SURFACE TENSION

Why can a steel needle float but a larger piece of steel sink?

Ducks have drowned in farmyard ponds into which washing water was emptied or in streams polluted with non-degradable detergents. Why?

Why can insects walk on water?

The surface of any liquid behaves as though it is covered by a stretched membrane. Small insects can walk on water without getting wet. The membrane is obviously quite strong: it will support dense objects, provided they are small and of the right shape - a needle, a small square of aluminium sheet, a razor blade, a container made of fine wire gauze and small insects. The strength of the surface membrane can be imagined to arise from a set of forces acting on each point of the surface, parallel to the surface, like the skin of a drum. These cohesive forces act between molecules of the substance without chemical bonding.
Cohesion: attractive forces between “like” molecules

Surface of any liquid behaves as though it is covered by a stretched membrane. The net force on a molecule at the surface is into the bulk of the liquid. The surface of a liquid behaves as an elastic rubber membrane (spring). If you try to pull a molecule from the surface an attractive restoring force due to cohesive forces acts on the molecule. If a surface molecule is depressed slightly into a liquid, then the molecule experiences a repulsive restoring force.

Why are soap bubbles spherical?

How do you make lead shot (small spherical lead balls)?

What is the difference between wet and dry hairs on a brush?
What is the difference when you hair is wet compared to when dry?

**Which shape corresponds to a soap bubble?**

Surface of a liquid acts like an elastic skin ⇒ minimum surface potential energy ⇒ minimum surface area for given volume

Generally, a system under the influence of forces moves towards an equilibrium configuration that corresponds to minimum potential energy. The sphere contains the most volume for the least area ⇒ minimum surface potential energy. There are no cubic raindrops.

The force $F_T$ a liquid surface exerts on an object that is in intimate contact with it is directly proportional to the length of the line of contact, $L$. The constant of proportionality $\gamma$ is called the **coefficient of surface tension of the liquid**.

$$F_T = \gamma L$$

Hence the coefficient of surface tension can be expressed

$$\gamma = \frac{F_T}{L}$$
**FLOATING NEEDLE**

Not a buoyancy phenomena

\[ F_T = 2 \gamma L \]

Length of needle, \( L \)

**Surface tension acts along length of needle on both sides**

Coefficient of surface tension \( \gamma \)

Equilibrium

\[ F_T = F_G \]

Why is it better to use hot soapy water to wash clothes in?

The strength of the membrane varies for different liquids, e.g. it is much less for soapy water than pure water. Substances that reduce surface tension of a liquid are called **surfactants**. Adding soap or detergent to water reduces the surface tension. Washing clothes: water must be forced through tiny spaces between the fibres and small crevices. To do this more effectively use hot soapy water.

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Surface Tension ( \gamma ) (N.m(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>water (20°C)</td>
<td>0.073</td>
</tr>
<tr>
<td>water (100°C)</td>
<td>0.059</td>
</tr>
<tr>
<td>soapy water (20 °C)</td>
<td>0.025</td>
</tr>
<tr>
<td>alcohol</td>
<td>0.022</td>
</tr>
<tr>
<td>glycerine</td>
<td>0.063</td>
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A thin, circular wire of diameter 40 mm and total mass of 0.70 g is gently pulled vertically from a water surface by a sensitive spring \( (k = 0.70 \text{ N.m}^{-1}) \). When the spring is stretched 34 mm from its equilibrium position in air the ring is on the verge of being pulled free from the water surface. Find the coefficient of surface tension of water. Neglect the mass of water lifted.

\[
k = 0.70 \text{ N.m}^{-1}
\]

\[
x = 34 \times 10^{-3} \text{ m}
\]

radius of ring
\[
R = 20 \times 10^{-3} \text{ m}
\]

mass of ring
\[
m = 7.0 \times 10^{-4} \text{ kg}
\]

spring restoring force = \( F_e = k x \)

weight of ring = \( F_G = m g \)

surface tension force = \( F_T = \gamma L \)

coefficient of surface tension = \( \gamma = ? \text{ N.m}^{-1} \)

The length of contact \( L \), with the water surface is **twice** the circumference of the ring since there is water on **both** sides of the ring.

\[
L = 2(2\pi R) = 4\pi R
\]
Equilibrium

\[ F_e = F_T + F_G \]

\[ k x = 4\pi R \gamma + m g \]

\[ \gamma = (k x - m g) / (4\pi R) \]

\[ \gamma = \frac{(0.70)(34 \times 10^{-3}) - (7.0 \times 10^{-4})(9.8)}{(4\pi)(20 \times 10^{-3})} \text{ N.m}^{-1} \]

\[ \gamma = 0.076 \text{ N.m}^{-1} \]

The base of an insect's leg is approximately spherical in shape with a radius of about 2.0×10^{-5} m. The mass of the insect is 3.00×10^{-6} kg and is supported equally by six legs. Calculate the contact angle \( \theta \) as shown in the diagram. The coefficient of surface tension is 0.072 N.m^{-1}.

Why can an insect walk on water?

radius of insect leg = \( R = 2.0 \times 10^{-5} \) m

mass of insect = \( m = 3.00 \times 10^{-6} \) kg

insect supported by 6 legs
coefficient of surface tension \( \gamma = 0.072 \text{ N.m}^{-1} \)

contact angle \( \theta = ? ^\circ \)

Assume the surface tension acts around the circle of radius \( R \) where \( R \) is the radius of a leg. This is not accurate since the radius of the surface depression is not precisely the radius of the leg.

