When the clockwork is used to drive one drum only (Fig. 3), the slowest speed is one revolution in fourteen hours. When two drums are used (Fig. 4), connected by a paper belt about 2.6 meters long, the slowest speed is one revolution in about fifty-two hours. Naturally, the speeds vary with the motor used. The cylinders are 25 cm high and 70 cm in circumference.

As stated above, disengaging the right lever stops the drum, which may then be turned to right or left in order to inspect the tracing or adjust the recording instruments.

W. T. PORTER
C. E. ROY
A. VIANEY
DOVER, MASSACHUSETTS

SPECIAL ARTICLES

A POSSIBLE RELATION BETWEEN NATURAL (EARTH) RADIATION AND GENE MUTATIONS[1]

THE discovery three years ago that X-rays and radium produce gene mutations under laboratory conditions has raised the question of how mutations in nature occur.

Muller,[2] Olson and Lewis,[3] Haldane[4] and others have suggested that possibly radiations from the earth, or even cosmic rays, may have played an important rôle in the evolution of species by furnishing heritable variations upon which natural selection may act. It is not improbable that in earlier times radioactive substances were distributed over the earth rather differently than they are to-day and may have been more powerful, as evidenced by the quantity of their end products, helium and lead, now present in the earth. Joly[5] has suggested that cosmic rays may change in intensity and infers that we may be now at the low ebb of a cycle of cosmic radiation. He ties up this decrease of cosmic radiation with the increase of cancer in recent times. Haldane[4] says that "mutants are produced in large quantities by X-rays, and it may be that much of normal mutation is due to the beta and gamma rays from potassium, other radioactive substances and cosmic radiations."

Olson and Lewis[3] were among the first to point out the desirability of testing experimentally the effects of natural radiation upon organisms. According to them, the rays are effective only when absorbed with resulting ionization. Hence the biological effects will be in proportion to the amount of ionization they set up. The above suggestions inspired at least two geneticists to put the matter to an experimental test.

Working independently, Babcock and Collins[6] and the present writers performed almost identical experiments to test this point. Using an electroscope Babcock and Collins discovered a location in a street-car tunnel in San Francisco where the natural ionizing radiation was fully twice as great as the radiation in their laboratory in Berkeley. Accordingly their experiment was designed to compare the rates of occurrence of sex-linked lethal mutations in *Drosophila* in the street-car tunnel and in the laboratory. Three thousand four hundred and eighty-one tests were made in Berkeley, and nine, or 0.26 per cent., produced no male flies and hence showed the occurrence of that many new lethals. Two thousand five hundred tests made in the tunnel gave thirteen, or 0.52 per cent., of lethal mutations. While the difference in rate, 2.5 times the probable error, is not fully significant statistically, it is believed by these authors that it may be fairly so considered. Upon a reanalysis of the data showing the actual experimental variation in rate in the several subgroups in each of the two series it was found that the difference between the average rates for the two locations was increased. This difference was 0.275 ± 0.086.

The present writers, in accepting the implied challenge to experiment contained in Olson and Lewis's paper, considered themselves suitably located for such an undertaking, *i.e.*, near the Ozark caves and lead mines of Missouri. But a long search with the electroscope in the numerous caves and lead mines of this region failed to reveal a location with a sufficient increase of ionization over that of the laboratory, or the middle of a Missouri corn-field, to justify breeding experiments.

Operations were then transferred to Colorado. There in the East Paradox Valley of western Colorado in an abandoned carnotite mine the air was strongly ionized. In addition to the electroscope readings a rough attempt was made to compare the

1 The expenses of this investigation were met in part by a grant from the committee on the effects of radiation upon living organisms of the National Research Council.

2 H. J. Muller, "The Problem of Gene Modification," *Verhandlungen des V. Internationalen Kongress für Vererbungswissenschaft*, Berlin, 1928, pp. 234–260.

3 A. R. Olson and G. N. Lewis, "Natural Radioactivity and the Origin of Species," *Nature*, 121: 673–674, 1928.

4 J. B. S. Haldane, "The Species Problem in the Light of Genetics," *Nature*, 124: 514–516, 1929.

5 J. Joly, "Cosmic Rays and Cancer," *Nature*, 124: 579, 1929.

6 E. B. Babcock and J. L. Collins, "Natural Ionizing Radiation and the Rate of Mutation," *Nature*, 124: 227–228, 1929.

amount of natural ionization in this mine with that of one mg of radium. Radiation in the mine was found to be 0.39 times as intense as that from one mg of radium when the rays were passed through a 0.156-inch lead filter.

