Optical Trapping Airborne Particles

Professor Don Clark

The trapping of airborne particles originated with the Millikan drop experiment (Electrizitätsmengen Phys. Zeit. 10: 308 1910) in which the charge on the electron was measured by the field required to suspend a singly charged particle of known size against the force of gravity. Subsequently the technique was adapted for the study of charged particles suspended in an electrical field. This technique does however have some disadvantages in that the particles must be electrically charged but the presence of ions in the gaseous medium make it impossible to keep the charge at a constant value. The position of the particle must therefore be constantly monitored and the electrical field rapidly adjusted in response to changes in order to keep the particle in a stable position.

Particles can also be manipulated by an optical field. In the simplest sense the photophoretic force of upwardly propagating photons that are scattered by the surface of the particle can move the particle through the suspending gas against the force of gravity (figure 1), but this does not trap the particle in a stable position. However, if the particle is a dielectric, transparent sphere and the light source is a highly focussed laser beam with a beam waist smaller than the diameter of the sphere, the reaction forces from photons leaving the sphere generate differential forces that can stabilise its position in space.

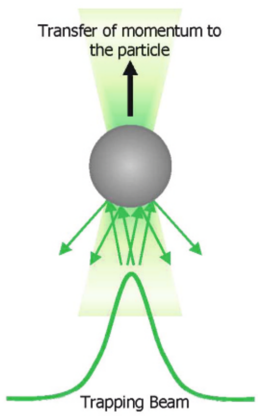

Figure 1: Suspending force from scattered light

Figure 2 shows how this works along the axis of beam propagation. As the particle is driven away from the beam focus by the scattered light the force on the particle falls rapidly but the counter-propagation force, due to refracted photons leaving the upper surface, remains constant, within narrow spatial boundaries. In a well-designed optical system the position of the particle will stabilise a little above the focus of the trapping beam.

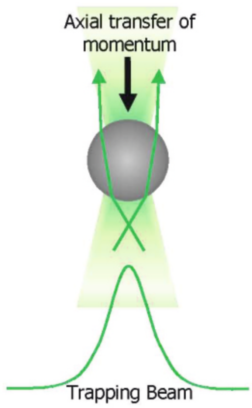

Figure 2: Axial force from refracted beam

Figure 3 demonstrates how the optical gradient around the beam focus stabilises the position of the particle laterally with respect to the direction of beam propagation. As the particle moves from being centred on the beam axis the intensity of the light on the particle becomes asymmetric. The refracted photons leaving the sphere therefore generate an asymmetric reaction force with a net component that drives the particle back to a central position in the beam.

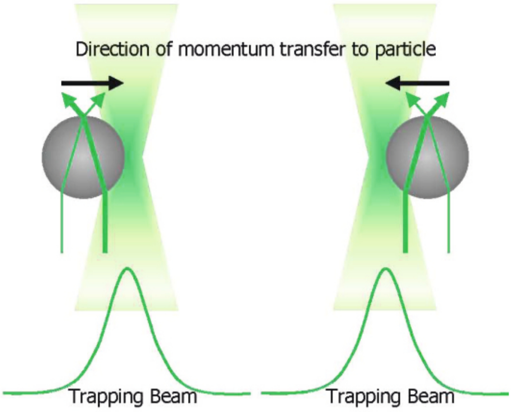

Figure 3: Lateral forces from refracted light

One of the great advantages of optical trapping is that the beam used to form the trap can also be used as an analytical probe to monitor the chemical and physical state of the trapped particle, continuously and in real-time.

A trapped transparent sphere will act as a resonant cavity for wavelengths which have an integral number with respect to the circumference of the sphere. Such a cavity acts as a powerful amplifier for low intensity Raman scattered light. The spectra generated by this phenomenon can be used to monitor chemical changes in the droplet, while changes to the points of resonance enable physical characteristics, such as size to be measured with exceptional sensitivity.

The AOT-100 Aerosol Optical Tweezers, a joint development between Biral and Bristol University Aerosol Research Centre, is the first commercially available instrument to offer optical trapping, particle size and refractive index measurement as well as Raman spectroscopy. More details of the AOT-100 can be found at http://www.biral.com/product/aot-100-aerosol-optical-tweezers.

About the Author

Don joined Biral in 2005 following his retirement from Dstl, Porton Down where he had been the leader of aerosol science and biological detection research groups. His initial work for Biral involved the development of instruments for biodetection, a field in which Biral was a world leader.

Don is now active in the development of the AOT 100, the world's first aerosol optical tweezers instrument and is looking at applications for the AOT 100, as well as researching new opportunities in aerosol characterisation and climate research.