making possible careful, prolonged study of subjects of ultraviolet color-translation photomicrographs.

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Examination of the Target Theory by Deuteron Bombardment of T-1 Phage

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THE BIOLOGICAL ACTION OF IONIZING RADIATIONS is of great current importance. The effects produced are often readily measured and a clear understanding of the process involved is therefore capable of yielding structural information about biological systems.

Lea (*2*) has examined carefully the target theory of biological action according to which a localized sensitive volume of definite size exists and within which there must be considerable liberation of energy for biological action to take place. This direct action is certainly not the only action and Lea has pointed out that indirect action by free radicals and by hydrogen peroxide will occur, particularly at low concentrations. According to his views a specimen irradiated in high concentration, and in the presence of a high concentration of large molecules, should have a low efficiency for indirect action and the direct, target type action should predominate.

There is today some question as to whether direct action ever occurs, since the similarity of action of mutagenic agents like nitrogen mustard and of X radiation is very striking, and certainly mutagenic agents must operate by collision rather than by penetration and ionization.

In view of this present uncertainty it appeared to us to be worth while to examine the target theory carefully in bombardments where it should certainly be valid. For this we chose T-1 bacteriophage (*1*) which acts on *E. coli*, strain B. This phage has a spherical head, diameter 50 mμ and a long tail, length 120 mμ of diameter 10 mμ. No complex genetic structure has been reported for this phage. We found it to be

[1] We wish to thank Mrs. Marjorie Reaume for very valuable help with the phage assays, Mr. F. Bisbee for help in constructing the bombarding equipment, and Drs. P. R. Burkholder and D. M. Bonner for much interest and helpful advice.

stable in broth, 0.4 grams percent. The stability was not affected by evacuation for several days. Our procedure was to bombard T-1 phage preparations in vacuo with a deuteron beam of known energy and to study the cross section of target resulting from such bombardment. By varying the energy of the deuteron beam the ionization density can be varied smoothly and accurately and a test of the target theory made.

Since the deuterons go in straight lines, distributed in a random manner in area, the target calculation assumes only that a deuteron passes through the target area. The chance of inactivation of N phage particles having a target area S each is then SN/A where A is the area of the whole preparation. The actual number of hits is given by $-dN$, and the chance is this number divided by the total beam, which is the preparation area times the number of deuterons per square centimeter or dB. This expression for the chance is $-dN/A\ dB$, and equating the two we have

$$\frac{SN}{A} = -\frac{dN}{A\,dB}$$

which leads to the relation $dN/N = -S\ dB$ or on integrating

$$\frac{N}{N_0} = e^{-SB} \qquad (1)$$

where N_0 is the number of phage particles present initially. When $N/N_0 = 37\%$, $SB = 1$ and in this way, by measuring B, S can be found.

The results are plotted as percent survival versus number of deuterons per cm^2 and show that relation 1 is obeyed. The results for three different beam energies are shown in Table 1.

TABLE 1

Beam energy (Mev)	Energy loss per cm air (Mev)	B for 37% survival ($\times 10^{11}$ deuterons)	Apparent radius mμ
3.5	0.18	1.2	16.5
2.5	0.25	1.04	17.5
1.5	0.40	0.83	19.5

The value of the apparent radius, assuming the target to be a spherical volume, is given, together with the value of B for 37% survival and the energy loss of the beam per centimeter air equivalent.

The number of ion pairs introduced into a target of this volume is in each case in excess of 8 so that on the simple hypothesis of Lea that one ion pair liberated in the target produces inactivation, the target should appear to have the same area. The fact that it does not requires some modification of the theory.

In order to have some basis for this modification, we studied the temperature inactivation (in broth) of the same phage. The results are given in Table 2.

TABLE 2

Temperature (absolute)	K (sec^{-1})
343	2.78×10^{-3}
338	7.94×10^{-4}
336	1.93×10^{-4}
333	5.03×10^{-5}

These show that there is an activation energy for the inactivation process of 73.6 kcal per mole or 3.2 ev. This, of course, includes a large amount of entropy change. Nevertheless, if it is assumed that the absorption of 3.2 ev of energy in a target of diameter about 30 mμ will cause inactivation it is possible to estimate the distance from which radiation can reach the target to produce inactivation. This distance increases with ionization density and accounts for the apparent increase in the target area.