Equilibrium

\[
F_T \cos \theta = F_G \\
F_T = (2\pi R) \gamma \\
F_G = mg / 6 \\
(2\pi R) \gamma \cos \theta = mg / 6
\]

\[
\cos \theta = (mg) / \{(12\pi R) \gamma\} \\
\cos \theta = (3.00 \times 10^{-6})(9.8) / \{(12\pi)(2.0 \times 10^{-5})(0.072 \}) \\
\cos \theta = 0.54157
\]

\( \theta = 57^\circ \)

If \( \cos \theta \geq 1 \) or \( \theta \geq 90^\circ \)
\[ \Rightarrow \] surface tension would not support insect.

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**Home activities**

- Place a dry razor blade flat on a still water surface. Is it easy to get the razor blade to float? Is it easier to float the razor blade in a particular orientation? Add some liquid detergent to the water and observe what happens.
- Place a loop of thread on the surface of still water. Note the shape of the loop. Place a drop of detergent inside the loop. What happens to the shape of the loop?
- Place three matches in a close triangle on the surface of still water. Add a drop of detergent inside the triangle.
Phenomenon of surface tension

Why can insects walk on water, but larger animals (no matter how much water repellent material they put on themselves) cannot? The surface of any liquid behaves as though it is covered by a stretched membrane. Small insects can walk on water without getting wet. The membrane is obviously quite strong: it will support dense objects, provided they are not very heavy and of the right shape e.g. a needle, a razor blade, a container made of fine wire gauze and small insects. In all these examples, the objects are denser than that of water and are not shaped like boats. The strength of the membrane varies for different liquids, e.g. it is much less for soapy water than pure water. Ducks swim on water without getting very wet. However, they cannot swim on soapy water. There are cases on record where ducks have drowned in farmyard ponds into which washing water was emptied, or in streams polluted with non degradable detergents. The strength of the surface membrane can be imagined to arise from a set of forces acting on each point of the surface, parallel to the surface, like the skin of a drum. So the needle shown in Fig. 1, is held up by an upward force due to surface tension. If the surface membrane is broken, that is, pierced by the needle, it will no longer be held up and will sink.
The force $F$ which a liquid surface exerts on any body with which it is in intimate contact is directly proportional to the length of the line of contact $L$

$$F = \gamma L$$

The constant of proportionality, $\gamma$ is called the **coefficient of surface tension** of the liquid. Here are the values of surface tension of some common liquids. They are listed here merely for the purpose of showing you what range the values of surface tension can have. Water has quite a high value of surface tension. Mercury is a liquid metal and glycerine is a thick liquid like honey. A little detergent added to the water lowers it surface tension considerably.

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Table 1. Values of surface tension for various substances.

To understand why the phenomenon of surface tension arises, we must think of intermolecular attraction. Molecules of any substance want to pack together so that their average separation is low. In solids, this separation is fixed, whereas in gases, the random motion due to heat predominates. In liquids, there is some random motion but, on the average, the molecular separation is low.

Consider a fixed number of liquid molecules. If they are packed so that they have a large surface area, their average intermolecular separation is relatively high. If they have small surface area, the average intermolecular separation is relatively low. Their total potential energy is lower in the latter case. A logical conclusion from this is that energy has to be added in order to increase the surface area of a liquid. The bigger the change in surface area, the more energy has to be put in. Associated with the surface there is a potential energy that depends on the area of the surface. This means that an alternative approach is to consider surface tension as an **energy per surface area**. Since, the equilibrium configuration of any system is that in which the potential energy is least, a liquid left to itself will assume a shape which minimises surface area, thereby minimising the total surface potential energy. The dimensions of energy are force $\times$ length, so $\frac{\text{energy}}{\text{area}}$ has the same dimensions as $\frac{\text{force}}{\text{length}}$. Sometimes it is easiest to explain surface phenomena in terms of energy considerations, sometimes in terms of force considerations.

So if we place a loop of thread on the surface of still water it will appear as in Fig. 2a. If we now place a drop of detergent inside the loop, surface tension of detergent and water is much lower that that of water.

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Add a drop of detergent inside the triangle, the matches move away as in Fig. 3b.

This is basically the same as the loop of thread, but it is easier to explain why each match moved in terms of forces using Fig. 4.
larger force
(water: higher
surface tension)

smaller force
(detergent: lower
surface tension)

Fig. 4 The net force acting on the match pushes it away from the detergent.

So what are detergents and why do they lower the surface tension of water?

**Detergents**
The properties of detergents arise from their complicated molecular structure. This is illustrated schematically by Fig. 5.

![Detergent molecule](image)

This end is repelled by water molecules [hydrophobic] and is attracted to oils, fats [lipophilic]

This end is attracted to water molecules [hydrophilic]

When detergent is put into water the detergent molecules on the surface are aligned with their hydrophobic ends pointing up as shown in Fig. 6. Other detergent molecules are dispersed throughout the water. Along the surface there are water molecules and hydrophobic ends. The surface membrane is broken by the detergent molecules. It is easier to pull this surface apart than it is to pull a surface of pure water apart because the surface tension is lower than that of pure water.
In washing up water the following sequence occurs as the water is stirred up (Fig. 7). The particles of organic matter are rendered soluble by being coated with detergent molecules: lipophilic ends stick to the particles and hydrophilic ends point outwards.

Emulsification occurs in a similar way. Many organic substances that are insoluble in water can be mixed into an emulsion with water by the addition of a little detergent. If we pour some oil and water into a container and shake the container, the oil and water will not mix. Add a few drops of detergent and shake the container again. The oil and water will mix more readily.