SUMMARY

1. Two hitherto undescribed colouring matters, skyrin and flavoskyrin, have been isolated from the mycelium of laboratory cultures of a morphologically typical but biochemically atypical strain of *Penicillium islandicum* Sopp.

2. Skyrin, $C_{30}H_{18}O_{10}$, crystallizes as clusters of orange-red rods or as yellow, hexagonal plates and does not melt below 380° . Several of its derivatives are described.

3. When an alkaline solution of skyrin is treated with sodium dithionite, $Na_2S_2O_4$, it undergoes reductive cleavage into two molecules of emodin, $C_{15}H_{10}O_5$, 4:5:7-trihydroxy-2-methylanthraquinone.

4. Flavoskyrin, $C_{15}H_{12}O_5$, crystallizes as yellow needles, m.p. 215° (decomp.).

5. Flavoskyrin loses a molecule of water to yield chrysophanol, $C_{15}H_{10}O_4$, 4:5-dihydroxy-2-methylanthraquinone, either by heating at its melting point or by the action of cold concentrated sulphuric acid.

6. The chrysophanol already reported as a metabolic product of this strain of *P. islandicum* has been shown not to be an artifact produced, during its isolation, by decomposition of flavoskyrin.

7. Possible structures for skyrin are discussed.

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Chemical Action of X-Rays on Nucleic Acids and Related Substances in Aqueous Systems

2. THE MECHANISM OF THE ACTION OF X-RAYS ON NUCLEIC ACIDS IN AQUEOUS SYSTEMS

BY G. SCHOLES AND J. WEISS

University of Durham, King's College, Newcastle-upon-Tyne 1

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The nature of the chemical changes which occur on irradiation of nucleic acids in aqueous systems with X-rays have been described in Part 1 of this series (Scholes & Weiss, 1953*a*). Evidence was presented to show that these changes were the result of chemical reactions involving the free radicals produced by the absorption of the radiation by the water which is split according to the net process (Weiss, 1944, 1947*a, b*):

In these experiments, the detection and isolation of the products of irradiation were facilitated by employing fairly high doses of X-rays (approx. 1×10^6 r).

Previous investigations of the action of X-rays on deoxyribonucleic acid (DNA) solutions, using doses in the region 20 000–100 000r have been essentially concerned with the physical effects of the radiation, for example the decrease in viscosity

and of streaming birefringence (cf. Taylor, Greenstein & Hollaender, 1948). No chemical changes have been reported. It was therefore of interest, particularly from a biological standpoint, to investigate the nature of any chemical effects which may result by the use of similarly low, or even lower, doses of radiation. In fact, it was found that ammonia and inorganic phosphate were both formed when solutions of DNA and RNA (ribonucleic acid) were irradiated with doses of the order of 30 000r (Scholes & Weiss, 1950). Furthermore, quantitative determination of these products formed under different experimental conditions (e.g. in the presence of oxygen, of hydrogen and *in vacuo*) has yielded information about the nature of the radicals involved in the various processes. In the following, our detailed results are presented and the mechanism of the degradation induced by X-rays of the polynucleotides is discussed.

EXPERIMENTAL

Materials. The commercial samples of (yeast) RNA (BY3) and (thymus) DNA (BT2) were the sodium salts supplied by British Drug Houses Ltd. The sample RNA (BYC) was a purified commercial specimen (cf. Scholes & Weiss, 1953a) and contained: N, 16.2; P, 9.2%. RNA (BY3) contained: N, 15.8; P, 9.1%. A specimen of highly polymerized (thymus) DNA (mol.wt. approx. 1×10^6) was kindly supplied by Prof. R. Signer (Berne). A pure but less polymerized sample of DNA, originally prepared by Hammarsten, has also been irradiated.

Adenine, adenylic acid (yeast) and cytidylic acid (yeast) were pure commercial products (Roche Products Ltd.); the pyrimidine nucleotide was further purified by recrystallization from 50% ethanol and had a ratio C/N of 2.98. (Microanalysis by Weiler and Strauss, Oxford.)

Irradiation

The arrangements for irradiation were similar to those described previously (Scholes & Weiss, 1953a).

