup. Explain the above observations in considering the variation of surface tension of water and oil with temperature.

2005 A/L

6) A soap bubble of radius $R = 2.5$ mm is formed at the lower end of a narrow vertical glass tube of length $l = 10$ cm and internal radius $r = 0.8$ mm. The soap bubble is kept at equilibrium by having a small column of the same soap solution of length 4.0 mm as shown in the diagram.



i) Calculate the surface tension T of the soap solution. Assume that the density of the soap solution is $1050\ kgm^{-3}$ and the angle of contact between glass and the soap solution is zero.

ii) a) If now the bubble is broken and the height of the liquid column is gradually increased by adding soap solution, calculate the height at which the lower meniscus becomes flat.

b) What is the maximum height of the liquid column that can be kept inside the tube?

iii) When a soap bubble of radius R is formed at the lower end of the narrow tube described above without trapping the air by a columns of the soap solution, air will escape through the upper end of the tube and the radius R of the bubble will decrease with time t according to the equation.

$$R^4 = \frac{-Tr^3}{2\eta l} t + A$$

Where A is a constant and η is the viscosity of air.

A student decides to find the viscosity of air by finding the racius of the bubble at different times. Since it was difficult to measure the diameter of the bubble directly, the student obtains a real image of the bubble on a screen using a convex lens. His observations are as follows

Distance between the soap bubble and the lens = 15.0 cm

Distance between the lens and the screen = 27.0 cm

Time (s)	Diameter of image
0	51.0 mm
30	36.5 mm

a) Find the radius of the soap bubble at $t = 0$ and $t = 30$ s, to the nearest mm.

b) Using the value of T obtained is (i) find a value for the viscosity of air.

2006 A/L

7) Read the following passage carefully and answer the questions given below.

The exchange of oxygen and carbon dioxide in the lungs takes place across the surfaces membranes of small balloon-like structures (see the figure1) called alveoli. There are abut 150 million alveoli in each lung. The presence of a large number of alveoli increases the effective surface area and thereby the exchange of air takes place more efficiently.

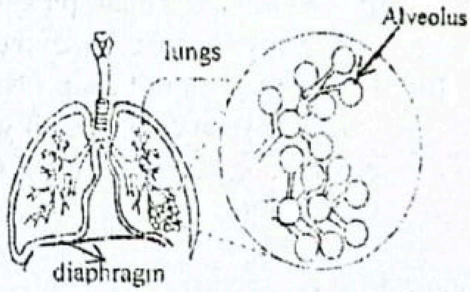


figure 1

Inflating these alveoli in the process of inhalation requires an excess pressure inside the alveoli relative to their surroundings. This pressure difference is achieved by making the pressure outside the alveoli less with respect to the atmospheric pressure by moving the diagram (see the figure 1) down. The maximum pressure difference that could be proved by this action is only 1.0 mm Hg.

During inhalation the radius of an alveolus normally increases from 0.05 mm to 0.10mm. The lining the inner surface of alveoli has a surface tension of 5.0×10^{-2} Nm^{-1}. The 1.0 mm Hg pressure change occurring due to the movement of the diaphragm is not sufficient to inflate an alveolus from 0.05 mm to 0.10 mm. Therefore these alveoli are fully by secreting a surface tension reducing liquid (surfactant) and thereby lowering the surface tension of the above mentioned fluid to about $\frac{1}{15}$. Once the surface tension of the fluid is reduced, a pressure change of 1.0 mm Hg is sufficient to inflate the alveoli fully. Another very important function of the surface reducing , liquid is to avoid all small being collapsed into one large alveolus.

All alveoli do not have the same size. If the surface tension, of the fluid takes the same value everywhere, air from smaller alveoli would flow into larger alveoli. This process would continue till the entire lung, is converted into one giant alveolus. But this does not happen because of the surface tension reducing liquid.

Consider two alveoli, one with radius r and another with radius R ($r < R$) connected together like two bubbles as shown in figure 2.