Male flies were exposed in this mine for 140 hours and then returned to St. Louis for the breeding tests. The well-known C1B method for detecting lethal mutations in the X-chromosome was employed.

In this technique lethals are revealed in the F_2 cultures. There were 2,860 test cultures, of which seven, or 0.245 ± 0.062 per cent., produced no male flies. In the 1,308 control cultures there was one lethal mutation, or 0.076 ± 0.051 per cent. The difference between tests and controls is 0.169 ± 0.081, a difference 2.09 times its probable error.

While this difference is theoretically not statistically significant it actually may be so. It is highly probable that if the flies could have been exposed for a much longer period than the 140 hours the results would have been more striking. This was impossible in this instance as the time consumed in taking the flies to Colorado and back, together with finding a suitable location there for the test, used up a considerable portion of their life span. The results secured, however, point to much greater success when the experiment can be repeated, hatching the flies, exposing them for several weeks and breeding them for results at the mine. Or a second possibility seems equally promising, namely, from the electroscope readings in the carnotite mine exactly equivalent amounts of radiation can be duplicated in the laboratory and the time of exposure extended accordingly.

These two experiments, one in California and one in Colorado, while falling short of being statistically significant, nevertheless are consistent in that both give an actually higher rate of mutation in flies exposed to natural radiation than in the controls. The least that can be said for the results is that they strengthen definitely the plausibility of the suggestions quoted above to the effect that natural radiation may be responsible for the mutations which are the grist of the natural selection mill with the resulting evolution of new forms.[7]

FRANK BLAIR HANSON
FLORENCE HEYS
WASHINGTON UNIVERSITY

[7] We take this opportunity of expressing our appreciation to Dr. R. D. George, state geologist of Colorado, for his many helpful suggestions which led to the finding of what must be one of the most radioactive locations in Colorado; also to Mr. R. S. Blitz, of the Vanadium Corporation, who kindly permitted the tests to be made in the carnotite mine. Mr. Walter D. Claus, of the physics department of Washington University, constructed the electroscope and made the ionization tests.

THE EFFECT OF VARYING THE DURATION OF X-RAY TREATMENT UPON THE FREQUENCY OF MUTATION

IT has been shown repeatedly that X-rays produce variations. We need now to learn more about the nature of the X-ray action in producing these variations, and to obtain further evidence regarding the question whether or not such dilute amounts of radiation as are present in nature might be expected to be producing the mutations found in nature. As a step in that direction, this experiment was begun, in the early part of 1928, at the suggestion and under the supervision of Dr. H. J. Muller, to find the relation between different doses of X-rays and the resultant effect upon the individuals—more definitely, to get the relation of dosage to the frequency of sex-linked lethal mutations produced in *Drosophila melanogaster*, and to analyze the results found.

The different dosages varied only in the length of time of treatment. All other factors were kept as nearly constant as possible. Adult males having the autosomal characteristic brown-eye were collected and kept at 27° C. for at least three days before treatment. The experiment was divided into four series in each of which the flies were divided in about the same proportions among the different dosage groups. All the flies, including the controls, were handled similarly except for the time of treatment. After treatment, these males were mated to virgins containing C1B in one X-chromosome and scute vermilion forked in the other, and after seven days these P_1 flies were discarded. The F_1 bar-eyed (C1B-containing) females were mated to their brothers. Normally half the F_2 males die because of the lethal in the C1B combination. Now if a lethal had arisen by treatment of the X-chromosome of the P_1 male, there would be no F_2 males appearing. However, it is necessary to check these apparent lethals in the F_2 cultures by further breeding in order to be certain that the no-male result was due to a lethal and not to other conditions. For that purpose, the non-bar-eyed F_2 females in the apparently lethal cultures were mated to scute vermilion forked males. Only the cultures showing a lethal in these F_3 results were recorded under column three in the table given.

The results are tabulated briefly in the following table in which "dosage" refers to duration of treatment: t_1 lasted three and one half minutes; t_2, double that time, etc. As previously indicated, the total number of lethals is based on the F_3 results from the matings of the non-bar females by sc v f males. The "per cent. of observed lethals due to treatment" is found by subtracting the control lethal per cent. $(0.24 \pm .051)$ from the per cent. found for each dosage. The "ideal per cent." is calculated from the