What are Contact Angles?

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This brief application note will explain in a non-technical way the importance of contact angle measurements. Contact angles are an easy-to-visualize and measure manifestation of surface energy, which in turn is a characteristic of chemical bonding. Contact angles, *per se*, describe the shape of a liquid drop resting on a solid surface.

Figure 1 defines the contact angle, which is nothing more than the angle between a tangent drawn on the drop's surface at the resting or contact point and a tangent to the supporting surface. The important concept is that the shape of the drop reveals information about the chemical bonding nature of the surface. This bonding will determine its wettability and adhesion. The relationship of drop shape to bonding is contact angle's utility.

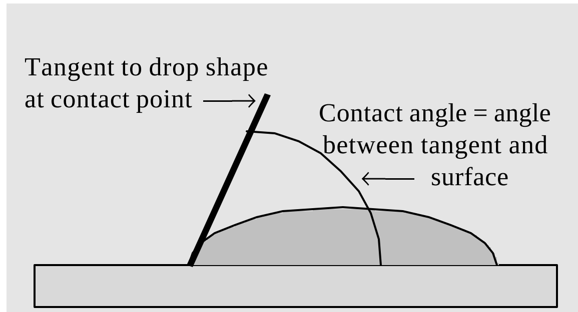


Figure 1: Definition of the contact angle between a resting fluid drop and a solid surface. The contact angle is about 70° in this example.

Chemical bonds, you will recall, are the attractive forces between atoms in a molecule and between adjacent molecules in a substance. These are the forces that hold things together. When molecules exist in close proximity in a liquid or solid, the atoms arrange themselves to optimally satisfy the bonding forces with nearby neighbors.

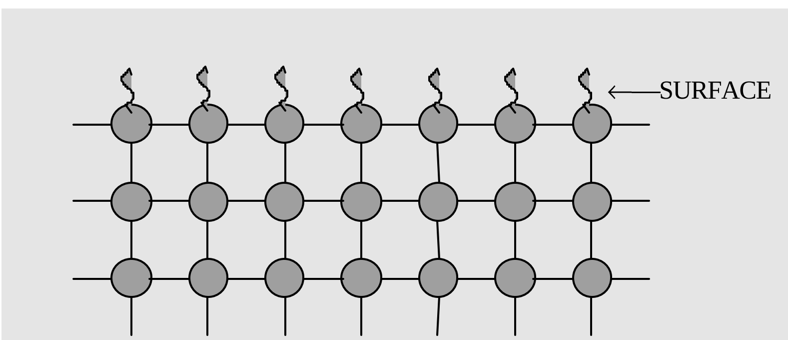


Figure 2: Schematic of idealized solid surface. Circles represent atoms, straight lines satisfied chemical bonds of electrons, and wiggly lines unsatisfied bonds of top layer of atoms at surface. Only a small region shown--material extends far to left, right, and down.

Now consider the idealized solid at left. An atom in the interior has satisfied bonds in all directions: four in this 2-D drawing and six in the real 3-D world. But atoms in the top row do not have one bond satisfied, because there is no neighbor above. These unsatisfied bonds consti-tute surface energy, a potential energy in the sense that another object brought up close might be able to satisfy some of these "dangling" bonds. ***These bonds are the source of wetting and much of adhesion***. We use contact angles to estimate the nature and strength of these bonds, mainly because we lack a direct-reading meter the way we have a thermometer for temperature or a voltmeter for voltage.

The interaction between bonds of surfaces brought together is not the same as two substances reacting to form a new chemical compound (e.g., hydrogen oxidizing to form water). With adhesion or wetting, one can, with effort, separate the constituents as no compound is formed.

Theoreticians have calculated the expected contact angle as a function of the surface energy of the solid and liquid in Figure 1. For clarity in distinguishing between solids and liquids, it is conventional to ascribe "surface energy" to solids and "surface tension" to liquids. The distinction is made because only fluids will change their shape in response to surface energy/tension. Let us write this relationship symbolically:

contact angle $\theta = f$ (surface energy γ_S, surface tension γ_L)

The letter "*f*" refers to function or relationship, also sometimes called a "model." It says given γ_S and γ_L, we can compute θ.

Since there are several kinds of bonds, there is more than one model in use. They all give about the same answer, but some users prefer one over the other. The FTÅ200 supports the four commonly used models. These are primarily distinguished by how many terms the model uses, each term being determined by a separate fluid measurement. The important point is *f* exists.

What we really want are the surface energies of solids and the corresponding surface tensions of fluids, given θ. The software "inverts" (solves backwards) the above equation, so

surface energy $\gamma_S = f^{-1}$ (contact angle θ, surface tension γ_L)

For the surface tension of fluids, we can use an equation like that immediately above, or use a more direct solution provided by our theoretician friends: substitute "drop shape" for "contact angle" and Bashforth-Adams (in the 19th century, no less) solved a difficult equation numerically so

surface tension $\gamma_L = g^{-1}$ (drop shape)

if the drop is symmetric about its vertical axis. ***To summarize, we can determine surface energy from measured contact angles and surface tension from measured drop shapes.*** Many times contact angle data is used directly without the trouble of converting to surface energy units, as, for example, this is a 30° surface or this is a 40° surface.

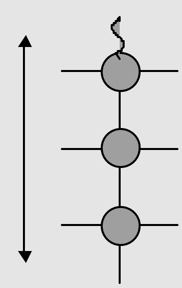
1. Contact angles are measured in degrees. "Low" is below about 20° and "high" is 90° or above. Water on Teflon™ is about 112°, very high. Low angles mean "wettable."

2. Surface energy and surface tension are measured in dynes/cm (in the old cgs system) or mN/m or mJ/m^2 in mks. Fortunately the numerical values are all the same, so no conversion is required. Water has a surface tension of 72.8 at room temperature. Most solids fall between 15 and 100.

3. If the surface tension of the fluid is below the surface energy of the solid, the fluid will spread rather than staying in a little droplet. Polymer surfaces are often treated to improve this wettability by raising their surface energy.

4. Good adhesives "wet" the surface so they will fill all of the little voids in a real surface and therefore have more bonds in contact. Real solids are not smooth like Figure 2.

The ***First Ten Angstroms*** into a surface is where surface energy is determined!



An Angstrom, Å, is 10^{-10} meters or 10^{-7} millimeters. A typical atom is 3Å or so in diameter.

5. Any contact angle depends on both the solid and the liquid, so you must specify both. Water is a common test fluid. Surface energies have the benefit of theoretically being independent of fluid.