

Application of the Uncertainty Principle to Electron Exposures in Silver Halides and its Implications for Attempts to Use Development Chemistry to Modify Granularity

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Abstract

The uncertainty principle is applied to electron exposures in silver halides to show that the granularity observed in silver halide photography is consistent with that principle and is present because of it. This provides the first consistent account for the differences in granularity due to light exposures and particle exposures in the silver halides. Implications for attempts to use development chemistry to modify granularity are discussed and observations are made regarding the limits on photographic response in terms of speed, contrast and granularity.

Introduction

Recent studies (Gokhale[1, 2]) on the response of silver halide microcrystals to exposure by light have shown that contrary to previous assumptions made initially by Hurter and Driffield, there is no unique response. This non-uniqueness does not arise from random fluctuations in exposure but from the fact that latent image formation renders photons detectable within the volume of a silver halide grain. The size of microcrystals used in silver halide photography is such that the Heisenberg uncertainty principle requires that there be a significant uncertainty in the energy of the exposing radiation which is only possible if the detection process is uncertain.

Application of Uncertainty Principle

In the case of exposure to light, the conjugate variable pairs momentum and position, energy and time give rise to the relation given previously (Gokhale[2]) in an earlier work viz.

$$\Delta E/E \geq \lambda/(2\pi\cdot\Delta x) \qquad (1)$$

Here ΔE is the uncertainty in exposure E, λ is the wavelength of the exposing radiation and Δx is the uncertainty in the position. For $\Delta x = 1$ micron (the size of a silver halide grain used in practical photography), $\lambda = 628$ nm, the uncertainty in exposure is

$$\Delta E/E \geq 0.1 \qquad (2)$$

Since,

$$1 \geq \Delta E/E \qquad (3)$$

there must be a condition on the smallest dimension of a silver halide microcrystal that can detect light of a certain wavelength. In fact this relationship is,

$$\Delta x \geq (\lambda/(2\pi)) \qquad (4)$$

This is the reason why tabular grains thinner than 0.1 micron have no sensitivity at 628 nm.

In the case of particle exposures, the particle energy is not related to the momentum in the same way as in the case of light and hence the uncertainty relation is now given by

$$\Delta E/E \geq h/(\pi(2mE)^{1/2}\cdot\Delta x) \qquad (5)$$

Here h is Planck's constant and m is the mass of the particle. By substitution of numbers encountered in actual practice, it can be seen that uncertainty limitations do not arise for electron exposures down to several angstrom. It is therefore clear that for small grain sizes (~0.1 micron) electron exposures only show the noise in the incoming electrons while light exposures will show noise that is so large as to preclude any detection of the photons.

For ordinary photographic materials it is well known that the only noise seen is that in the stream of incident electrons. This noise, especially at low frequencies, can be reduced by controlling the exposure (e.g. scanning instead of using a wide aperture). The granularity of electron exposures is then much lesser than for light exposures.

Chemical Development Effects

In the light of the above discussion it is clear that development effects cannot affect the noise except to worsen it. Considerable effort has been expended in the attempt to devise compounds that will, upon development in one place, release inhibitors that diffuse to other spots and alter the development to improve granularity. However, granularity as defined by Selwyn relates to low frequency noise that cannot be affected by the diffusion process. Indeed, even the pieces of film developed are separated in time and space, so compounds affecting development chemistry can never improve granularity. They can be used to worsen the low frequency noise by distributing in a non-uniform manner in position.

Reciprocity

Since silver halide emulsions show no reciprocity failure when exposed to electrons, it follows that their speeds can be increased without increasing granularity or noise because speed becomes merely an artificial number (a given exposure can be considered to be made up of a pre-exposure and an actual exposure). The granularity is naturally the same since one is really considering a single situation.

This observation points to a method for increasing speed without affecting a) the curve shape or b) granularity. When an emulsion with no reciprocity failure (such as is the case at very low temperatures approaching -180° C) is pre-exposed to light, its mean response will be shifted to the region of greater sensitivity while its approximate or mean shape will remain the same. No increase in noise will be associated with this since the noise will remain at the same level as would have existed with the full exposure. It may be noted that low temperature exposures have in fact been used in astronomical photography with great success. Finally, it is expected that mean sensitivity will increase to the level of less than one photon per grain due to the fact that the development of some grains at least can become observable even if exposure has changed by less than one photon per grain. In fact, this situation already exists when a single photon produced in the decay of mesons is photometrically observed (e.g. Powell, C. F. et al[3]). It is also observed in routine use of lith films where the contrast is quite high and the speed can be considered to be arbitrarily high since it is possible to start counting exposure from a point arbitrarily close to the toe region of the mean photographic response.

References

1. V. V. Gokhale, Uniqueness of the Photographic Response in the Silver Halides, *Proceedings of the 47th Annual Meeting (ICPS 1994) of the Society for Imaging Science and Technology* (1994).
2. V. V. Gokhale, Enhance ment of Mean Sensitivity due to Uncertainty Induced Fluctuations in the Silver Halides, *Proceedings of the 48th Annual Meeting of the Society for Imaging Science and Technology* (1995).
3. C. F. Powell, et al *Study of Nuclear Particles by the Photographic Method* (1953).