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PENETRATING RADIATION ASSOCIATED WITH THE X-RAYS.

As the following investigation is made with the aid of nuclei, certain of their properties bearing on the present subject will first have to be specified. Exhaustions are preferably made at a pressure difference (δp) just below the point (to be called *fog limit*) at which dust-free non-energized saturated air condenses without foreign nuclei. δp depends on the particular apparatus used.

1. *Fleeting Nuclei.*—Let the X-radiation to which the dust-free air is exposed be relatively weak, so that the density of ionization may remain below a certain critical value. The nuclei observed on condensation are then very small and they require a high order of exhaustion, approaching the fog-limit of non-energized air. They are usually instantaneously generated (within a second) by the radiation, so that their number is definite independent of the time of exposure. They decay in a few seconds after the radiation ceases; *i. e.*, roughly to one half their number in two seconds, to one fifth in twenty seconds in the usual exponential way. I fancy that these nuclei are what most physicists would call ions; but nevertheless the particles are not of a

size, their dimensions depending on the intensity of the penetrating radiation to which they are usually due; and they pass continuously into the persistent nuclei as shown in the next paragraph, where decay of ionization and of nucleation are very different things. Finally (§ 3) they are stable on solution. The case seems rather to be one in which the rate of decay exceeds the rate of production. The following is an example of data bearing on this case, N being the number of nuclei caught per cubic centimeter. The anticathode is at a distance from the fog-chamber and the exhaustion carried to the verge of the fog-limit of dust-free air.

Time of exposure: (rays on)	0	5	15	30	60	120 secs.
$N \times 10^{-3}$	*1.6	74	74	—	74	—
Time after exposure: (rays off)	0	5	15	30	60	120 "
$N \times 10^{-3}$	92	30	23	18	10	4

The two series refer respectively to generation and to decay.†

2. *Persistent Nuclei.*—If the X-ray bulb is approached nearer the fog-chamber or if a more efficient bulb is used so that the density of the ionization within the fog-chamber is sufficiently increased, the rate of production of nuclei will eventually exceed the rate of decay. The nuclei are now persistent for hours after the radiation ceases. The number N per cubic centimeter increases in marked degree and at an accelerated rate with the time of exposure to the radiation, certainly for ten minutes or more, barring the invariable loss of efficiency of the X-ray bulb. These nuclei are large, requiring very little supersaturation for condensation and are much like any ordinary nuclei. They are pronouncedly of all sizes and the initial coronas are apt to be distorted and stratified beyond recognition. Whirling rains and fog accompany the first condensation. While small nuclei occur throughout the chamber, the end near the bulb is at first the seat of growth which gradually extends to the other end, as I have shown elsewhere.* The following two series of data showing the generation and decay of nuclei in question may be cited as illustrations. The pressure difference $\delta p = 20$ cm., much below the fog-limit for dust-free air, in the given apparatus.

Time of exposure	0	5	10	20	60	120	180 secs.
$N \times 10^{-3}$	0	2	11	10	20	†(100)	†(500)
Time after exposure		0	36	85	240 minutes.		
$N \times 10^{-3}$		†(100)	36	20	vanishing.		

Hence there is a decay of one half in ten minutes, and to one fifth in eighty minutes, or the degree of persistence is 200–300 times larger than in the first paragraph. The data indicate, moreover, that both of these extreme types of nuclei and all intermediate types now occur together, as may be tested by changing the pressure difference, δp, on exhaustion. Intermediate rates of generation and decay may be obtained by moving the bulb nearer to or farther from the end of the fog chamber. Finally the rates at which the nuclei and the ionization severally decay, between which it would be difficult to distinguish in the case of the very fleeting nuclei, stand in sharp contrast with the persistence of the nuclei of the present paragraph.

3. *Fleeting Nuclei Become Persistent on Solution. Origin of Rain.*—Let the fog-chamber be exposed to radiation for a few seconds and thereafter exhausted ($\delta p = 25$) as usual. Closing the exhaustion cock and allowing only time enough to measure the first corona, let the influx cock be opened and the fog-chamber be refilled with dust-free air. The (primary) corona observed is thus dispelled before much subsidence of fog-particles can take place, though the rain will naturally drop out. If the fog-chamber is now left without interference

* Fog limit of dust-free air just exceeded.

