= 1 and rf =
r , the Cassie ? Baxter equations becomes the Wenzel equation . On the other hand , when there are many different fractions of surface roughness , each fraction of the total surface area is denoted by <formula> .
A summation of all fi equals 1 or the total surface . Cassie ? Baxter can also be recast in the following equation :
<formula>
Here ? is the Cassie ? Baxter surface tension between liquid and vapor , the ?i , sv is the solid vapor surface tension of every component and ?i , sl is the solid liquid surface tension of every component . A case that is worth mentioning is when the liquid drop is placed on the substrate and creates small air pockets underneath it . This case for a two @-@ component system is denoted by :
<formula>
Here the key difference to notice is that there is no surface tension between the solid and the vapor for the second surface tension component . This is because of the assumption that the surface of air that is exposed is under the droplet and is the only other substrate in the system . Subsequently the equation is then expressed as (1 ? f) . Therefore , the Cassie equation can be easily derived from the Cassie ? Baxter equation . Experimental results regarding the surface properties of Wenzel versus Cassie ? Baxter systems showed the effect of pinning for a Young angle of 180 to 90 ° , a region classified under the Cassie ? Baxter model . This liquid / air composite system is largely hydrophobic . After that point , a sharp transition to the Wenzel regime was found where the drop wets the surface , but no further than edges of the drop .

= = = = Precursor film = = = =

With the advent of high resolution imaging , researchers have started to obtain experimental data which have led them to question the assumptions of the Cassie ? Baxter equation when calculating the apparent contact angle . These groups believe the apparent contact angle is largely dependent on the triple line . The triple line , which is in contact with the heterogeneous surface , cannot rest on the heterogeneous surface like the rest of the drop . In theory , it should follow the surface imperfection . This bending in triple line is unfavorable and is not seen in real @-@ world situations . A theory that preserves the Cassie ? Baxter equation while at the same time explaining the presence of minimized energy state of the triple line hinges on the idea of a precursor film . This film of submicrometer thickness advances ahead of the motion of the droplet and is found around the triple line . Furthermore , this precursor film allows the triple line to bend and take different conformations that were originally considered unfavorable . This precursor fluid has been observed using environmental scanning electron microscopy (ESEM) in surfaces with pores formed in the bulk . With the introduction of the precursor film concept , the triple line can follow energetically feasible conformations and thereby correctly explaining the Cassie ? Baxter model .

= = = = " Petal effect " vs. " lotus effect " = = = =

The intrinsic hydrophobicity of a surface can be enhanced by being textured with different length scales of roughness . The red rose takes advantage of this by using a hierarchy of micro- and nanostructures on each petal to provide sufficient roughness for superhydrophobicity . More specifically , each rose petal has a collection of micropapillae on the surface and each papilla , in turn , has many nanofolds . The term ? petal effect ? describes the fact that a water droplet on the surface of a rose petal is spherical in shape , but cannot roll off even if the petal is turned upside down . The water drops maintain their spherical shape due to the superhydrophobicity of the petal (contact angle of about 152 @.@ 4 °) , but do not roll off because the petal surface has a high adhesive force with water .
When comparing the " petal effect " to the " lotus effect " , it is important to note some striking differences . The surface structure of the lotus leaf and the rose petal , as seen in Figure 9 , can be

used to explain the two different effects . The lotus petal has a randomly rough surface and low contact angle hysteresis , which means the water droplet is not able to wet the microstructure spaces between the spikes . This allows air to remain inside the texture , causing a heterogeneous surface composed of both air and solid . As a result , the adhesive force between the water and the solid surface is extremely low , allowing the water to roll off easily (i.e. " self @-@ cleaning " phenomenon) .

However , the rose petal 's micro- and nanostructures are larger in scale than those of the lotus leaf , which allows the liquid film to impregnate the texture . However , as seen in Figure 9 , the liquid can enter the larger @-@ scale grooves , but it cannot enter into the smaller grooves . This is known as the Cassie impregnating wetting regime . Since the liquid can wet the larger @-@ scale grooves , the adhesive force between the water and solid is very high . This explains why the water droplet will not fall off even if the petal is tilted at an angle or turned upside down . However , this effect will fail if the droplet has a volume larger than 10 μl because the balance between weight and surface tension is surpassed .

= = = Cassie ? Baxter to Wenzel transition = = =

In the Cassie ? Baxter model , the drop sits on top of the textured surface with trapped air underneath . During the wetting transition from the Cassie state to the Wenzel state , the air pockets are no longer thermodynamically stable and liquid begins to nucleate from the middle of the drop , creating a ? mushroom state ? as seen in Figure 10 . The penetration condition is given by :

<formula>

where

?C is the critical contact angle

? is the fraction of solid / liquid interface where drop is in contact with surface

r is solid roughness (for flat surface , r = 1)

The penetration front propagates to minimize the surface energy until it reaches the edges of the drop , thus arriving at the Wenzel state . Since the solid can be considered an absorptive material due to its surface roughness , this phenomenon of spreading and imbibition is called hemiwicking . The contact angles at which spreading / imbibition occurs are between 0 and ? / 2 .

The Wenzel model is valid between ?C and ? / 2 . If the contact angle is less than ?C , the penetration front spreads beyond the drop and a liquid film forms over the surface . Figure 11 depicts the transition from the Wenzel state to the surface film state . The film smoothes the surface roughness and the Wenzel model no longer applies . In this state , the equilibrium condition and Young 's relation yields :

<formula>

By fine @-@ tuning the surface roughness , it is possible to achieve a transition between both superhydrophobic and superhydrophilic regions . Generally , the rougher the surface , the more hydrophobic it is .

= = Spreading dynamics = =

If a drop is placed on a smooth , horizontal surface , it is generally not in the equilibrium state . Hence , it spreads until an equilibrium contact radius is reached (partial wetting) . While taking into account capillary , gravitational , and viscous contributions , the drop radius as a function of time can be expressed as

<formula>

For the complete wetting situation , the drop radius at any time during the spreading process is given by

<formula>

where