Surface Tension

There are several macroscopic phenomena that occur as a result of the intermolecular forces near and at a fluid surface that we will describe in this and some linked sections.

First we address the phenomena known as **surface tension** and describe some of the observable effects that result from this fluid property. In the bulk of a liquid nominally at rest the molecules experience forces exerted by the surrounding molecules which, averaged over time, are isotropic. The state of the liquid at that point is a function of that isotropic pressure as well as the temperature. However, the liquid molecules on or near an interface between the liquid and another fluid experience intermolecular forces that are different on different sides, most particularly that facing the liquid and that facing the other fluid. For simplicity we consider just the circumstance in which the other fluid is a gas or a vaccuum which exerts little or no force on the liquid molecules; we call this a "free surface". Then, as a result of the asymmetry described above, the liquid molecules are bound more tightly to the molecules on the bulk liquid side and this tighter binding necessarily implies an additional strain energy in the free surface of the liquid. This additional stored energy is called "surface energy" and, for reasons described below, is characterized by a property called "surface tension". More particularly, there is a certain amount of this surface energy stored in each unit area of the surface and the surface tension is the amount of energy per unit surface area. The surface energy or surface tension is a function of the particular liquid and of its temperature since the intermolecular forces depend on temperature.
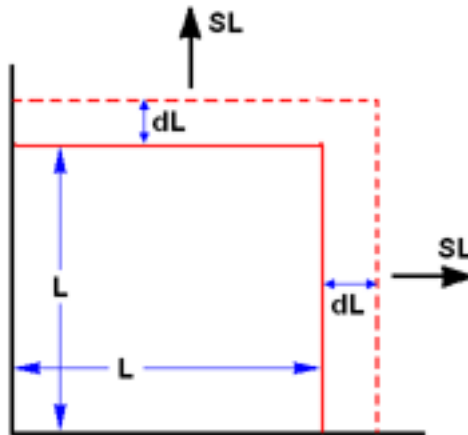

Figure 1: An $L \times L$ element of liquid surface being stretched.

The units of surface energy are therefore those of energy per unit area or kg/s^2 or N/m. It is called surface tension because of what happens when one expands a certain area of surface. Consider a square section of liquid surface with sides, L, as shown in Figure 1 and denote the surface energy per unit surface area by S. If that area is now stretched so that the sides measure $L + dL$, the stored surface energy must increase by $S\left[(L + dL)^2 - L^2\right] \approx 2SLdL$. It follows that in order to deposit this additional energy in the surface we must do work on the surface in order to expand it. We can imagine doing this by pulling on the top and right-hand-side of the area shown in Figure 1. Since the displacement in both cases is dL and the total work that must be done is $2SLdL$, it follows that the force that must be applied to the top and the right-hand-side is SL. In other words the force per unit length of the sides is S. Hence the presence

of surface energy can also be visualized as an additional tension present in the surface of a liquid. This tension can be visualized by considering making a imaginary incision in a liquid surface. Then the force that one side of this incision applies to the other side is a tension or force tangential to the surface equal to S times the length of that incision. It is for this reason that S is called the surface tension though the property is more accurately envisaged as stored energy per unit area.

The surface tension is a declining function of temperature because, as the temperature and random motions in the liquid increase, the intermolecular forces decrease. Thus as we approach the critical temperature in a liquid, the surface tension declines to zero. Indeed surface tension in almost all simple liquids is a linearly decreasing function of temperature. Some typical surface tension values for pure liquids are listed in Table 1 and values at other temperatures can be accurately obtained by using the linear behavior described above and data on the values of the critical temperature for that liquid. When the fluid on the other side of the "free surface" is a vapor or gas, it has little effect on the surface tension. However, when it is another liquid the molecules of that other liquid cause forces which do alter the value of the surface energy or surface tension. Therefore, in Table I we also list the "other fluid" in parentheses.

TABLE 1. Some values of the surface tension for common liquids (in N/m).
References: CRC (1974)

Water (air) at $20°C$	0.073	Water (air) at $100°C$	0.059
Mercury (air) at $20°C$	0.466	Mercury (water) at $20°C$	0.375
Carbon tetrachloride (air) at $20°C$	0.268	Carbon tetrachloride (water) at $20°C$	0.449
Oxygen (vapor) at $90°K$	0.0132	Nitrogen (vapor) at $80°K$	0.00826
Carbon dioxide (vapor) at $220°K$	0.0153	Ammonia (vapor) at $240°K$	0.0300
Butane (vapor) at $300°K$	0.0117	Methane (vapor) at $110°K$	0.0143
Freon 12 (vapor) at $300°K$	0.0086	Toluene (vapor) at $367°K$	0.0200

Parenthetically we need to add that these are values for pure fluids and even a small amount of contamination can cause significant changes in the surface tension. Thus tap water usually has a surface tension significantly lower than 0.073 N/m often in the range $0.05 - 0.06$ N/m. Common household detergent will reduce the surface tension still further. The contamination can either be chemical or particulate.

One of the common macroscopic effects of surface tension is the pressure difference it causes between the two sides of a curved surface (see **Surface Tension on a Curved Surface, Section (Cm)**).