The solutions (100 ml.) were prepared in triply distilled water, ordinary distilled water having been redistilled in an all-glass still from alkaline permanganate and then from phosphoric acid. When required, the solutions were buffered by the following systems: for pH < 4, H_2SO_4 ; pH 4–8, boric acid-borax; pH 5–8, $\text{Na}_2\text{HPO}_4\text{--KH}_2\text{PO}_4$ (Sørensen); pH 8–10, boric acid-NaOH; pH 9–11, Na_2CO_3 -borax (Parnas); and for pH > 11, NaOH. All reagents were of A.R. grade and minimum quantities of the standard buffers were used (usually about 10 ml. buffer solution/100 ml. solution to be irradiated). Besides irradiations in the presence of air, experiments were also carried out in an atmosphere of O_2 (the solutions being saturated with O_2 by bubbling the gas through the solution for about 30 min.), *in vacuo* and in the presence of H_2 (1 atm.).

Evacuation was effected by passing CO_2 through the solution for a short while and pumping out the vessel by means of a Hyvac oil pump; this process was generally repeated once or twice. In certain cases (e.g. when evacuating alkaline solutions) purified O_2 -free N_2 was used in place of CO_2 . Commercial ' O_2 -free' N_2 was purified for this purpose by passage through Fieser's solution (Fieser, 1924), through a CuSO_4 solution and then through a CaCl_2 and soda-lime scrubber and finally through a tube containing Cu gauze at approx. 380° . The gas so purified was found to contain less than one part per million of O_2 when tested with a trypanflavine-silica gel (Kautsky & Hirsch, 1935; Franck & Pringsheim, 1943). After the evacuation procedure less than 0.01 ml. of non-condensable gas remained.

For the experiments in the presence of H_2 , the vessel containing the solution to be irradiated was first evacuated as described above, and then purified, O_2 -free H_2 was slowly admitted to atmospheric pressure. In order to ensure saturation, the gas was slowly bubbled through the solution for a further 30 min.

Quantitative methods

Determination of ammonia. Samples (50 ml.) were analysed according to the method described by Scholes & Weiss (1953a).

Fig. 1. Calibration curves for the determination of inorganic phosphate by the methods of Berenblum & Chain (1938) (curve A) and Lowry & Lopez (1946) (curve B). Samples (10 ml.) treated with reagents to a final volume of 25 ml. Optical densities measured with a Spekker photoelectric absorptiometer (Ilford 608 filter). Calibration constructed with KH_2PO_4 .

Determination of inorganic phosphate. Of the various available methods for the determination of inorganic phosphate in the presence of 'labile' phosphate, those of Lowry & Lopez (1946) and Berenblum & Chain (1938) were used. Both these methods were found to be suitable for the determination of small amounts of inorganic phosphate; Fig. 1 shows the corresponding calibration curves. In all cases 10 ml. samples were analysed, measurements being made in triplicate and compared against the corresponding blanks.

With the Lowry & Lopez procedure, the irradiated nucleate solutions (which were analysed without prior removal of unchanged nucleic acid) showed some lag in colour development; but the maximum was attained after about 45 min. The method was found to be reproducible (to approx. $\pm 5 \times 10^{-3}$ mole P/10 ml. sample) if, in all cases, the extinction was measured always at the same time (45 min.) after the addition of the reagents.

The Berenblum & Chain method was found to have certain advantages; interfering substances which hindered colour development were removed, the extinction for a given amount of P was much greater than that given by the Lowry & Lopez procedure and the blank values were very low. Measurements were reproducible to approx. $\pm 2 \times 10^{-9}$ moles P/10 ml. sample.

RESULTS

Formation of ammonia

The yields of ammonia from 0.05 % (w/v) solutions of RNA (BY3), DNA (Signer A) and adenine, produced on irradiation with different doses and under different specified conditions, are shown in Figs. 2-4, respectively. The yields were proportional to the dose (with a 'break' in the presence of air) and in all three cases there was the same sequence in the relative positions of plots of yield versus dose, that is, the yields decreased on passing from irradiations in the presence of oxygen to those *in vacuo*, the lowest values being obtained in the presence of molecular hydrogen. This particular sequence indicates that the liberation of ammonia from the nucleic acids is the result of an attack by oxidative radicals on the constituent bases. This follows from a consideration of the nature of the radicals present under these various experimental conditions: in evacuated solutions, there are the H atoms and the OH radicals, produced according to process (1); in the presence of molecular oxygen the H atoms react as follows,

thus being transformed, to a greater or lesser extent, into HO_2 radicals; in the presence of molecular hydrogen the OH radicals can react as follows,

thus giving H atoms to a greater or lesser extent. A process involving oxidative radicals will therefore be enhanced in the presence of oxygen and inhibited in the presence of hydrogen. The observed 'breaks' in the graphs of ammonia yield against dose in the presence of air (cf. Figs. 2-4) represent the points at which practically all the atmospheric oxygen in the solution has been used up.

