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.

The writer desires to thank Dr. L. A. Milkman for his cooperation in administering the X-ray treatments.

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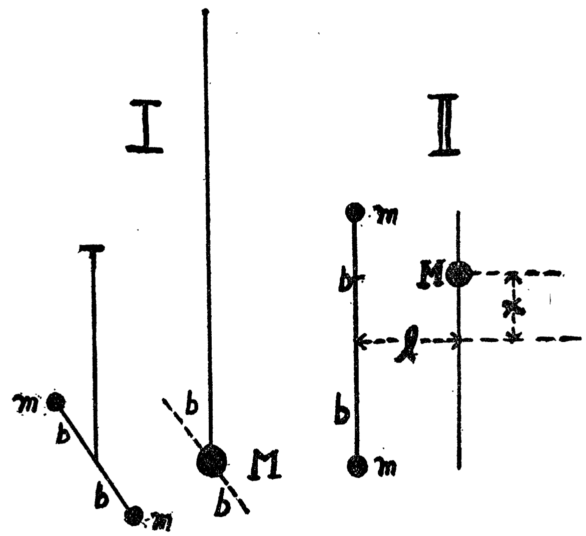
A DETERMINATION OF THE NEWTONIAN CONSTANT OF GRAVITATION BY A STUDY OF THE VIBRATIONS OF A TORSION PENDULUM

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



pendular vibrations; but these may be neglected. Let I be the moment of inertia of the torsion pendulum; k the couple due to damping for unit angular velocity; and μ the moment of torsion of the suspension. Let the displacement $\varkappa$ of M at time t be $\varkappa = b \sin \varrho t$. Set

$$2a = \frac{k}{I};\quad n^2 = \frac{\mu}{I}.$$

Then the differential equation of motion of the torsion pendulum is

$$(1)\ldots \frac{d^2\vartheta}{dt^2} + 2a\frac{d\vartheta}{dt} + n^2\vartheta = \frac{GMmb}{I\,l^2}\left[\frac{1}{\left\{1+\frac{1}{l^2}(b-\varkappa)^2\right\}^{3/2}} - \frac{1}{\left\{1+\frac{1}{l^2}(b+\varkappa)^2\right\}^{3/2}}\right]$$

where G is the constant of gravitation. The right hand member of (1) may be replaced by the first term of its Fourier sine series (suggested by E. P. Adams), which it very nearly equals:

$$(2)\ldots\ldots \frac{GbMm}{I\,l^2}\left(1-\frac{1}{\left(1+\frac{4b^2}{l^2}\right)^{3/2}}\right)\sin \varrho t = B \sin \varrho t.$$

The solution of (1) which satisfies the initial conditions is

$$(3)\ldots\vartheta = \frac{B}{\left\{(n^{1^2}-\varrho^2)^2 + a^2(a^2+2n^{1^2}+2\varrho^2)\right\}^{1/2}} \left\{e^{-at}\frac{\varrho}{n^1}\sin(n^1t+\varepsilon^1) + \sin(\varrho t - \varepsilon)\right\}$$

where $n^{1^2} = n^2 - a^2$; $\tan \varepsilon = \frac{2a\varrho}{n^{1^2}-\varrho^2+a^2}$;

and $\tan \varepsilon^1 = \frac{2an^1}{\varrho^2 - n^{1^2} + a^2}$.

The period of free torsional oscillation $T = \frac{2\pi}{n^1}$; and $aT = \log \eta$, the logarithmic decrement of the torsion pendulum for complete swings.

Suppose that we make the periods equal, so that $n^1 = \varrho$: Then

$$(4)\ldots\ldots \vartheta = \frac{B}{a(4\varrho^2+a^2)^{1/2}}\left\{e^{-at}\cos(\varrho t+\varepsilon^1) + \sin(\varrho t - \varepsilon)\right\}$$

where $\varepsilon = \varepsilon^1 = \tan^{-1}\frac{2\varrho}{a} = \frac{\pi}{2}$ nearly.

As $t \rightarrow \infty$, the amplitude approaches a maximum $\vartheta_m = \frac{B}{2\varrho a}$ nearly. Substituting for B its value from (2), $\varrho = \frac{2\pi}{T}$, $a = \frac{1}{T}\log \eta$, $1 = 2mb^2$, and solving for G, we find:

$$(5)\ldots\ldots G = \frac{8\pi b\, l^2 \log \eta.}{MT^2\left(1-\frac{1}{\left(1+\frac{4b^2}{l^2}\right)^{3/2}}\right)}\vartheta_m.$$

In the writer's experiments the torsion pendulum was adjusted until its period was 7.4485 sec. That of the common pendulum was 7.4508 sec. M was the bob of a Foucault pendulum, and weighed 5.5×10^5 grams. In one particular experiment b was 38.5 cm., l was 29.7 cm., and $\log \eta$ was found by an auxiliary experiment to be .00603. The only effect of convection currents in the torsion pendulum box could have been to hasten the approach of the amplitude to ϑ_m (which might otherwise be asymptotically approached). After about fifty minutes, ϑ_m was reached; and by a set of readings by mirror and scale was found to be 3.8×10^{-4} radians. By (5) G was found to be 6.75×10^{-8} C.G.S. units. The average of the results of several such experiments was

$$G = 6.6_5 \times 10^{-8} \text{ C.G.S. units.}$$
$$(\text{True value } G = 6.6576 \times 10^{-8})^1$$

Though not as accurate as the refined Cavendish method, this experiment is a simple one to perform. The writer's apparatus was assembled in about six hours' time, since he was aided by the presence of a large Foucault pendulum. In case no great accuracy is desired, the method presents the advantage that it is free from errors due to non-periodic convection currents, so troublesome in the Cavendish form of the experiment.

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[1] C. V. Boys, Phil. Trans. A, 1895, part 1.