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Degradation of Naum Gabo's Plastic Sculpture: The Catalyst for the Workshop

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Some dramatic events have occurred to several sculptures by Naum Gabo in Tate's collection. Quite suddenly they have changed from being relatively intact sculptures to being unstable and unusable items. This is because they are made from cellulose acetate. Gabo created many sculptures by cutting, bending and gluing sheets of transparent material, beginning with cellulose nitrate, which proved to be highly unstable, subsequently replacing it as his preferred medium with cellulose acetate and then with polymethylmethacrylate (Perspex or Plexiglas). In this way he mirrored industrial developments by readily adopting new materials more suitable for his task as they became available. The motion-picture industry went through a similar evolution, and experienced dramatic consequences for old nitrate film stock, much of which has been lost and the rest has had to be copied onto new materials or into digital format.

Cellulose nitrate was developed in the 1880s and first sold by Eastman in 1889. It is relatively transparent, less breakable than glass and can be moulded into shapes. It was produced industrially for a number of useful purposes. Unfortunately, it proved to be highly unstable, sometimes even igniting or exploding. Cellulose acetate was developed in 1904 to provide a more stable replacement, being produced as a film, a lacquer and also as a textile fibre. Both products are made by chemically treating wood fibre or cotton linters with strong acid (nitric or acetic), converting natural cellulose into the ester derivative. Both suffer similar chemical and physical degradation, but in the nitrate it is much faster. (By contrast, polymethylmethacrylate is a truly synthetic polymer and degrades entirely differently at a very slow rate).

Pure cellulose acetate is a brittle, glass-like material but it is plasticised to make it flexible. The plasticiser is essentially a heavy liquid solvent, perhaps as a soft solid at room temperature, and it slowly evaporates. In the timescale of a commercial product, this may not be too crucial (for example, nitrate products plasticised with camphor, such as hair grips and combs, were cheap and not expected to last very long). For an archive or museum object the rate of evaporation is significant within the period of use. A thin film of cellulose acetate loses plasticiser, perhaps a phthalate ester type, from its surface relatively quickly, whereas a thick film will retain it longer. Diffusion of the plasticiser through the film may be slower than evaporation from the surface, helping retain it. The early effects of loss of plasticiser are brittleness, a loss of transparency at the surface and shrinkage.

This physical process is by no means the only problem. Cellulose derivatives tend to oxidise readily in air; indeed guncotton, a form of cellulose nitrate, is a very effective explosive. Oxidation is driven by exposure to light, which provides energy to activate the reaction. Slow oxidation during display over many years has few physical effects, perhaps some slight yellowing when the object is kept in store, but this will bleach out on further exposure, disguising the changes that have occurred at the molecular level.

The oxidation products are acidic: Lavoisier called oxygen 'the acid generator'. Acidity catalyses a reaction with a second material readily available in the environment, water, in a process called hydrolysis. This breaks the chemical bonds that hold together this natural polymer which is made up of a linear chain of anhydroglucose units. Depolymerisation causes loss of strength and increased brittleness. This is similar to the degradation of paper or textiles, but industrially produced cellulose no longer has a cell structure and the longer fibres of natural cellulose which provide paper with some strength and flexibility long after it has become chemically degraded. In paper, degradation takes place first in the amorphous parts of the cellulose molecule, but these are the very parts that have been utilised in the production of cellulose acetate because

they are more readily dissolved by acid. Cellulose acetate therefore lacks a fibrous skeleton; even when new, it is just a thick jelly.

Another reaction with water causes the acetate component to split off from the cellulose, releasing acetic acid. The vinegar smell is the first readily identifiable warning, but it comes too late. Keeping the sculpture in an enclosed unventilated space allows the build-up of acid vapour, and may be the trigger for a rapid deterioration phase.

The chemical changes in cellulose acetate reduce its compatibility with the plasticiser, forcing it out of solution. Accumulation of plasticiser on the surface has been observed and this indicates that migration through the film is faster than evaporation from the surface, because the material has been enclosed and because the plasticiser is now less compatible. During manufacture, the film was extruded, dried and pressed to make it flat, locking in stresses related to differential drying and other undulations of the original film. As there is now little plasticiser, the forces locked into the acetate film begin to reassert themselves. Sheets distort and buckle, pull away from their joints and slump under gravity, shrinkage from loss of plasticiser and degraded material, or other external stress.

Since this degradation involves (more than one) positive feedback it is catastrophic and once triggered will only get worse, like an explosion in very slow motion. What can be done? An understanding of the mechanism gives us the possibility of radical intervention, such as removing the sculpture from the agents of further deterioration, including oxygen and water, de-acidifying the degraded film and re-plasticising it. But this analysis may not be complete and crucial details, such as interaction with the plasticiser, are not sufficiently well known for such a treatment to be recommended. Currently, we are attempting to record the sculptures in as much detail as possible and restricting their display.

If these important works are to be lost or to become unexhibitable, we need to find ways of interpreting them for future audiences.

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