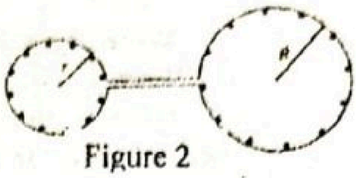


Figure 2

The number of molecules of the surface tension reducing liquid, shown as black dots, is the same in both alveoli, but its distribution is more dense (more liquid molecules on a unit surface area) in the small alveolus. Therefore the reduction of the surface tension is more in the small alveolus than that in the large one. Due to this, the internal pressures could be maintained at the same value i both alveoli and the smaller alveolus would both collapse. into the larger one.

(i) What is the advantage of having a large number of small alveoli in a lung, instead of one big alveolus ?

(ii) a) Taking the radius of a single inflated alveolus to be 0.1 mm, calculate the total surface area of 1.5×10^8 number of such alveoli. (Take $\pi = 3$)

b) If a lung is made of one large spherical alveolus, estimate the radius that the lung should have in order to achieve the surface area calculated in (ii) a) above. (Take $\pi = 3$ and $\sqrt{1.5} = 1.22$)

(iii) a) Take the excess pressure inside an alveolus to be $\frac{2T}{r}$. Here T is the surface tension of the fluid (5.0×10^{-2} Nm^{-1}) without surfactant, and r is the radius of the alveolus. Calculate the excess pressure. (ΔP_1) that should be inside the alveolus to make $r = 0.05$ mm. Similarity calculate the excess pressure (ΔP_2) that should be inside the alveolus to make $r = 0.10$ mm.

b) Calculate the difference of these excess pressures ($\Delta P_1 - \Delta P_2$) in mm of Hg. (1 Pa = 7.5×10^{-3} mm Hg)
Hence show that this pressure difference cannot be achieved only by moving the diaphragm.

c) Show that with low surface tension $\left(\frac{5.0}{15} \times 10^{-2}\, Nm^{-1}\right)$ in the fluid due to secretion of the surface tension, reading liquid, 1.0 mm Hg pressure difference is sufficient to fully inflate the alveolus.

(iv) Now draw your attention to the figure 2 of the paragraph.

a) Why is the reduction of surface tension is more in the small alveolus than that of the large alveolus due to the secreted liquid?

b) If the effective surface tensions with the secreted liquid in the small alveolus and the large alveolus are T_r and T_R respectively, obtain an expression which should have for the ratio $\frac{T_r}{T_R}$, in terms of r and R, in order to prevent air flowing from the small alveolus to the large alveolus. Assume that the pressure outside both alveoli is the same.

c) i) An expression for the effective surface tension, T_r can be written as.

$$T_r = 5.0 \times 10^{-2} - \frac{k}{r^2}, \text{ when } k \text{ is a constant.}$$

Write down the dimension of k.

ii) Write down a similar expression for T_R

d) Using these two expression and the relationship obtained in (iv) (b) above determine values for T_r and T_R. (Take $r = 0.5$ mm and $R = 1.0$ mm)

2011 A/L

8) (a) A capillary tube of internal radius r, is immersed vertically in water under atmospheric pressure. Show that the value of the capillary rise h in the tube is given by $h = \frac{2T}{\rho g r}$ when T is the surface tension of water and ρ is the density of water. Take the contact angle between water and the material of the tube to be zero.

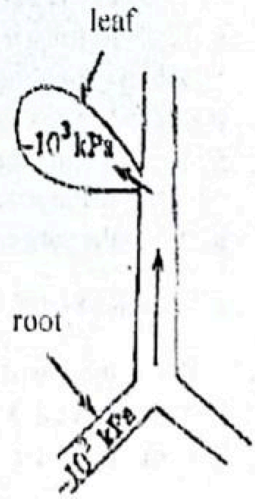
(b) In plants. water ascends through capillaries, known as xylem tubes. When answering parts (b) (i) and (b) (ii) consider a, xylem tube having both ends open to atmospheric pressure.