† Including loss by diffusion or other time-loss.

* *American Journ. Sci*, XIX., 175.

† Computed from the second exhaustion, after subsidence of the dense fogs of the first.

(the radiation having been cut off immediately after the first exhaustion) for one or more minutes or longer, a second exhaustion to the stated limits will show a large (secondary) corona relatively to the primary corona. In other words, relatively many of the fleeting nuclei or ions caught in the first fog have persisted, whereas without condensation, they would have vanished at once after the radiation was cut off. The following is an example of data bearing on this point, t denoting the time elapsed from the evaporation of the first corona to the precipitation of the second, N_1 the number of nuclei in the first and N_2 the number in the second corona.

$t=$	60	120	300 seconds.
$N_1 \times 10^{-3}=$	53	27	53
$N_2 \times 10^{-3}=$	16	7	15

The experiments are complicated by the variable X-ray bulb; but it is obvious that while all the nuclei would have vanished in a few seconds without condensation, about one fourth (in other experiments more) persist indefinitely if reevaporated after condensation from fog-particles.

This result has an important bearing on the whole phenomenon of condensation and nuclei. Clearly the latter, after the evaporation specified, become solutional or water nuclei, in which the original fleeting nucleus or ion behaves as a solute. The decreased vapor pressure due to solution eventually compensates the increased vapor pressure due to curvature, after which at a definite radius, evaporation ceases and a water nucleus results. Such a nucleus, however small, must be large in comparison with the dissolved ion. Hence on condensation the water nuclei will capture the moisture soonest and grow largest. Now in any exhaustion about one eighth of the fog particles, *i. e.,* those which are smallest and whose nuclei have been caught at the end of the exhaustion, regularly evaporate into the larger particles to a residue of water nuclei. These are then the first to be caught in a succeeding exhaustion. This is the explanation of the *rain* which not only accompanies all coronas in dust-free air, but is often dense. It is also an explanation of those indefinite alternations of large and small coronas (periodicity) which I described in detail elsewhere.

4. *Secondary Generation.*—This is a curious phenomenon, showing that the decaying nucleus is apparently radioactive, or that the walls of the fog-chamber are so, or else that the large nuclei if left without interference break into a number (on the average about three) of smaller nuclei, whereby the nucleation is actually increased in the lapse of time after exposure. In other words, if the nucleation is observed without cutting off the radiation in one case, and if in the second case the nucleation identically produced is observed at a stated time after the radiation has ceased, the number in the latter case (anomalously enough) is in excess. The following examples make this clear, the X-ray bulb being 5 cm. from the fog-chamber, and the exhaustion carried to $\delta p = 20$ cm.

Rays on	2	2	2	2	2	2	2	2	2 minutes
Rays off	0	4	0	4	0	2	0	20	0 "
$N \times 10^{-3}$	20	52	20	32	25	30	13	34	30

These data are computed from the second exhaustion, as the first show the densely stratified fogs unavailable for measurement. With the bulb at different distances from the fog-chamber, the following data admit of the same interpretation.

Distance, $D=$	5	10	15	5	10	15 cm.
Rays on	2	2	2	2	2	2 minutes.
Rays off	0	0	0	0	0	0 "
$N \times 10^{-3}$	22	3	1	58	9	1

The phenomenon vanishes when the radiation is too weak to produce persistent nuclei, therefore either when the bulb loses efficiency or when it is too far from the fog-chamber. These results recall the corresponding behavior evoked by radium in sealed tubes, specified in my last article.* See § 6.

5. *Space Surrounding the X-ray Tube a Plenum of Radiations.*—While the phosphorescence, photographic and electric effects of X-radiation decreases rapidly with the distance D from the tube, the nucleating effect (N nuclei generated per cubic centimeter, instantly) is nearly constant over relatively enormous distances.† Thus to give an example among many ($\delta p =$ 25 cm.):

$D =$	6	200	600	6	200	600 cm.
$N \times 10^{-3}$	88	83	83	79	79	79

The law of inverse squares would predicate a reduction of 10,000 to 1 between these limits; and in fact at 6 cm. the phosphorescent screen is intensely luminous, at 200 cm. very dim, at 600 cm. quite dark, as in the case of any ordinary illumination. The leaves of an electroscope within a glass bell-jar collapse in a time which is directly as the square of the distance from the energized X-ray bulb. The result obtained with nuclei is astonishing; the nuclei-producing radiation would at first sight seem to be of an extremely penetrating kind, akin to the gamma rays of radium and distinct from the ordinary phosphorescence-producing X-rays. This impression is accentuated by the fact that the radiation can not be stopped by lead screens many centimeters in thickness, placed between bulb and fog chamber. The following are typical examples, in which the distance between the lead plates screening the fog chamber and the X-ray tube is $D = 600$ and 200 cm., respectively. N shows the number of nuclei instantly generated behind the plates in the two cases.

