PHYSICS IN DAILY LIFE:

FOG AND RAINDROPS

* L.J.F. (Jo) Hermans * Leiden University, The Netherlands * Hermans@Physics.LeidenUniv.nl * DOI: 10.1051/epn/2009602

As every physicist knows, fog – or mist – is just a collection of tiny drops of water, at least if it is caused by nature. What distinguishes them from rain is, of course, their size. They are so small that their vertical speed is almost negligible. The dramatic effect of size on speed is obvious if we realize that for droplets smaller than, say, 0.1 mm, the flow profile around the droplet is purely laminar, so the friction F is determined by Stokes' law: $F = 6\pi\eta Rv$, with η the viscosity, R the radius and v the speed. And since the friction is balanced by weight, which is proportional to R^3, we see that the speed is proportional to R^2. This means that small droplets fall very slowly indeed. Take, for example, water droplets of 2 μm diameter, much larger than the wavelength of light and therefore still visible. We find that they fall through air at a speed of about 0.1 mm per second. That's not particularly fast: even the slightest wind or air turbulence will offset such low speed.

But wait: do we really need turbulence to keep such tiny droplets airborne? Isn't thermal motion sufficient to keep them from falling? Don't they behave like ordinary molecules in the atmosphere, having a height distribution obeying Boltzmann's law? We can easily check if this is the case. We remember that the Boltzmann distribution for this case implies a distribution over height h decaying as $\exp(-mgh/kT)$. In normal atmospheric conditions, the 1/e value is reached at a height of around 8000 m. Obviously, for particles much heavier than nitrogen or oxygen molecules we must settle for a distribution that stays closer to earth. Let us scale down the atmosphere for water droplet by a factor of one thousand, choosing a 1/e-value of 8 m. For this to be the case, the mass of a water droplet must be 1000 times that of a nitrogen or oxygen molecule, *i.e.*, it must consist of about 1500 water molecules. This is more like a large cluster than a droplet. Its diameter can be readily estimated by using the typical 'size' of 0.3 nm for small molecules or atoms in a liquid. In the case of water, we can even do a simple calculation if we consider a litre of water and use Avogadro's number. Sure enough, we find pretty exactly 0.3 nm for the distance between the centres of two neighbouring water molecules. From this it follows that the diameter of the cluster is only 5 nm. This is *really* small, much smaller than the wavelength of light. So we cannot see such clusters, but they surely make efficient light scatterers.

The conclusion? Mini-droplets smaller than about 5 nm would stay airborne forever, even in perfectly calm atmospheric conditions. They would form a perfect fog that never reached the ground. If we were to walk or cycle through such a fog, it would be our *front* that got wet, not so much our head.

Alas, these mini-droplets do not survive very long. Inevitably, they collide and form larger drops. Slowly but surely they will start to fall. And by the time we can distinguish individual drops, we can be sure that we are walking in the rain. ■