

Film Speed and Graininess Are Two Sides of Grain Size: Doubling the Diameter Makes Film Four Times Faster and Twice as Grainy

— the span of light from 10 % to 90 % developed is **1.339538**, **0.583089** and **0.281522** decades for 1, 4 and 16 required photons, unchanged by grain size — the separator is whether one asks about grain size or the number of photons a grain needs to develop — [Paper 889]

Yuuki YAMAGISHI (山岸 勇輝)

Yamagishi Complexity Torus Lab, Japan

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YOI: <https://www.yamagishiyuuki.com/yoi/889>

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Abstract

It is easy to assume that fast film is made of a different material that catches light better. This paper counts, in a model where grains count photons to be developed, that speed and graininess both come from the same grain size. No new theorem or law is claimed. First, larger grains develop with less light: the light needed to develop half the grains is **3.672061** for diameter 1, 0.918015 for 2 and 0.229504 for 4 (Section 2). Second, doubling the diameter needs exactly a quarter of the light, two stops faster: the grain area quadruples, so the same light brings four times the photons; the ratio was 4 within a relative difference of 10^{-9} (Section 2). Third, and this is the core. The same doubling of diameter doubles graininess: density fluctuations between windows are 0.008980 for diameter 1 and 0.017767 for diameter 2, a ratio of **1.978537** (Section 3). Fourth, graininess is set by how many grains fit in a window: a window holds 800 grains of diameter 1 and 200 of diameter 2, and the fluctuation formula 0.008839, 0.017678, 0.035355 matches the random counts (Section 3). Fifth, the steepness of the rise does not change with grain size: the span of light from 10 % to 90 % developed is **1.339538**, **0.583089** and **0.281522** decades for 1, 4 and 16 required photons, and the same when grain area is quadrupled (Section 4). Sixth, the separator is whether one asks about grain size or the number of photons a grain needs to develop: grain size moves speed and graininess together; the required photon count moves the steepness (Section 4). **Keywords:** silver-halide photography, film speed, graininess, Poisson distribution, photon count.

Scope of this paper (scope note): No new theorem or law is claimed: that larger emulsion grains give higher speed and coarser graininess, that a grain forms a developable centre from a few photons, and counting with the Poisson distribution, are all known in photographic chemistry. No real film is claimed: grain diameters, the 4 required photons and the covered share 0.5 are model values matching no film. Chemistry is not included: developer action, sensitising dyes and grain shape are not included. Image sensors are not entered: digital pixel size and noise are not treated. Relation to earlier papers: Paper 878 showed that the span of concentration from first effect to full effect is set not by the effective concentration but by the degree of cooperativity. This paper stands beside it. There the effective concentration set the curve's position and cooperativity its span. Here grain size sets the position (speed) and the required photon count the span. What is added is finding the light that develops half the grains for three diameters, counting window fluctuations at random and measuring 1.978537 times for doubled diameter, measuring the rise span for each required photon count, and placing the separator on grain size versus required photons.

1. Notation and the Question

Setting: a grain of area a receiving light H per area gets a Poisson number of photons with mean Ha . The grain is developed once it receives k or more photons.

$$p(H) = P(\text{Poisson}(Ha) \geq k), \quad \sigma_{\text{window}} \approx \sqrt{\frac{p(1-p)}{n}} \times \frac{na}{S}$$

We took $k = 4$ and grain area as the square of the diameter. Speed is the light H_{50} developing half the grains, and graininess the standard deviation between windows of area $S = 1600$ (half covered by n grains) of the covered share. 400 windows were generated at random.

Question: why is fast film grainy?

2. Grain Size and Speed

Computation 2.1: for each grain diameter, the light developing half the grains was computed.

grain diameter	light for half developed	grains per window
1	3.672061	800
2	0.918015	200
4	0.229504	50

Observation 2.2

doubling the diameter needs exactly a quarter of the light. The ratio of light for half developed is 4.000000, or 2.000000 stops: the grain area quadruples and the same light brings four times the photons, so a quarter of the light gathers the same number.

3. Grain Size and Graininess

Computation 3.1: 400 random windows were generated and the mean and fluctuation of the covered share counted.

grain diameter	mean covered share	fluctuation between windows	formula
1	0.249855	0.008980	0.008839
2	0.248675	0.017767	0.017678
4	0.250200	0.034633	0.035355

Observation 3.2

this is the core. The same doubling of diameter doubles graininess. The fluctuation between windows grew 1.978537 times from diameter 1 to 2: the grains in a window fall from 800 to 200, each covering four times the area. With a quarter as many, the fluctuation grows by $\sqrt{4} = 2$. The same change that makes the film four times as fast makes it twice as grainy.

4. Steepness of the Rise

Computation 4.1: varying the required photon count k and grain area, the span of light from 10 % to 90 % developed (in decades) was computed.

required photons k	grain area 1	grain area 4
1	1.339538	1.339538
4	0.583089	0.583089
16	0.281522	0.281522

Observation 4.2

the steepness is set by the required photon count, not by grain size. Raising the required photons from 1 to 16 narrows the span from 1.339538 to 0.281522 decades: quadrupling grain area leaves the span unchanged, only shifting the curve toward less light.

Observation 4.3

the separator is whether one asks about grain size or the number of photons a grain needs to develop. Grain size moves speed and graininess together: the required photon count moves the steepness of the rise and does not enter the fluctuation formula. Raising speed without graininess means moving something other than grain size.

Observation 4.4

placed beside Paper 878.878 showed that the effective concentration sets a curve's position and cooperativity its span. Here grain size sets the position and the required photon count the span. It is the same shape, with position and span moved by separate quantities.

5. Census and Closing

1. developed at k or more photons (Section 1): **Poisson distribution**.
2. **3.672061** for diameter 1 (Computation 2.1): **light for half developed**.
3. **0.918015** for diameter 2 (Computation 2.1): **exactly a quarter**.
4. **two stops faster** (Observation 2.2): **area quadruples**.
5. **fluctuation 1.978537 times** (Observation 3.2): **the core**.

6. **grains per window 800 to 200** (Computation 2.1): **fewer grains**.
7. **formula 0.008839, 0.017678** (Computation 3.1): **matches random counts**.
8. **span 0.583089 decades at $k = 4$** (Computation 4.1): **independent of area**.
9. **0.281522 decades at $k = 16$** (Computation 4.1): **steeper**.
10. **grain size, or required photons** (Observation 4.3): **the separator; Paper 878**.

Closing: Film speed and graininess are two sides of the same grain size: doubling the diameter makes film four times as fast and twice as grainy. In a model where a grain develops after 4 or more photons, doubling the diameter needs exactly a quarter of the light to develop half the grains, and window fluctuations grow 1.978537 times, because quadrupling grain area gathers four times the photons but fits a quarter as many grains in a window. The rise span is 1.339538, 0.583089 and 0.281522 decades for 1, 4 and 16 required photons, unchanged by grain size: grain size moves speed and graininess together, and the required photon count moves steepness. Placed among the earlier papers: beside Paper 878's "position by effective concentration, span by cooperativity", we placed the same shape: position by grain size, span by required photons. To be honest: grain and photon numbers are model values, and neither development chemistry nor grain shape is included.

References

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Yuuki YAMAGISHI (山岸 勇輝)

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