were found harmless except olive oil, kerosene and xylol, each of which caused a considerable diminution of brilliance. Evidently the slight solubility and slow diffusion downward of these substances saved the bacteria from cytolyzing effects.

The impermeability or very slight permeability of viscous motor oil to oxygen is in agreement with the finding of Kruse (1926)[2] that alkaline pyrogallate solutions under medium motor oils were not perceptibly oxidized after eight weeks, while those covered with kerosene and mineral oil were oxidized 30 per cent. and less than 5 per cent., respectively. This difference Kruse ascribes to the greater viscosity of the motor oils.

It will be noted that of the liquids used the medium motor oil is by far the best for exclusion of oxygen. Heavy rubber stoppers and thick tubing, if time is allowed for diffusion out of the oxygen dissolved in the surface, will introduce only small errors, the diffusion of oxygen through rubber as thick as 1 cm. being slight.

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SPECIAL ARTICLES

THE PRODUCTION OF MUTATIONS AND REARRANGEMENTS OF GENES BY X-RAYS

MUTATIONS and rearrangements of genes have been produced by Muller by subjecting *Drosophila melanogaster* to the action of X-rays.[1] Similar experiments have since been performed by the writer; and these, while not so extensive, are in entire agreement with those of Muller. As a result of X-ray treatment, there have been obtained mutations producing visible and lethal effects, as well as genetic modifications of the frequency of crossing over, and attachments between genes of different chromosomes.

Males of *Drosophila melanogaster* were exposed to X-rays in dosages corresponding approximately to those designated by Muller as T4 and T2, the former being about twice the latter. The treated males and untreated brothers used as controls were mated to untreated females. The fertility of the irradiated males and of their offspring was reduced, the stronger treatment being the more effective in each case. As has been suggested by Muller, sterility might be produced in the treated males by mutations resulting in dominant lethal genes, and it might be produced in the offspring by mutations resulting in dominant genes for sterility.

The experiment was designed primarily to test the effect of the treatment on the X-chromosome. In order that the treated and control X-chromosomes might be recognized in subsequent generations, the males were mated to females that differed from them in certain sex-linked genes. Since every daughter received a treated or control X, any change in this chromosome would be inherited by half her sons and would be detected if it produced a visible or lethal effect.

Nine of the thirty-seven F_1 females in the T4 series and ten of the forty-seven F_1 females in the T2 series were found to have inherited altered X-chromosomes from their fathers. No changes in the X were observed in the fifty-six F_1 females of the controls. (Only the fertile females are included in the reckoning.) In X's of the T4 series there were three mutant genes (one dominant, two recessive) producing visible effects, and six lethals. In X's of the T2 series there were two genes (both recessive) producing visible effects, and eight lethals. Of the non-lethal mutant genes, three recessives are allelomorphs of genes already known (deltex, furrowed, uneven); the others seem to be changes in hitherto unknown loci.

The experiment was not designed to detect mutations in the autosomes; and such changes resulting in recessive genes would, for several reasons, have escaped discovery. (One autosomal recessive was found in an F_2 culture in the control series, but it must have been present in heterozygous form in either the male or the female of the P_1 generation.) New autosomal dominants, however, could be recognized; and three were found, all in the T2 series. One of these (an eye color—the only dominant mutant eye color known in *D. melanogaster*) arose in a treated male; the two others (probably allelomorphs of Star and Hairless, respectively) may have originated in either the males or the females of the P_1 generation.

In the offspring of the treated flies there were found six translocations in which genes of the second chromosome behave as if attached to the X; that is, they are inherited in sex-linked fashion. In at least some of these cases, genes along the entire length of the second chromosome behave in this way. The point of attachment in the X differs in different cases; whether or not the point of attachment in the second chromosome differs is not known. The results would

[2] Kruse, T. K., "The Relative Efficiency of Several Oils for the Exclusion of Oxygen," *J. Phar. and Exp. Ther.*, *27*, No. 3, April, 1926.