(i) Calculate the height to which water rises in such a capillary of radius 100μm. (Surface tension of water $= 7.2 \times 10^{-2}$ N m^{-1} density of water $= 10^3$ kg m^{-3})

(ii) Water rises up to height of even 100 m in tall trees. If water goes up the zylem tubes due to capillary action alone. calculate the internal radius of a capillary that would raise water by 100 m to the to of a tree.

(c) However scientists have never found such small capillaries calculated in (b) (ii) above in tree xylem. Therefore capillary action cannot be solely responsible for water getting to the top of tress.

To explain how water ascends from roots in leaves, scientists use the concept known as the water pressure (water potential per unit volume). At standard temperature and pressure, pure water is given a water pressure of zero. Adding solute molecules to the water has the effect of lowering the water pressure, i. e making it negative. When water evaporates from leaf tissues it raises the solute concentration of water in leaves. This results the water pressure of leaves to be relatively low compared with the water pressure at roots. This water pressure gradient pushes the water up from roots to leaves.



(i) The figure shows a root and a leaf of a tree. If the water pressures of the root and the leaf are -10^2 kPa and -10^3 kPa respectively, estimate the height of the water column that can be sustained by this pressure difference. Neglect the surface tension of water.

(d) (i) Assuming the water flow in the zylem tube (internal radius = 100 μm) to be streamlined, use the Poiseuille's equation to determine the average speed of rising water. Neglect the weight of the rising water column. Viscosity of water $= 10^{-3}$ Pa s. Take the length of the zylem tube to be equal to the height calculated in (c) (i) above.

(ii) Calculate the power needed ot raise this water column up in the zylem tube. (take $\pi = 3$)

9) Read the passage below and answer the questions given.

The magnitude of the contact angle of water depends on the nature of the surface with which water is in contact. Water drops can settle on certain ideally flat surfaces so that the angle of contact is less than 90°. Such a surface is known to have been wetted by water and acts as a hydrophilic surface.

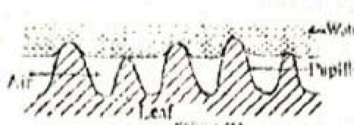


Figure (1)

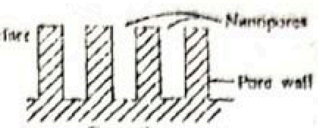
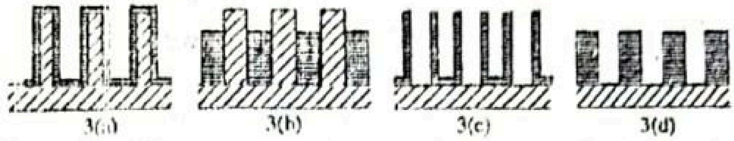


Figure (2)


3(a) 3(b) 3(c) 3(d)

However, some surfaces consisting of rough structure at micro/nano scale can act as hydrophobic surfaces showing non-wetting properties.
The lotus leaf, compared to other natural leaves, shows superhydrophobic properties with a contact angle of water greater than 150° and remains clean in muddy, dirty ponds and tanks. When rain drops fall on the surfaces of lotus leaves, instead of wetting the leaf, they immediately bead up like shiny spherical balls and roll off the surface even at the slightest disturbance, collecting dirt and debris away. This water repellent self cleaning property of lotus leaf is known as the "Lotus effect"

The lotus effect arises due to the dual scale micro/nano structures present in the lotus leaf. Covering its surface, the lotus leaf has a series of protrusions (parts that stick out like bumps) called papillae that are nearly 10 μm in height. Each papilla is covered with a nano-metre scale thick superhydrophobic waxy layer. The roughness introduced by papillae allows air to be trapped under water drops as shown in figure (1) contributing to the non-wetting behaviour of the leaf. Using the lotus effect, a variety of surfaces has been patterned to produce roughened hydrophobic surfaces with high contact angles of water necessary for water repellent window glasses, self cleaning clothes and paints, and low-drag (show low resistance by water against motion) marine vessels, etc. Wettability of a surface also depends on the nature of the liquid. Some liquids wet roughened surfaces whereas, some liquids show non-wetting properties. Property of wetting of roughened surfaces by liquids is used to fabricate nano-structures such as nanotubes and nanorods by means of the technique known as 'template wetting nano fabrication'. This technique uses a solid template that contains an array of nanopores as shown in figure (2).
A non-wetting liquid does not penetrate the pores and settles on the protrusions of the template whereas, a wetting liquid penetrates into pores by wetting walls and filling the pores. When nanopores are filled with a wetting solvent that contains a desired solid and the template is heated, due to evaporation of the solvent, the solid is left behind on the pore walls or in the nanopores as shown in figures 3(a) and 3(b) respectively. Removal of pore walls of the template by a chemical treatment known as etching will leave behind structures with nano-tubes or nanorods as shown in figures 3(c) and 3(d), respectively.