According to Gulland (1947), the highly viscous character of DNA solutions may be due, in part, to the presence of hydrogen bonding between amino and hydroxyl groups. The attack by the oxidative radicals on the component bases, with subsequent elimination of amino groups, should destroy this particular type of hydrogen bonding; this could account for part of the decrease in structural viscosity and of streaming birefringence observed on irradiation of these solutions.

Fig. 2. Formation of ammonia by irradiation of aqueous solutions of RNA (BY3) with 200 kv X-rays. RNA soln., 0.05 %, w/v; pH ~ 5. $\odot$, in oxygen (1 atm.); $\circ$, in air; $\otimes$, *in vacuo*; $\bullet$, in hydrogen (1 atm.).

Fig. 3. Formation of ammonia by irradiation of aqueous solutions of DNA (Signer A) with 200 kv X-rays. DNA soln., 0.05 %, w/v; pH ~ 6.5. $\odot$, in oxygen (1 atm.); $\circ$, in air; $\otimes$, *in vacuo*; $\bullet$, in hydrogen (1 atm.).

Fig. 4. Formation of ammonia by irradiation of aqueous solutions of adenine with 200 kv X-rays. Adenine soln., 0.05 %, w/v; pH = 7.0 (phosphate buffer). $\odot$, in oxygen (1 atm.); $\circ$, in air; $\otimes$, *in vacuo*; $\bullet$, in hydrogen (1 atm.).

Fig. 5. Formation of inorganic phosphate by irradiation of aqueous solutions of RNA (BY3) with 200 kv X-rays. RNA soln., 0.05%, w/v; pH~5. Phosphate determined by method of Lowry & Lopez (1946). $\odot$, in oxygen (1 atm.); $\circ$, in air; $\otimes$, in *vacuo*; $\bullet$, in hydrogen (1 atm.).

Fig. 6. Formation of inorganic phosphate by irradiation of aqueous solutions of DNA (Signer A) with 200 kv X-rays. DNA soln., 0.05%, w/v; pH~6.5. Phosphate determined by method of Lowry & Lopez (1946). $\circ$, in air; $\otimes$, in *vacuo*; $\bullet$, in hydrogen (1 atm.).

Table 1. Formation of inorganic phosphate by irradiation of DNA (Hammarsten) with 200 kv X-rays

(DNA soln., 0.05%, w/v.)

Dose ($r \times 10^{-5}$)	Yield of inorganic phosphate (moles $\times 10^9$ /100 ml.)		
	In air	In <i>vacuo</i>	In hydrogen (1 atm.)
1.28	0.855	0.985	1.57
1.76	1.39	1.48	1.96

Fig. 7. Formation of inorganic phosphate by irradiation of aqueous solutions of yeast adenylic acid with 200 kv X-rays. Adenylic acid soln., 0.05%, w/v; pH=3.3. Phosphate determined by method of Lowry & Lopez (1946). $\odot$, in oxygen (1 atm.); $\circ$, in air; $\otimes$, in *vacuo*; $\bullet$, in hydrogen (1 atm.).

Formation of inorganic phosphate

The yield/dose curves for the formation of inorganic phosphate from RNA (BY3) and from DNA (Signer A) solutions are shown in Figs. 5 and 6. There was no observable difference in the yields of inorganic phosphate when RNA solutions were irradiated under the different conditions indicated in Fig. 5. In the case of DNA, on the other hand, phosphate production was enhanced when atmospheric oxygen was excluded from the solution and, in fact, the highest yields were obtained in the presence of molecular hydrogen. Irradiation of a DNA sample prepared by Hammarsten gave results (Table 1) which were similar to those obtained with the Signer acid. Thus, on the basis of the principles outlined above, it appears that the hydrogen atoms may play some part in the degradation of the nucleic acids. If this is the case, it would appear that, with RNA solutions, hydrogen atoms and oxidative radicals are equally effective dephosphorylating agents, whilst with DNA, hydrogen atoms appear to be more reactive.