It is therefore proposed that Lea's hypothesis be modified by including the possibility that inactivation can be caused by secondary radiation reaching the target from an ion path which does not go through the target. An approximate quantitative treatment can be given as follows. Suppose I ev/cm^2 are released by the deuteron. Let the path of the deuteron approach within a distance y of a target of radius R. Then it can be assumed that approximately the intensity at the surface of the target is aI/y, where a is some slowly varying quantity dependent on the proportion of energy emitted as ultraviolet light suitable for inactivation and on absorption in the medium. If the absorption coefficient of the target is μ then the energy absorbed is approximately $\frac{2\pi\mu a I R^3}{y}$ so that the condition for inactivation is

$$\frac{2\pi\mu a I R^3}{y} = 3.2.$$

This can be rewritten as $y = \left[\frac{2\pi\mu a R^3}{3.2}\right] I.$

This equation cannot be interpreted literally since the requirement that 3.2 ev be sufficient is clearly only a hypothesis and also the approximations regarding absorption are rather rough.

However, the ideas it expresses can be put to good use. If one regards the term in brackets as constant, and it is essentially so, one can write

$$y + R = \text{constant} \cdot I + R$$

Now $y + R$ is the radius of the apparent target volume as calculated above. When $y + R$ is plotted against I

(Continued on page 386.)

Superior students are encouraged to do this, and perhaps rightly, but the result is that there are not very many really good high school biology teachers. This situation has apparently concerned most professional biologists very little, but I believe that there are now many who will agree with Dr. van Overbeek as to the importance of a biologically literate public and the role of the secondary schools in producing it.

Professional biologists, through their various societies, might well support a program designed to improve the quality and quantity of secondary school biology. While there may be little hope of attaining the goals set by Dr. van Overbeek, I think that substantial progress could be made toward securing the more general requirement of a year of biology for graduation from high school, and toward the improvement of these high school biology courses and the recruiting of more capable and interested teachers for them.

I believe that professional scientists might also take a greater interest in supporting and encouraging the extension of the excellent elementary school science programs which have been established in some cities. It is quite possible that good elementary school science instruction can have a more thorough and lasting influence than secondary school science instruction in developing a public with an interest in and appreciation of science and its methods, attitudes, and problems of general concern. Here again, one of the principal difficulties is adequately trained teachers.

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Errata

My attention has been drawn by correspondents to two incorrect statements in my article "Research and Politics" (*Science*, March 4, 1949). First, it was stated that Vavilov died in a concentration camp. This should have read "died in exile in a remote region of the USSR," since the details are unknown. Second, I said that Kammerer committed suicide after going to Russia. Actually, he did so while still in Vienna, at the moment when he was finally to move to Moscow.

RICHARD B. GOLDSCHMIDT
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I would like to call your attention to an error that crept into the paper on neomycin by Waksman and Lechevalier (*Science*, March 25). On page 307, right column, lines 1, 8, and 9, the letter μ should read *u*, or *unit*.

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In the paper "The Effect of Choline-Deficiency on Uterine Activity of Rats," by Kraatz and Gruber (*Science*, March 25), the tenth line from the end, p. 312, ". . . choline every second" should be amended to read ". . . choline every second day."

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(*Continued from page 375.*)

a plausible straight line is obtained which has an intercept on the $y+R$ axis of value R since $y=0$ when $R=0$.

The value so derived for R is 14 ± 2 mμ. Careful measurements over a wider range of ionization densities are in progress. The figure agrees well with the figure 18 mμ deduced by Luria and Exner (*3*) from observations of X-ray inactivation.

The results of deuteron bombardment of T-1 phage are thus consistent with the following hypotheses:

1. A target exists, of diameter 28 ± 4 mμ which is very much smaller than the phage itself and indeed smaller than the head of the phage.

2. The measured target size is larger than the true target, due to the fact that radiation from the path of a deuteron which misses the target can inactivate the phage.

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