Ubbelohde’s viscometer
Leo Ubbelohde (1877-1964)

Viscosity is one of those ideas that most of us think we have an intuitive feel for. Liquid nitrogen is runny. Honey is not. But if you are asked to define it and explain its origin, things quickly get sticky. In spite of it being one of the strangest and most fundamental properties if we want to understand life on earth, few of us really spend time worrying about it. As the physicist Edward Purcell pointed out in a playful but challenging seminar entitled “Life at Low Reynolds Number”, viscosity is strongly scale-dependent. A human can swim in water by pushing water backwards, but microorganisms, trapped in a world where the forces they can generate are far exceeded by those of the water around them, require a totally different strategy. And by measuring viscosity we can get myriad insights not only into flow but into molecular structure too.
A chemist who thought carefully about how liquids move invented a device whose self-cancelling features made it almost trivial to use. Leo Ubbelohde’s parents were involved in the peat business in and around Hanover. His adolescence was severely disrupted by the bankruptcy of the family firm in 1883 which forced his father to resign his position as a lawyer and notary. As a result the family of seven siblings were split up, with the older children moving with their father to nearby Celle – his father found work at the local Higher Regional Court. The younger children moved to Neustadt am Rübenberge with their mother who worked to restore the family fortunes. In school Leo showed real promise in scientific and technical subjects and by 1890 when the family was reunited, he was aiming to study science a university. Disaster struck four years later when his father died suddenly leaving the family virtually destitute. While his mother scrambled to set up a business to use peat to make cardboard, Ubbelohde studied chemistry at the Berlin/Charlottenburg Technical University where the teaching was dominated by Hans Heinrich Landolt (of clock reaction fame) and Emil Fischer, the organic chemist. To help his mother, he directed the construction of a peat-processing plant in Groningen in the Netherlands, designing and patenting its equipment. But, a scientist at heart, he found a job in the petroleum department of the Royal Materials Testing Office in Berlin. To improve vacuum distillations, he developed a compact and portable mercury vacuum pump, using a water aspirator (Sprengel CK7- March 2008) to back a Töpler pump (CK41 – Jan2011) equipped with a McLeod gauge (CK49). The distillates were characterized in part by viscometry. For the most viscous glops he was dealing with, the principal method at the time was the Engler viscometer, essentially an insulated cup with a hole in it. The time required for 200 ml of liquid to drain out of the cup relative to the same volume of water is the viscosity in “degrees Engler”. Carl Engler, the head of Department at the Technical University in Karlsruhe was one of the leading petroleum chemists in Germany, and Ubbelohde moved to study in his lab. By 1910 he had his habilitation and was on the faculty the following year.
His colleagues were an impressive lot. Fritz Haber creating modern electrochemistry and thinking about big questions. Hermann Staudinger was beginning to explore polymer chemistry and turn it into a quantitative science. Staudinger’s student Leopold Ruzicka was just finishing his doctorate. All three would be honoured with Nobel Prizes in the ensuing decades.
Ubbelohde worked on petroleum and fat chemistry as well as on textile fibres, patenting as much as he published. He was a highly effective administrator setting up conferences and and institute in textile research. But viscosity remained one of his central concerns. In a time before analytical spectroscopy and chromatography, viscometry provided a quick and simple way of assaying and distinguishing oils and fats; Ubbelohde’s textbook “Uber Viskometrie” ran to five editions. The problem with the Engler viscometer was that it did not provide absolute values for the kinematic viscosity and its precision was modest. The only precise instrument available was Ostwald’s U-shaped capillary device (CK22 June 2009) in which a relatively running liquid was timed as it flowed through a capillary in one arm.
As Ubbelohde surveyed viscometry in general, the limitations of Ostwald’s device were all too apparent.As the liquid level dropped it slowed down in the capillary. This required a kinetic energy correction. In addition, the difference in curvature of the meniscus at the top and the bottom of the

capillary introduced a systematic but indeterminate error. This meant using very precise volumes; measurements as a function of temperature were exceptionally tedious because of thermal expansion.