[1] Muller, H. J., "Artificial Transmutation of the Gene," SCIENCE, Vol. 66, pp. 84–87 (1927); "The Problem of Genic Modification," *Proc. Fifth Int. Congress of Genetics* (in press); "The Effects of X Radiation on Genes and Chromosomes," abstracts in *Anat. Record*, Vol. 37, p. 174, and SCIENCE, Vol. 67, p. 82.

seem at first sight to imply attachments between entire chromosomes; but they might also be produced by the attachment to one chromosome of a piece of another, provided that individuals receiving more or less than the normal complement of genes did not survive. Tests are being made to decide between these alternatives and to discover (if fragmentation is involved) which chromosome is broken. Three of the translocations occurred in the T4 series (where such changes could have been detected in seventeen cases), and three in the T2 series (where they could have been detected in forty-three cases). None were observed in the controls, although here they could have been detected in fifty-five cases. It seems probable that in the irradiated flies there occurred in addition to the translocations observed others involving genes not followed in the experiment. (No genes of the third or fourth chromosome were followed.)

Eight cases of genetic reduction of crossing over in the X-chromosome were observed; some prevent crossing over almost entirely, others affect only part of the chromosome. Five were in the T4 series and three in the T2 series; but this does not represent the total frequency of such modifications, since they could have been recognized in only twenty-two cases in the former and thirteen in the latter. In the controls no such changes would have been detected; but it is very unlikely that they occurred, for in all the *Drosophila* work in which X-rays have not been used only five genetic modifications affecting crossing over in the X-chromosome have been found. In the present experiment one of the modifiers is associated with no other effect, one is associated with a non-lethal mutant gene, the others with lethals or translocations.

The dominant eye-color gene behaves as if it were continually mutating in both germ and somatic cells. It is not yet certain, however, that the behavior is to be ascribed to mutation.

Apart from this, the new genes (they have all, with the exception of one lethal in the T2 series, been followed through several generations) seem to behave like ordinary mutant genes. It is possible that some of the lethals are not due to point-mutations. Six of them are associated with crossover modifiers or with translocations; and this suggests that the same disturbance may be responsible for all the effects in each case. There is also a possibility that some of the other lethals are due to translocations involving genes not followed in the experiment. Nevertheless, it is probable that at least some of the lethals are due to changes in single genes. One of the lethals apparently crosses over from the translocated genes with which it is associated. And all the non-lethal genes behave like point-mutations—some of them are, in fact, allelomorphic to, if not identical with, genes produced by ordinary mutations. The nature of the crossover modifiers has not yet been ascertained.

A comparison of the mutation rates is best made on the basis of the changes in the X-chromosomes. If we include the visible mutants and the lethals, about one X-chromosome in four mutated in the T4 series, about one in five in the T2 series, and none in the controls. The figures suggest that a greater effect was produced by the stronger treatment (and the same is true of the translocations). But the numbers are not large enough to decide whether the effect is proportional to the dosage or to some function of it. Moreover, it may be that the effect of the stronger treatment is relatively underestimated. For there was more sterility in the T4 series; and if the frequency of mutation was correlated with sterility (quite apart from whether sterility was produced by mutations), then the individuals in which the greatest number of mutations occurred were the very ones that could not be tested.

But if the results do not show precisely how the mutation rate varies with the strength of the treatment, they demonstrate the effectiveness of the treatment itself. There were eight (possibly ten) mutant genes producing visible effects and fourteen lethals in the eighty-four treated individuals, and none in the fifty-six controls. The results are being subjected to further analysis; but the work has gone far enough to show that, as in the experiments of Muller, genes can be modified and rearranged as a result of treatment with X-rays.

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A DETERMINATION OF THE NEWTONIAN CONSTANT OF GRAVITATION BY A STUDY OF THE VIBRATIONS OF A TORSION PENDULUM

CONSIDER the result of suspending an enclosed torsion pendulum, supposed for simplicity to consist only of two massive particles m, m at distances b from the axis of suspension, in the vicinity of the spherical bob of a common pendulum; the latter being symmetrically placed with respect to the torsion pendulum and executing vibrations of amplitude b in a plane parallel to m, m. If the two periods are nearly equal, the alternate gravitational attractions of the large mass upon the two particles m, m will cause the torsion pendulum to vibrate about its axis of suspension. Besides the torsional oscillations there will be forced