poral overlap between verbal responses and the stimuli contingent upon them. Under normal sidetone, this overlap is present whether the subject is instructed to listen or not to listen. It may also be present when the subject is speaking under delayed sidetone and is instructed not to listen, since such instructions may facilitate control by nonauditory stimuli which overlap the responses. When, however, the non-overlap is auditory (delay) and the subject is instructed to listen to it, the similarity to normal overlap conditions is minimized. This may account for the high reading rates under the first three conditions, and the low rates under the fourth condition displayed in Fig. 1.

A stimulus which maintains the strength of a response when contingent upon it is reinforcing. Reinforcement is maximal when it is immediate. The auditory stimulus is generally contingent upon a verbal response in this sense (*6*). In the typical operant conditioning experiment, the experimenter controls such stimuli; the stimuli in verbal behavior, however, are under control of the speaker, or self-controlled. Delayed feedback separates these stimuli from the responses and may bring them under the control of the experimenter. Their role in maintaining behavior can thus be analyzed experimentally (*7*). Delayed feedback may prove a useful tool not only for experimental analysis and control, but also in identifying the stimuli that maintain continually ongoing behaviors, of which verbal behavior is one example (*8*).

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3. The stutterer mentioned was on an avoidance schedule during which delayed feedback was present continuously, except when he stuttered. This turned off the delay and presented normal feedback for 10 seconds. The prolongation pattern was accompanied by virtually no stuttering, hence the delayed feedback was practically continuous throughout the session. Where delayed feedback was presented continuously without being contingent upon responses of the speaker, a stutterer reacted as did the normally fluent subjects: an initial lowering in reading rate, followed by recovery. Details are reported by Goldiamond (*2*).
4. The amounts of delay used were 200, 300, and 400 msec. No functional relations were discovered between these amounts and reading rates during the sessions.
5. This is considered as "consistent with maintaining a 'normal' experience at the ear" by J. W. Black (*1*).
6. The reinforcing stimulus can also serve as a discriminative stimulus which controls the next response as well as reinforcing the preceding class of responses, a process called chaining. See F. S. Keller and W. N. Schoenfeld, *Principles of Psychology* (Appleton-Century-Crofts, New York, 1950); B. F. Skinner, *Verbal Behavior* (Appleton-Century-Crofts, New York, 1957); J. G. Holland and B. F. Skinner, *The Analysis of Behavior* (McGraw-Hill, New York, 1961).
7. This issue is considered in greater detail by I. Goldiamond, "Perception," in *Experimental Foundations of Clinical Psychology*, A. Bachrach, Ed. (Basic Books, New York, in press).
8. The research described in this report was sponsored by the Operational Applications Laboratory, Air Force Command and Control Development Division, Air Research and Development Command, under contract No. AF 19 (604)-6127. This report is identified as AFCCDD TR-60-38.

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On the Increase of Sites for Chromosome Exchange Formation after Chromosome Duplication

Abstract. Although radiation-induced chromosome exchanges are not distributed among cells according to a Poisson distribution, chromatid interchanges are. In *Vicia faba* the lack of fit to a Poisson distribution has been attributed to the occurrence of only two sites per cell where the chromosomes are close enough to form exchanges if broken. When chromatid aberrations are induced, after chromosomal duplication, the number of sites more than doubles.

One of the most common and significant effects of radiation on biological systems is the nuclear damage manifested as chromosome aberrations. According to the most widely accepted theoretical explanation of the induction of such aberrations, the radiation first breaks the chromosomes, and the broken ends then rejoin in new configurations that are frequently visible at metaphase.

Although most chromosome aberrations are distributed among cells according to a Poisson distribution, indicating that breaks occur at random (*1*), cases of nonrandomness have been reported (*2*). In particular, the chromosome exchanges that are induced before the chromosome duplicates do not fit such a distribution (*3*). This is contrary to the results observed for chromatid interchanges (induced after chromosome duplication) in *Tradescantia* microspores (see *1*). The nonrandom distribution of chromosome exchanges in *Vicia faba* lateral roots, *Tradescantia* microspores, and *Hordeum* seeds is characterized by the occurrence of too few cells having multiple exchanges (*3, 4*).

This lack of randomness is attributed to the occurrence of a limited number of places within the nucleus where the strands of the chromosomes would lie close enough to one another to rejoin if broken (*4*). Lea originally calculated this rejoining distance, called h, to be 1 μ, but more recent calculations by Wolff (*3*) and Wolff, Atwood *et al.* (*4*) indicate that this distance is less than 0.3 μ and is probably about 0.2 μ. If there were a large number of sites where the chromosomes come within h microns of one another by chance, more cells would be expected to have multiple exchanges and the aberrations would be distributed randomly. Atwood and Wolff's calculations have shown that the average number of sites per cell for *Vicia* root tip cells is two or less, and the average number for *Tradescantia* microspores is four (*5*). Furthermore, the chromosome exchange aberrations are distributed among the cells according to the binomial distribution of

$$[p + (1 - p)]^n \qquad (1)$$

where p is the probability of obtaining an exchange in a site and n is the number of sites in the cell.

There were four such sites in the *Tradescantia* microspore nucleus before chromosomal duplication, and after duplication one might expect this number of sites to increase. If the number of sites as much as doubled after chromosome duplication, it would be impossible to distinguish between a binomial and a Poisson distribution of aberrations (because it is extremely difficult to score cells with excessive chromosomal damage accurately), and the binomial distribution for a large number of sites would approximate a Poisson distribution. In *Vicia* root tip cells, however, which have only two such sites before chromosome duplication, if the number of sites doubled to become four, then it would be possible to distinguish between the two types of distributions.