(a) Write down three applications of artificially fabricated hydrophobic surfaces.

(b) How does the lotus effect help to remove dirt from the surface of a lotus leaf?

(c) How do you categorise hydrophilic, hydrophobic and superhydrophobic surfaces in terms of the contact angle of water?

(d) Show using a diagram how a wetting liquid and a non-wetting liquid settles on an ideally flat solid surface.

(e) By copying the rough surface in figure (2) draw diagrams to show how a wetting liquid and non-wetting liquid settles on it.

(f) When dew begins to form, do you expect water molecules to condense in the pores on the surface of a lotus leaf? Give reasons for your answer.

(g) State the effect of employing roughened hydrophobic surfaces on low-drag marine vessels.

(h) Mention two nano-structures that can be fabricated using the technique 'template wetting nano fabrication'.

(i) Consider a parallel gold plate capacitor having plates consisting of gold nanorods of diameter of 100 nm and height of 50 μm with 10^{12} nanorods per square meter. Assuming that the capacitance of this capacitor increases due to the increase in the effective surface area, calculate by what factor would the capacitance increase compared to a gold plate capacitor without nanorods, but has identical dimensions. Assume that the separation between capacitor plates is much greater than the height of a nanorod.

2017 A/L

10) Read the following passage and answer the questions.

Instability of soil that occurs due to the infrastructure developments such as road constructions in mountain regions without proper study, can create problems such as sinking roads and landslides. Landslides are now a common tragedy in many parts of the country during rainy seasons. The stability of sand, a constituent of soil, heavily depends on the amount of water present in the sand. Anyone who has built structures such as 'sandcastles' using wet sand knows that the adhesive properties of wet and dry sand are very different. Wet sand can be used build sharp-featured sandcastles whereas dry sand just crumbles down in this process. Some of the aspects these phenomena related to the stability of soil or sand can be explained by fundamental physics concepts such as gravity, friction and surface tension.

Soil is generally a porous medium comprising a mixture of mineral particles such as clay, silt and sand of different sizes, and voids. Voids are filled with either air or water as shown in figure 1(a). The porous nature of soil can create practical problems, such as sinking of heavy structures on the ground. This occurs due to the compression of voids caused by the heavy loads on the ground. Leaning of Pisa tower and sinking of the Meethotamulla dump site and the earth in the vicinity of the Uma Oya tunnel are a few

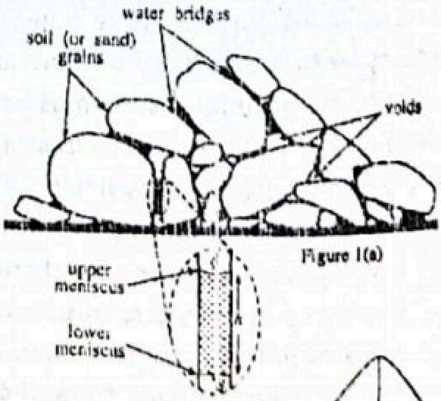


Figure 1(a)

Figure 1(b)

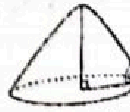


Figure (2)

examples. Another important parameter which determines the stability of soil (or sand) is the angle of repose. When a bucket of dry soil is emptied on to a hard leveled floor the soil particles slide easily and form a conical pile due to the friction between grains as shown in figure (2).

