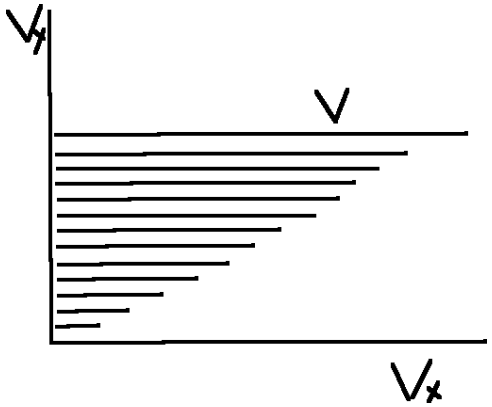
Viscosimetry method. About Some Hydrodynamic properties of DNA

The study of the viscosity of the macromolecule solutions is the one of the most old methods of investigation, which was used already in the early works in the field of physico-chemistry of macromolecules. And today, a viscosimeter is the one of the most wide-spread instruments in biophysical laboratories

Let us dwell briefly on the nature of the information, which a study of viscosity of the macromolecule solutions gives. At the laminar motion of a clean solvent between two planes, one of which is fixed, and the other moves with a speed of V (see Fig.) flow lines can be considered as parallel and a gradient of velocity ($g=dV_x/dy$) as constant and directed perpendicular to the flow. If a macromolecule turns out to be in this area, it takes part in the common motion (it moves along the flow and begins to rotate under the influence of the gradient of velocity) and disturbs the flow of solvent around itself. This leads to the additional energy dissipation and enlarges the common macroscopic viscosity of the solution. The ratio η/η_0, where η and η_0 are the viscosity of the solution and the clean solvent accordingly is called the relative viscosity. It is accepted to characterize the contribution of the soluted substance by a value of the specific viscosity

$$\eta_{sp}=(\eta-\eta_0)/\eta_0$$

The specific viscosity, generally speaking, depends in a rather complex manner on such parameters of a macromolecule, as molecular mass, sizes, a form of molecules, the degree of its hydratation and the ability to be deformed under the action of hydrodynamical forces.

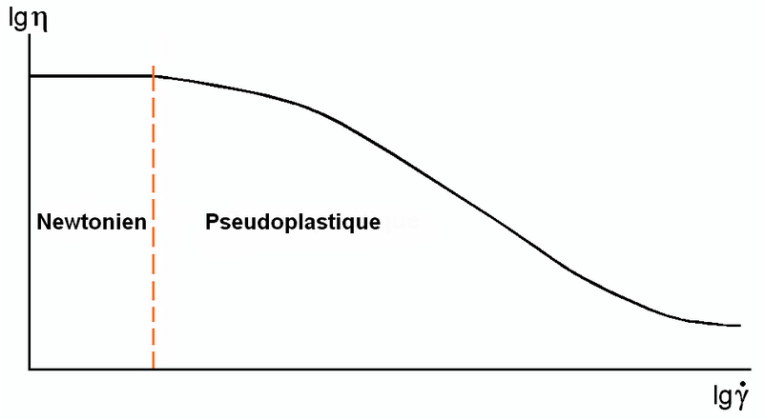


Besides that, the essential role is played by the conditions of an experiment: the concentration of the soluted substance, the value of the velocity gradient, its distribution within the volume under investigation. The related viscosity $\eta_{re}=\eta_{sp}/C$ or, the viscosity number or, the specific viscosity, where C is the concentration of a substance in the units of gram on the deciliter (***g/dl***; the concentration unit for the viscosimetric experiments accepted all over the world), takes into account the dependence of the specific viscosity on the macromolecule concentration.

However, the value of the related viscosity depends also on the solution concentration and on the value of the velocity gradient, so, the most important value is the "characteristic viscosity" $[\eta]$, characterizing the property of the soluted substance (an isolated macromolecule):

$$[\eta]=\lim(\eta-\eta_0)/\eta_0 C \qquad at \qquad C\to 0 \qquad and \qquad g \to 0.$$

The two problems appear: the direct and the inverse one. The first consists in the calculation of solution specific viscosity in the given conditions of the flow on the grounds of some suggestions on behaviour of particles, i.e. under certain models. However, viscosimetry can become an efficient method of investigation only after the solving of an inverse problem: the determination of structural and dynamic behaviour of a macromolecule on the grounds of data on the solution viscosity.



For the measurement of the viscosity of the diluted solutions of biopolymers, different viscosimeter types are used. The numerous viscosimeter types form basically are two classes: capillary and rotary. The extreme simplicity and good reproducibility of the results have led to the broad spreading of the capillary viscosimetery (for instance, Ostwald or Ubbedole capillary viscosimeters). However, definite defects are inherent for them.The large velocity gradients

($g>>1c^{-1}$) limit the possibility of the work with macromolecules with the significant axial asymmetry (e.g. ***DNA***) because of the danger of their degradation; the nonuniform distribution of a gradient on the radius of the capillary (from the zero on the axis of the capillary up to the maximum value at the walls) complicates the obtaining of the dependence $\eta(g)$. In some cases the essential role can be played by the surface tension forces, influencing the effective value of pressure and changing the flowing volume of the solution because of the wetting of the walls of the calibrated reservoir.

In this respect the rotary viscosimeters have the essential advantages. Two coaxial cylinders are their main part, the clearance between which is filled with the substance under investigation. One of the cylinders (more often the external one) is set in the uniform rotation and the appearing rotating moment acting on the internal cylinder which is hung up on the fine elastic thread and the angle of rotor turning are measured (Quett viscosimeter). At the small value of the clearance between the cylinders (with respect to the radius of rotor) the velocity gradient can be considered as practically constant in all the working volume of the viscosimeter. Its value can be easily changed by a simple regulation of the angular velocity of the rotating cylinder. However, the given instrument has a number of defects, too, which are connected with the impossibility of the getting of a small velocity gradient because of the mechanical contact of rotor and stator. The small velocity gradients are required for the investigation of such large asymmetric macromolecules as the high-molecular ***DNA*** are ($M>10^7$ ***Dà***).

$$0.665\lg M=2.863+\lg([\eta]+5)$$

The principle step towards the improvement of the behaviour of rotary viscosimeters, intended for the polymer solutions investigation was done in the work of Zimm and Crothers. This instrument appeared to be very useful when studying the solutions of ***DNA*** with the large molecular mass ($M>10^7$ ***Da***), but it is not also free from the certain defects. The most essential problem is an action of meniscus surface films (edge effects) on the velocity of rotor rotating, and some solutions or small admixtures can have dispostion to the formation of surface active film; the properties of this film are difficult predictable and often can vastly distort the result of a measurement.