Tiny Droplets Bring Big Benefits

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What significance can a tiny droplet of a liquid have? Does anything happen inside these tiny droplets (say the size of a droplet is a millimeter)? It is not very informative to say that things are happening inside the droplets as the droplets are small, and we do not see any motion inside them with the naked eye. When a drop of rain falls, it accumulates air pollutants like soot, sulphates, and other organic particles as if the droplet is hungry for them. As a consequence, acid rain can occur or we may use this phenomenon to our advantage to clean our atmosphere by creating artificial rain. My research answers fundamental questions about interesting things that happen inside a tiny drop of rain.

Sometime or the other, we may have mistakenly spilled coffee or liquid food on the table. Let us assume that a drop of coffee is spilled by mistake. We may notice that it leaves a stain after it evaporates. . For some reason, the coffee particles inside the coffee drop tend to move towards the edges as it evaporates (see image).

Coffee Ring

There must be something happening inside these drops that are making these particles settle towards the edge. Research shows that there is a flow inside the droplet, which controls the motion of coffee particles.

Although the droplets are small, they have large scale ramifications in day-to-day life. Generally, we would want to avoid stains.

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It would be great to have clothes that never become dirty and if anything falls on them it rolls off. Such surfaces are called super-hydrophobic surfaces. However, there are applications where we would want the particles to deposit the way we want them to, that is, if we do not want the deposit to be in the shape of a ring, and we want it to be uniform or of some shape of our choice. For example, we might want to print using drops of ink and we want the ink particles in the drop to deposit uniformly. Using drops, we can even print an electronic circuit of required shape with the functionality.

To control deposition of particles inside the drops in such applications, we need to control the flow inside. So, we used zoom lenses attached to digital cameras to see what happens inside these droplets. We suspended some particles coated with a dye and traced it inside the droplet to visualize the internal flow. We will call this particle a tracer particle. These particles faithfully follow the flow without disturbing it. The tracer particles used are of the size of a micrometre made of polystyrene material.

We found a unique way to control the flow inside these drops without even physically touching them. When we surrounded a non-uniform alcohol vapour across a water droplet, it created a directional flow inside the droplet. When these droplets were placed adjacent to each other, they interact with each other through their vapour field. This interaction created a directional flow inside the droplets, which was used to study the control of agglomeration of particles inside the droplet as it evaporated.

Generally, the flow inside the droplets on a substrate is minimal. However, we observed that when droplets of different volatility were placed adjacent to each other, the flow inside low volatility droplet significantly increased by a whopping 1000 times! This is one of our novel findings. And, strategic positioning of alcohol droplet could control the flow. The flow velocity inside the droplets is calculated by a technique called Micro-Particle image velocimetry. A computer algorithm keeps track of the motion of tracer particles to calculate the velocity of flow. This can be used in several applications in medical diagnostic devices that require fast mixing. For example, if we want to test the glucose level in blood. A drop of blood mixed with reagent would change colour depending on the glucose level. For this to happen, it is essential that the drop of blood must mix well with the reagent. Enhanced mixing in such drops can be achieved by placing an alcohol droplet adjacent to it.

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The reason for the change in flow is due to the local change in surface tension due to non-uniform vapour adsorption, that is,, the vapour molecules adsorb the droplet and thus establish communication with it. The difference in surface tension drives the flow in the bulk of the droplet.

Manipulation of tiny droplets of micro-nano liter volumes has seized the attention of researchers worldwide because it can be applied when building miniature devices. A decade ago, not many people believed that Nano/Micro-science could deliver the next generation of technologies. After all, big things come in small packages.

Miniaturization of devices has many advantages. Smaller devices are easy to carry. If miniature versions of chemical reactions are conducted, there will be less consumption of reagents. Additionally, many reactions can be carried out in a small space. Such a device in which several reactions are carried out in a small chip is called a lab on a chip device. However, miniaturization of electronic devices has a disadvantage that it generates more heat for a given volume. Droplets are also useful for cooling electronic components. Just like a blow fan near a hot surface cools the surface, increasing the flow inside the droplets will also cool their surface.

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Applications of droplet studies is ubiquitous. The study of droplets of splattered blood helps in investigation of crime scene. Food processing, spray painting, cosmetics, combustion in engines, medical diagnostic are other useful applications to name a few.

Our motto is to further experiment with complex fluids that will help in improving medical diagnostics techniques. The idea is to integrate this technique to a lab on a chip device. The interaction between the droplets is governed by rich physics.