Thickness of lead screen	0	.14	.28	.56	.84	1.12	0 cm.
$N \times 10^{-3}$	67	28	28	31	29	31	76
$N \times 10^{-3}$	79	44	48	41	—	44	70

Again the X-ray tube apparently emits this radiation forward as well as rearward, as if the thin anticathode were quite pervious. I found, for instance, for the radiation of the anticathode at 6 meters from the fog chamber,

from the front face (tube directed), $N \times 10^{-3} = 42$
from the rear face (tube reversed), $N \times 10^{-3} = 35$,

or 81 per cent. of the former apparently issues from the rear face. Even the reversal of the current does not stop the radiation, for about 16 per cent. of the normal intensity is still radiated when the concave mirror is made the anode.

The total efficient radiation may be reduced to a limit by lead screens a few millimeters in thickness or less; thereafter it can not be further reduced by lead screens many centimeters in thickness. For instance, when the radiation comes from 600 cm., a single lead plate (thickness .14 cm.) is more than sufficient to reduce the effective radiation to a minimum, which amounts to (somewhat less than) one half of the total intensity, at least when estimated in terms of the number of nuclei produced. If the nucleation comes from 200 cm., one plate has the same effect, even though a thickness of 400 cm. of air has been removed. The thickness, .14 cm., is more than enough to reduce the radiation to the limit in question. This again amounts to a little more than one half the total intensity. At a distance of 5 centimeters no more plates may be needed; but the conditions are now too complicated to be described here, chiefly because persistent nuclei are producible. Moreover 80 per cent. of the total intensity may ultimately escape absorption. Thus the rays from different distances behave alike for the more pervious media (§ 5), and in relation to very dense screens.

* SCIENCE, XXI., 275.

† Supposing that the fog-chamber is not enclosed in impervious metal. In the latter case, with the lead covering open towards the X-ray bulb only, there is constancy of N within 20 per cent. over 6 meters.

6. *Lead-Cased Fog-Chamber.*—To interpret these surprising results it will be necessary to surround the fog-chamber with a casket of lead, having a lid on the side fronting the X-ray bulb; for even though the lead plates above may efficiently cut off the primary rays, they would leave the secondary radiation free to enter laterally through the broadsides of the fog-chamber. When this was done the results reduced the penetrability of lead to a more reasonable figure as may be seen from the following example of results when the distance between bulb and fog-chamber was 2 meters.

Thickness of lead penetrated	= 0	.14	.28	.42	cm.
$N \times 10^{-3}$	= 77	10	7	5	

i. e., 14, 9 and 7 per cent. of the total intensity passes one, two and three plates respectively. A glass plate 7 mm. thick and an iron plate .5 mm thick allowed about 90 per cent. to pass, when the casket was left open and the lead plate placed near the bulb 17 per cent. of the total radiation was effective, the excess being of secondary origin. The passage through a plate of tinned iron may be observed for a bulb 6 meters distant as follows:

Thickness of plate	0	.05	.10	.20	cm.
$N \times 10^{-3}$	36	28	11	7	

It follows then that in the above examples (§ 5) nearly one half of the total radiation was derived from secondary sources since the primary radiation was certainly stopped off to within 10 per cent. by the lead plates. To the eye of the fog-chamber, therefore, the walls of the room are aglow with radiation, and no matter in what position the bulb may be placed (observationally from 6 cm. to 6 m. between bulb and chamber), the X-illumination as derived from primary and secondary sources is constant everywhere. It is to be understood that the 'X-illumination' here referred to may be corpuscular. In fact, so far as I see, the primary and secondary radiation here in question may be identical; for the corpuscles may come from the circumambient air molecules shattered by the shock of gamma rays. The latter would in turn be traceable to the atomic disintegration of the anticathodal platinum while under bombardment by the cathode torrent.

