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Rheology is the branch of physics which deals with deformation and flow of matter. It is important in many fields. To the physiologist, rheology governs the circulation of blood and lymph through capillaries and large vessels, flow of mucus, bending of bones, stretching of cartilage, contraction of muscles, and spreading of the gluteal region when sitting down. To the physician, the fluidity of solutions to be injected with hypodermic syringes or infused intravenously, flexibility of tubing used in catheters, extensibility of gut, action of fecal softeners, and strength of sutures and ligatures are important rheological properties. To the pharmacist, rheology is important in the flow of emulsions through colloid mills and pumps, working of ointments on slabs or roller mills, trituration of suspensions in mortar and pestle, and properties of glass or plastic containers and of rubber closures. To the consumer, rheology comes into play when he squeezes toothpaste from a collapsible tube, spreads lotion on his skin or butter on a slice of bread or paint on a surface, writes with a pen, sprays liquids from atomizers or aerosol cans, chews food, hits balls with racket, paddle, bat, or club, jumps on a trampolin or off a diving board, swims, and lays down in bed and compresses the stuffing and metal springs in the mattress.

From the rheological viewpoint, systems are solid if they preserve shape and volume, liquid if they preserve their volume, and gaseous if neither shape nor volume remains constant when forces are applied to them. Of the three systems, the transport properties of gases, described by the kinetic theory of gases, are best understood, but they are of minor importance in pharmacy.

Ideal solids are deformed when stresses are applied to them but regain their original shape completely when the stresses are released. The ability to restore their shape is called elasticity. Similarly, liquids can be compressed to somewhat smaller volumes, but assume their original volumes when the pressure is released. The dividing line between solids and liquids is not clear-cut. As explained below, some systems which behave as elastic solids when subjected to small stresses and/or to moderate stresses of short duration will undergo permanent deformation, resembling very viscous liquids, if the stresses are larger and/or applied for longer periods of time.

Fundamentals

The concepts and quantitative aspects of rheology are described in this section.

Elastic Solids

When a ball (rubber ball, steel ball bearing, or baseball) is dropped on the floor or hit with a bat, it is temporarily flattened. After the impact, the original spherical shape is restored. When we pull on a rubber band, steel spring, or muscle, they stretch or extend. On release, they resume their original length. This behavior, characteristic of solids, is called elasticity.

The force F producing the deformation, or the equal and opposite restoring force in the deformed solid, divided by the area A over which F is applied, is called stress. In the stretching process, A is the cross-sectional area of the filaments, and the deformation is said to be in tension. Other modes of deformation are by bending or flexure, torsion, compression, and shear. The deformation or strain of the stretched filaments, or their elongation, is the difference between their length while under tension, L_s, and their original length, L_o, which is equal to the length after the stress is released, expressed as a fraction of the original length, namely, $(L_s - L_o)/L_o$.

For an ideal elastic solid, the stress is directly proportional to the strain. In tension:

$$\frac{F}{A} = E\left(\frac{L_s - L_o}{L_o}\right) \qquad (1)$$

This relationship, called *Hooke's law*, is obeyed by real solids at moderate stresses and strains sustained for short periods of time. The proportionality constant E, called the *modulus of elasticity* or *Young's modulus*, is a measure of the stiffness, hardness, or resistance to elongation. There is also a modulus of shear or rigidity and a compression or bulk modulus. *Tensile compliance* is the reciprocal of Young's modulus, or the ratio of strain to stress.

In the CGS system, the units of stress are dyne/cm^2 or, since force = mass × acceleration, (g cm/sec^2)/cm^2 = g/cm sec^2. Since strain is dimensionless, Young's modulus has the same dimensions as stress. Modulus values for solids important in appliances, as packaging materials, and in physiology are listed in Table I.