Fig. 7 records the results obtained from a study of the dephosphorylation induced by X-radiation of yeast adenylic acid in aqueous solution. The yields of inorganic phosphate were, in general, higher than those obtained from the nucleic acids, but, the break in the 'air-curve' and the greater yields *in vacuo* again suggest some role of the hydrogen atoms in the degradation process. The position of the 'hydrogen' curve, that is midway between curves referring to air and vacuum conditions, is a somewhat unusual feature: this may suggest that while some direct dephosphorylation by the radicals can take place, initial attacks by oxidative radicals may enhance subsequent reductive phosphate release.

The curves of phosphate yield against dose in general seem to approach linearity only after a certain time of irradiation and this may indicate a building up of some more reactive species. However, inorganic phosphate is already produced with relatively very low doses, and, in fact, could be detected in RNA solutions even after a dose of 4000r and in yeast adenylic acid solutions after only 2000r.

As the figures reveal, the yields of inorganic phosphate from the nucleic acids are comparatively small but this is not unexpected, as multiple attacks on pentose residues may be required to liberate the bound phosphate groups. From less highly polymerized nucleic acids, where there are relatively more terminal phosphate groups, one may expect greater yields of inorganic phosphate. This, for example, is demonstrated in Fig. 8, which shows a correlation between the yields of phosphate and the state of polymerization of different DNA preparations; the lowest yields were obtained from the highly polymerized Signer acid and the highest from the degraded commercial sample. These observations are in keeping with our general concepts discussed below.

In the case of nucleate solutions, the yields of inorganic phosphate measured by the method of Berenblum & Chain (1938) were always lower than those obtained by the Lowry & Lopez (1946) procedure. Fig. 9, for example, shows the yields of inorganic phosphate obtained by these two different methods when applied to some irradiated RNA solutions. Such evidence lends support to the view that on irradiation of aqueous solutions of the nucleic acids there is a primary formation of some labile phosphate esters, these being subsequently decomposed to some extent under the conditions prevailing in the Lowry & Lopez method. Recent experiments by Weil-Malherbe & Green (1951) have indeed shown that such labile esters may easily decompose in the presence of molybdate as used in this determination, whereas, under the conditions of Berenblum & Chain this molybdate catalysis may not play an important part. Additional experimental

evidence for the presence of labile phosphate esters arises from our recent observations that considerable amounts of inorganic phosphate can be liberated on subsequent (acid) hydrolysis of the irradiated RNA and DNA solutions (Scholes & Weiss, 1953b). For example, it has been found that after doses of the order of 9×10^4 r (in the presence

Fig. 8. Formation of inorganic phosphate by irradiation of aqueous solutions of different nucleic acids and of yeast adenylic acid with 200 kv X-rays in the presence of air. Soln., 0.05%, w/v. Phosphate determined by method of Lowry & Lopez (1946). ((a) pH=3.3; (c) pH~5; (b), (d) and (e) pH~6.5.) (a) yeast adenylic acid; (b) DNA (BT2); (c) PNA (BY3); (d) DNA (Hammarsten); (e) DNA (Signer A).

Fig. 9. Formation of inorganic phosphate by irradiation of aqueous solutions of RNA (BY3) with 200 kv X-rays in the presence of air. RNA soln., 0.05%, w/v; pH~5. Phosphate determined by methods of Lowry & Lopez (1946) (O) and Berenblum & Chain (1938) (●) respectively.

of oxygen) the additional amounts of inorganic phosphate liberated on hydrolysis are about 15 times the amount of free phosphate formed during the irradiation. These observations may be of considerable significance in connexion with the so-called 'after-effect' (the decrease in viscosity of DNA solutions which occurs after cessation of irradiation) and suggest that this effect may be due, at least in part, to slow hydrolytic fission of labile phosphate ester bonds, thus leading to further depolymerization. This is also in agreement with the fact (Taylor *et al.* 1948) that the 'after-effect' is strongly temperature-dependent, as would be expected in the case of a relatively slow hydrolytic process.

Effects of pH

It has already been reported that the amount of ammonia produced from the purine bases depends upon pH (Scholes & Weiss, 1953*a*). Fig. 10 shows the pH-dependence in adenine solutions (0.05%, w/v) which have received a (constant) dose of 102900r (*in vacuo*). While there was little change in the ammonia yields at higher pH's, a fairly marked increase was observed in the neighbourhood of pH 4, tending to reach a maximum in more acid solution. A similar behaviour was exhibited by adenosine solutions.