The fog-chamber, if open at the end toward the bulb, shows the same total intensity; but in such a case the inner walls of the casket, etc., become the source of secondary rays. The closed lead casket, however, sometimes introduces a discrepancy, for the coronas on second exhaustion are fainter, but nearly as large as on the first. Hence the lead itself is radioactive or it becomes so after becoming energized by the X-rays. This recalls § 3 on the behavior of radium in the sealed tubes as specified in my last paper.

7. *Ordinary Dust-free Air an Aggregate of Nuclei.*—The steam jet shows that nuclei of small relative size, but, nevertheless, large as compared with the molecules of air must normally be present in dust-free air: for the axial colors may be kept permanent at any stage by fixing the supersaturation. Such nuclei may be called colloidal molecules. Moreover, the available nuclei to be reckoned in millions per cubic centimeter increase with enormous rapidity with the supersaturation, in proportion as the molecular dimensions are approached. But even when the yellows of the first order vanish, condensation probably still takes place on the colloidal molecules specified. It is natural to associate these extremely fine nuclei with the existence of a very penetrating radiation, known to be present everywhere. Moreover, the occurrence of many nuclei with but few ions is not contradictory, if the latter are only manifest when the former are made or broken.

8. *Conclusion.*—It has been shown that for very short exposures (§ 3), the nuclea-

tion is the same, whether the bulb is placed at 6 cm. or 6 m. from the fog-chamber. But only in the former case ($D = 6$ cm.) is the effect cumulative; only for very short distances will persistent or large nuclei appear if the exposure is prolonged several minutes. I have, therefore, suspected that the radiation from the X-ray bulb is twofold in character, that the instantaneous effect (fleeting nuclei) is due to a gamma-like ray quick-moving enough to penetrate several millimeters of iron plate appreciably even for $D = 6$ meters; furthermore, that the cumulative effect (persistent nuclei) is due to X-light properly so called, which produces the usual effects subject to the law of inverse squares.

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*THE BIOLOGICAL LABORATORY OF THE BUREAU OF FISHERIES AT WOODS HOLE, MASS. REPORT OF WORK FOR THE SUMMER OF 1904.**

THE laboratory was opened to investigators on the fifteenth of June, and continued in operation until near the close of September. During the whole or a part of this period twenty-eight investigators were engaged in work upon problems of marine biology. A brief statement of the special subjects of research will be given below.

I. EQUIPMENT, STAFF, ETC.

The same portions of the station were occupied as during the preceding season, and need not again be detailed; the steam vessels *Fish Hawk, Phalarope* and *Blue Wing* were in service during the whole or a part of the season; the zoological library of Brown University was again generously placed at the disposal of the laboratory. Two fish pounds were set, one being placed, as formerly, in Buzzards Bay, not far from the station, the other being planted at No Mans Land, a small island a few miles to the south of Marthas Vineyard. Here a camp was located, several assistants being detailed to tend the trap for a period of about seven weeks.

The staff of the laboratory, for the past season, consisted of a director and seventeen assistants, together with a matron, two janitors and a chambermaid. To this list should be added a clerk and a collector, permanently attached to the station, and the crews of the various vessels. Of the assistants, three had immediate supervision of certain branches of the survey work; three others had charge respectively of the library, the supply room and the fish traps; while the remaining eleven rendered various services in the laboratory or in the field. Mention should also be made here of seven salaried investigators, employed by the bureau to conduct independent researches.

The plan of having a 'seminar' or research club, for the discussion of work in progress at the laboratory, was successfully continued, some of the meetings being largely attended by outsiders, as well as by investigators at the station.

II. BIOLOGICAL SURVEY.

The biological survey of the neighboring waters, commenced during the preceding season, was actively continued. The *Fish Hawk* was at the disposal of the laboratory for some five weeks, during which period she was chiefly engaged in dredging work in Buzzards Bay. In all 66 'stations' were dredged by this vessel, these being located at regular intervals over the bottom of the entire bay. The supervision of this branch of the work was intrusted to Mr. Leon J. Cole. Dredging in Vineyard Sound was likewise continued. A number of the stations (18) of the preceding year were again located and dredged, but the principal work

* Report to the Commissioner of Fisheries by the director of the laboratory.