The experiments reported here were undertaken to determine the magnitude of the increase in the number of sites which occurs after chromosomal duplication.

Inflorescences of *Tradescantia paludosa* were collected, placed in waxed containers with spring water, and irradiated in air with 120 r of x-rays at

Table 1. Test of goodness of fit for chromatid interchanges. In the columns headed "Aberrations per cell," when a number is placed between two columns, it represents the sum of the expected values for those two columns. In all chi-square tests there is one degree of freedom.

Material		X-ray dose (r)	Aberrations per cell 0	1	2	3	χ^2 test
			All interchanges				
Tradescantia microspores	Observed	120	208	76	14	2	$\chi^2 = 0.05$
	Expected*		209.4	75.3	15.3		$P = .5$
Vicia lateral root tips	Observed	200	202	76	17	5	$\chi^2 = 0.85$
	Expected*		197.7	82.5	19.8		$P = .3$–$.4$
	Expected†		193.5	89.7	16.8		$\chi^2 = 4.07$
							$P = .045$
			Symmetrical interchanges				
Tradescantia microspores	Observed	120	260	40			$\chi^2 = 0.33$
	Expected*		263.4	36.6			$P = .62$
Vicia lateral root tips	Observed	200	234	58	6	2	$\chi^2 = 0.99$
	Expected*		226.8	63.6	9.6		$P = .3$–$.4$
			Asymmetrical interchanges				
Tradescantia microspores	Observed	120	232	66	2		$\chi^2 = 0.86$
	Expected*		238.5	61.5			$P = .35$
Vicia lateral root tips	Observed	200	257	37	6		$\chi^2 = 2.75$
	Expected*		255	41.7	3.3		$P = .1$

*Expected values calculated from the Poisson formula (Eq. 2). †Expected values calculated from the binomial formula (Eq. 1) when $n = 4$.

a dose rate of 100 r/min from a G.E. Maxitron tube operated at 250 kv (peak), 30 ma, with a 3-mm aluminum filter (half-value layer, 0.441 mm Cu). Squash preparations of the microspores were made 18 hours after irradiation; they were stained in aceto-carmine and permanently mounted in Euparal. Metaphases were studied and scored for aberrations.

Vicia lateral roots were grown in continuously aerated, glass-distilled water after the peeled soaked seeds had been germinated between layers of wet cotton batting and filter paper. The roots were irradiated in air with 200 r, placed back in the aerated water, collected 24 hours later, treated in 0.2-percent colchicine solution for 2 hours, fixed in Ford's modification of Flemming's fixative, and stained by the Feulgen method. Squash preparations were made, and again metaphases were studied and scored for aberrations.

Both symmetrical and asymmetrical chromatid interchanges produced after chromosomal duplication were scored in both materials. The distributions of such aberrations were then tested for the goodness of fit to the Poisson formula of

$$e^{-m} \cdot m^r / r! \qquad (2)$$

where r is the number of aberrations in the cell, whether a cell had zero, one, two, three, or more interchanges, and m is the mean number of aberrations per cell observed in an experiment.

As may be seen in Table 1, the chromatid interchanges induced in cells of *Vicia* lateral roots are distributed according to the Poisson formula. This is contrary to the results for chromosome exchanges (*3*) or for chromatid interchanges induced close to metaphase when the chromosomes are relatively condensed (*6*).

For chromosome aberrations, however, only asymmetrical exchanges were scored since most symmetrical exchanges can not be distinguished as exchanges at metaphase. For chromatid interchanges, however, because of sister attraction of the chromatids, both symmetrical and asymmetrical exchanges can be scored. We thought, therefore, that a more accurate test would be to check the distribution of asymmetrical chromatid interchanges, which are more comparable to the aberrations scored as chromosome exchanges. Table 1 shows that both the symmetrical and asymmetrical chromatid interchanges taken separately still fit the Poisson distribution.

The chromatid interchanges in *Vicia* lateral root tip cells, analyzed for goodness of fit to the binomial distribution of Eq. 1, did not fit such a distribution when n (the number of sites in the cell) was taken to be equal to four, the number of sites expected after chromosomal duplication since the number of sites for the interphase nucleus has been calculated to be two (*5*). The results, however, show a good fit to the Poisson formula, as good a fit as the *Tradescantia* microspore data show.

The Poisson distribution obtains when there is a large number of places where an event can occur (sites) and a small probability of its occurrence. The fact that the *Vicia* data give a good fit to the Poisson formula indicates that after chromosomal duplication the number of sites where the chromosomes lie within h microns of one another is greatly increased.

It is concluded, therefore, that the number of sites where by chance the chromosomes are close enough to interchange if they are broken, increases after the chromosomes are duplicated and that the increase is not a mere doubling of the original number. The increased number of sites leads to a Poisson distribution of interchanges among cells. This is contrary to the results obtained when the number of sites is smaller, either before synthesis of deoxyribonucleic acid (*3, 4*) or after chromosomal condensation has progressed (*6*).

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Mineralization of Bacteria

Abstract. A variety of viable and nonviable bacteria became mineralized with hydroxyapatite when implanted in dialysis bags in the peritoneal cavities of rats. The microscopic pattern of mineral deposition appeared analogous to that in the formation of oral calculus. Since nonviable organisms were mineralized at an accelerated rate, bacterial metabolic processes may not be essential for mineralization.

It has been demonstrated that certain preparations of collagen undergo calcification when implanted in the peritoneal cavities of living animals (*1*). This phenomenon is now serving as a basis for in vivo studies of the mineralization process. A recent refinement in experimental technique has been the implanta-