In the case of the ribonucleotides and the nucleic acids, on the other hand, the pH-dependence was more complex. Figs. 11–13 show the results obtained from irradiation of yeast adenylic acid, yeast cytidylic acid and RNA (BYC) solutions respectively. Although the yields differ somewhat (the highest was obtained from the pyrimidine nucleotide) the similarity in the shape of these curves is quite marked, each exhibiting minima and maxima in the regions of pH 4–5 and pH 8–9 respectively. Thus, the presence of the phosphoryl group exerts a characteristic influence on the pH-dependence of the deamination, this being particularly pronounced in the neutral range.

Fig. 10. pH dependence of the formation of ammonia from solutions of adenine irradiated with 200 kv X-rays *in vacuo*. Adenine soln., 0.05%, w/v; total dose, 1.03×10^5 r units.

Fig. 11. pH dependence of the formation of ammonia from aqueous solutions of yeast adenylic acid irradiated with 200 kv X-rays in the presence of oxygen (1 atm.). Yeast adenylic acid soln., 0.05%, w/v; total dose, 9.45×10^4 r units.

Fig. 12. pH dependence of the formation of ammonia from aqueous solutions of yeast cytidylic acid irradiated with 200 kv X-rays in the presence of oxygen (1 atm.). Yeast cytidylic acid soln., 0.05%, w/v; total dose, 9.45×10^4 r units.

Fig. 13. pH dependence of the formation of ammonia from aqueous solutions of RNA (BYC) irradiated with 200 kv X-rays in the presence of oxygen (1 atm.). RNA soln., 0.05%, w/v; total dose, 9.45×10^4 r units.

This resemblance in the behaviour of the mono- and poly-nucleotides is further demonstrated by a comparison of the yields of inorganic phosphate at different pH values (Figs. 14 and 15). Here the minimum and maximum dephosphorylations occur at pH 4-5 and pH 7-8, respectively, that is in regions which are not very different from those observed in the deamination process.

Pronounced pH effects have been previously observed by Stein & Weiss (1949), and by some other authors (Dale, Davies & Gilbert, 1949; Rotherham, Todd & Whitcher, 1951) on the yields of ammonia from amino acids, and it has been suggested that this may be due to interactions of different ionic species (Stein & Weiss, 1949). With the nucleic acids and certain related lower molecular-weight compounds it is apparent that, here again, the polar nature of the molecules may be an important factor for their reactivity.

Fig. 14. pH dependence of the formation of inorganic phosphate from aqueous solutions of yeast adenylic acid (curve *a*) and yeast cytidylic acid (curve *c*) irradiated with 200 kv X-rays in the presence of oxygen (1 atm.). Soln., 0.05%, w/v; phosphate determined by method of Berenblum & Chain (1938); total dose, 9.45×10^4 r units.

Fig. 15. pH dependence of the formation of inorganic phosphate from aqueous solutions of RNA (BY3) irradiated with 200 kv X-rays in the presence of air. RNA soln., 0.05%, w/v; Phosphate determined by the method of Berenblum & Chain (1938). Total dose, 1.54×10^6 r units.

DISCUSSION

The nature of the chemical changes produced by the action of the radiation on the nucleic acids indicates that some of the primary linkages (i.e. glycosidic, ester, and internucleotide) are broken; thus, there appear to be various concomitant reactions, the net result of which is a fragmentation into molecular species of variable size. Owing to the complex nature of the polynucleotides, any interpretation of the mechanism of their degradation can only be regarded as tentative.

From the experimental results obtained by irradiation of the nucleosides and nucleotides (Scholes & Weiss, 1953*a*) it follows that radical attacks will occur at both the nitrogenous and carbohydrate centres of the nucleate molecule. As pointed out above, the liberation of the amino groups from adenine, guanine and cytosine should lead to a loss of hydrogen bonding and thus to a marked decrease in the structural viscosity. An attack on the pentose constituents, on the other hand, could account for the formation of free bases. Breakage of the polynucleotide chain as a result of these various reactions should lead to an increase in the number of free phosphoryl groups and this, in turn, could account for the observed increase in titratable groupings in the irradiated nucleate solutions.