The angle α of the pile is known as the angle of repose which is the steepest stable slope that a particular substance can form. Removal of soil from the base of slope, increasing the angle of repose, can create instability on the slope.

Sand in soil can be considered as a porous medium. I consists of a system of randomly oriented complex capillary tubes of different sizes similar to the structure shown in figure 1(*a*). Capillary forces draw water into the sand changing the physical properties of sand medium. Damp sand forms capillary water bridges between its grains (see figure 1(*a*)). Nanometer - scale water bridges between millimeter - scale grains dramatically increase the attraction between grains. It is due to the adhesive forces associated with the water bridges between grains. Dry sand grains maintain stability due to frictional forces, and in addition wet sand grains attract each other due to adhesive forces. The enhancement of the attraction of the grains due to these capillary forces leads to the increase of the repose angle creating sand clumps. The surface of a water bridge is concave (figure 1(*b*)) and so generates 'capillary action' which helps to hold the sand grains firmly together due to surface tension.

During rainy season the soil saturated with water creates high pressure on the voids and grains. Gradually increasing the pressure inside voids increases the curvature of the surface of water bridges decreasing the capillary force between the grains. The addition of more water to the soil can decrease friction and strength between the grains, and increase the weight of the soil making an ideal situation for landslides. Damage on the Earth's soil surface due to the addition of large amounts of pesticides and fertilizers decreasing the surface tension force between the grains can also dramatically increase the likelihood of a landslide.

a) Name **three** fundamental physics concepts which can be used to explain some aspect of the stability of soil and sand.

b) Write down **three** main mineral constituents of soil.

c) In a road construction, soil has been removed from a certain section of the slope altering the natural slope as shown in figure (3). This is a vulnerable place for landslides. Explain this using the information given in the passage.

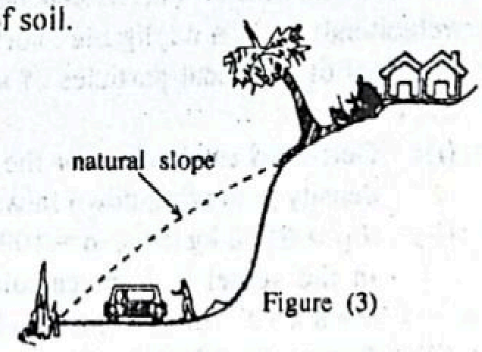


Figure (3)

d) Addition of water into dry sand dramatically increases the stability of sand. Explain the main reason for this.

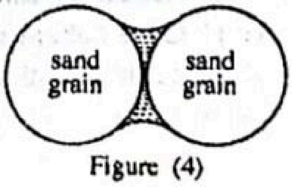


Figure (4)

e) A water bridge between two spherical sand grains is shown in figure (4). Copy the figure (4) to your answer script and draw the **resultant** reaction forces (using arrows) on each grain due to the surface tension

f) Consider a water bridge formed by two sand grains shown in figure 1(b) where the radii of curvature of the upper and lower miniscii are r_1 and r_2 respectively. Using the expressions for the pressure differences across the upper and lower air-water interfaces, derive an expression for the height h of the water column in figure 1(b). Take surface tension and density of water as T and d respectively. Assume that the pressures at points A and B, shown in the figure, are **equal.**

g) Calculate the height h for the situation mentioned in (f) above. Take $r_1 = 0.8\ mm$, $r_2 = 1.0\ mm$, $T = 7.2 \times 10^{-2}\ Nm^{-1}$ and $d = 1.0 \times 10^3\ kgm^{-3}$.

h) Consider a situation where the pressures at points A and B are **higher** than the situation shown in figure 1(b). Copy the figure 1(b), **including the two meniscii**, to your answer script and draw the shapes of the two new meniscii and **clearly** label them as X and L.

i) If the pressures at points A and B, shown in figure 1(b), are continuously increasing, what will happen to the radii of the meniscii, contact angle and the resultant reaction forces due to the surface tension forces between the grains? Explain your answer.

j) Write down **two** human activities mentioned in the passage, which can increase the likelihood of landslides.