Ubbelohde identified the shape of the liquid at the base of the capillary – the suspended level – as a critical parameter affecting the speed of the liquid emerging from the capillary. By attaching a bulb with a precisely hemispherical cross-section below the capillary, the liquid flowed as a film along the walls effectively cancelling out the capillary forces. A second larger bulb above the capillary acted as the reservoir.

His elegant new viscometer was very simple to use. A liquid was poured into the lower reservoir bulb. It was then drawn across by suction into the bulb above the capillary, the tube on the right introducing air to allow excess liquid to drain back into the lower reservoir. The time taken for the liquid to drop from marks M and M^1 as it flowed through the capillary was recorded. By adjusting the dimensions of the apparatus with extreme precision – Ubbelohde explicitly recommended commercial manufacture – he ensured that the absolute viscosity could be calculated simply by multiplying or dividing the time by a power of ten. With a set of "Ubbelohdes" of different sizes viscosities across six orders of magnitude could be measured in minutes. Its simplicity was such that even an analyst with little mathematical ability could use it.

Today, a quick glance at a rheology textbook reveals scores of approaches to viscosity measurements that have grown alongside the development of the myriad glops and goops we use today. And it leaves us to ponder deeper questions like how would we swim if we fell into a bucket of shampoo or of treacle.

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References: L. Ubbelohde, US2048305A 1936; L. Ubbelohde, *Ind. Eng. Chem. Anal. Ed.*, **1937**, *9*, 85–90.

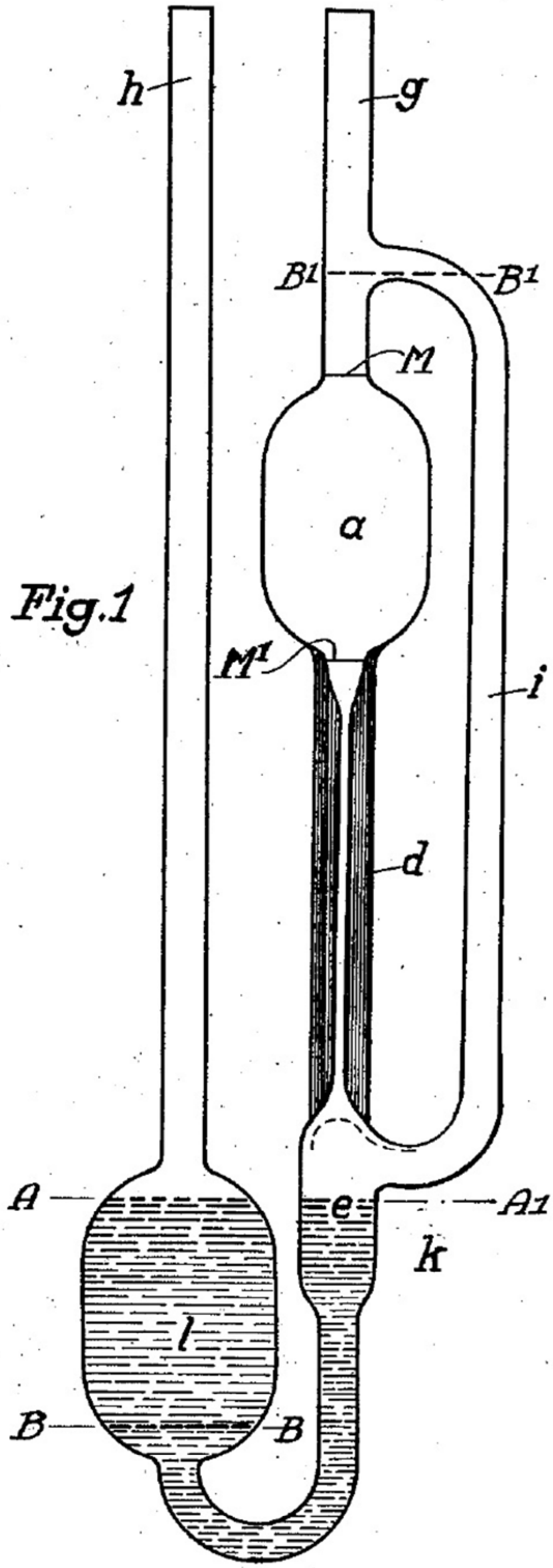

Fig.1