One of the interesting features of the depolymerization of DNA solutions is the 'after-effect', and a somewhat similar phenomenon has also been observed in the irradiation of some RNA preparations (Grinnan & Moscher, 1951).

As pointed out above, hydrolytic processes may largely contribute to this effect and these processes may involve labile phosphate esters (see also Scholes & Weiss, 1953*b*). However, attack on the pyrimidine ethylenic bonds may also be a factor in the breakdown of the nucleic acid. It is known, for instance, that the introduction of substituents into the ethylenic centres of the pyrimidine nucleosides and nucleotides very considerably weakens the glycosidic and probably also the phosphate ester linkages. Thus bromination of uridine markedly facilitates subsequent hydrolysis by acids (Levene & La Forge, 1912). Hydrogenation of yeast cytidylic acid has also been found to enhance the rate of phosphate release by subsequent acid hydrolysis (Levene & Jorpes, 1929): this latter observation may be of some significance in view of our findings that hydrogen atoms produced by irradiation may also play a part in the dephosphorylation of the nucleic acids.

It has been stated (Butler & Conway, 1950; Conway & Butler, 1952) that the 'after-effect' in DNA solutions occurs only if the irradiations are carried out in the presence of molecular oxygen, and

these authors have suggested that the HO_2 radicals, formed under these conditions, can react with the nucleic acid forming a peroxide compound which then slowly decomposes, giving rise to the observed decrease in viscosity. If, as suggested above, the 'after-effect' is due to slow hydrolysis of labile substances formed during the irradiation process, it seems very unlikely that such compounds should be formed exclusively in the presence of molecular oxygen, as oxidizing effects can also be brought about by OH radicals which are present under conditions *in vacuo*. This has been fully confirmed by some recent experiments (Daniels, Scholes & Weiss, 1953) where it has been shown that there is also a definite 'after-effect' if the irradiations are carried out *in vacuo*: the magnitude of this effect is usually of the order of 30% of the corresponding effect in oxygenated solutions.

In the presence of oxygen, owing to the formation of hydroperoxy radicals (HO_2) according to reaction (2), back reactions such as $\text{H} + \text{OH} \rightarrow \text{H}_2\text{O}$ may be inhibited. Probably more important still, the oxidation yield may also be increased by reaction of the initially formed organic radicals ($\text{R}^\cdot$) with oxygen, for example

It is therefore clear from the experimental results that although molecular oxygen is not the decisive factor for the 'after-effect', its presence may enhance this effect for the reasons outlined above.

This effect of oxygen is also in complete agreement with experiments on a number of other solutes, for example the formation of acetaldehyde from methanol, pyruvic acid from lactic acid and alanine (Johnson, Scholes & Weiss, 1953), where the ratios of the yields in the presence and absence of oxygen were found to be between 3 and 6, depending on the substance and on the experimental conditions.

SUMMARY

1. Aqueous solutions of the nucleic acids have been irradiated with X-rays, using doses approaching those employed in biological experiments and the nature of the chemical changes has been investigated.

2. Quantitative determinations of the ammonia and inorganic phosphate produced by the radiation and comparison of the yields when the irradiations were performed in air, in oxygen, *in vacuo* and in hydrogen have allowed the deduction of certain features of the mechanism of attack and of the nature of the reacting species involved. In general, it has been found that the liberation of ammonia results predominantly from an attack on the constituent amino bases by the oxidative radicals OH and HO_2 . In the dephosphorylation process, however, both these oxidative radicals and presum-

ably also hydrogen atoms play an important part. Irradiations of adenine, yeast adenylic acid and yeast cytidylic acid have confirmed these views.

3. The effect of pH on the yields from these various substances has shown that, as in the case of the amino acids, the ionic nature of the substrate molecules is an important factor affecting their reactivity.

4. The decrease in viscosity observed on irradiation of DNA solutions may be attributed, at least in part, to a loss of hydrogen bonding as a result of elimination of some of the polar groups (e.g. amino or hydroxyl groups). It appears that hydrolytic processes may contribute largely to the 'after-effect' (the decrease in viscosity of nucleate solutions which occurs after cessation of irradiation) and these may involve the further slow hydrolysis of labile phosphate esters and also of compounds formed by attack on the pyrimidine ethylenic bonds.

5. Some aspects of the mode of degradation of the nucleic acids by X-rays under various experimental conditions have been discussed.

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