a "sewage pipe," a "cesspool," but to discover its original purpose and ascertain how far we can modify our mode of living to suit its inherited capacity. What that capacity is we have yet to discover, for we have no complete or exact knowledge of the uses of the great intestine in any animal whatsoever. So far as the human organ is concerned, surgery has stepped far in advance of physiology.⁸

Since Metchnikoff first promulgated his belief that the appendix, cæcum, and colon had become superfluous organs in man's body, our knowledge concerning the evolution of these structures, and of certain conditions which regulate their action, has increased. That increase of knowledge rehabilitates the ancient belief that Nature in her evolutionary mood exercises not only a surprising ingenuity but also the strictest economy. The ferments and catalysts elaborated by plants for their own use were made to serve in the animal body as vitamins. How necessary such substances are for the proper working of the great bowel has been shown by the recent researches of McCarrison⁹ and of Cramer.¹⁰ It was for the purposes of economy that the great bowel came into existence. In fishes, the earliest vertebrate forms known to us in the living state, potent digestive juices have to be produced at the expense of body tissues; with the evolution of land-living, air-breathing forms, much of this expenditure was saved by the utilisation of bacterial digestion. The great bowel was added to the original intestine for this purpose, the oldest part of this annex being the cæcum and appendix. The great bowel as we know it in fishes is a mere diverticulum from the

hinder end of the gut; it takes no part in the digestion of food. Its epithelium forms a glandular structure which has all the appearance of an organ designed for the supply of an internal secretion.¹¹ That secretion, whatever it may prove to be, is carried to the liver by the inferior mesenteric vein.

In the mucous membrane of the human great bowel, there are embedded in a stratum of reticular tissue—of reticulo-endothelium—some 15 millions of minute test-tube glands—the glands of Lieberkühn. No one who has noted the structure and setting of these glands, and the fine changes which their cells undergo in the course of action, can believe that their sole function is to supply a lubricating fluid for the intestine; they have all the appearance of also supplying an internal secretion, and the evolutionary history of the colon favours such an inference.¹² The reticular stratum of the colon, which Dr. Scott Williamson¹³ regards as the most important constituent of its mucous membrane, and in this I agree with him, represents a spleen of considerable size. Indeed, just as the liver and pancreas represent extrusions of highly specialised parts of the intestinal epithelium, the spleen represents a specialisation of the reticulo-endothelium of the alimentary canal; in cyclostomes¹⁴ the spleen is still intra-intestinal. Nor must we forget how greatly the large intestine is linked to the central nervous system—both by afferent and efferent pathways. When we take all these considerations into account, we must conclude that the great bowel of man is not a useless or superfluous organ, but one which we, in our ignorance, are maltreating.

¹¹ Dr. Doris R. Crofts, *Proc. Zool. Soc.*, 1925, Part I., pp. 101, 170.

¹² I have not mentioned the excretory function of the colon. This has been investigated by Dr. Owen T. Williams, see *Brit. Med. Journ.*, 1912, vol. 2, p. 1281.

¹³ *British Journal of Surgery*, 1914, vol. 2, p. 306.

¹⁴ J. Mawas, *C.R. Acad. Sci.*, 1922, vol. 174, pp. 889, 1041.

(To be continued.)

High Frequency Rays of Cosmic Origin.¹

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IT was so early as 1903 that the British physicists, Rutherford and McLennan, noticed that the rate of leakage of an electric charge from an electroscope within an air-tight metal chamber could be reduced by enclosing the chamber within a completely encircling metal shield or box with walls a centimetre or more thick. This meant that the loss of charge of the enclosed electroscope was not due to imperfectly insulating supports but must rather be due to some highly penetrating rays, like the gamma rays of radium, which could pass through metal walls as much as a centimetre thick and ionise the gas inside.

In view of this property of passing through relatively thick metal walls in measurable quantity, the radiation thus brought to light was called the "penetrating radiation" of the atmosphere and was at first quite naturally attributed to radioactive materials in the earth. But in 1910 and 1911 it was found that it did not decrease as rapidly with altitude as it should upon this hypothesis. The first significant report upon this

point was made by a German physicist, Gockel, who took an enclosed electroscope up in a balloon with him to a height of 13,000 feet and reported that he found the "penetrating radiation" about as large at this altitude as at the earth's surface, despite the fact that Prof. Eve, of McGill University, had calculated that it ought to have fallen to half its surface value in going up 250 feet.

In 1912-14 two other German physicists, Hess and Kohlhörster, repeated these balloon-measurements of Gockel's, the latter going to a height of 9 km., or 5.6 miles, and reported that they found this radiation decreasing a trifle for the first two miles and then increasing until it reached a value at 9 km., according to Kohlhörster's measurements, eight times as great as at the surface.

This seemed to indicate that the penetrating rays came from outside the earth, and were therefore of some sort of cosmic origin. The War put a stop to the world over to further studies of this sort, but so soon as we could get the proper instruments built after the War in the newly equipped Norman Bridge Laboratory of Physics, I. S. Bowen and myself went to Kelly Field,

¹ Address delivered before the National Academy of Sciences, Madison, Wis., U.S.A., on November 9.

near San Antonio, Texas, with four little recording electroscopes which we succeeded in the spring of 1922 in sending up in sounding balloons to almost twice the heights which had previously been attained. The highest flight reached the altitude of 15.6 km., or nearly 10 miles.

These instruments were interesting in that, though they were built to hold 300 cubic centimetres of air at 150 pounds pressure, and were provided each with a recording barometer, thermometer, and electroscope, also with three different sets of moving photographic films and the necessary driving mechanism, the total weight of the whole instrument was yet but 180 grams, or about 7 ounces.

In these experiments we expected, if the results previously reported were correct, to find very large rates of discharge; for our instruments went up to such heights that nine-tenths of the atmosphere had been left beneath them, and only one-tenth was left to cut down, by its absorption, the intensity of the hypothetical rays entering from outside. The results were contrary to this expectation. They proved conclusively, however, in agreement with the observations of Hess and Kohlhorster, that the penetrating radiation was greater at great altitudes than at the surface, but that the amount of the increase was not more than a fourth of that predicted from the results of the German observers. (Two years later they reduced their estimates, after further experiments, so that they were no longer in conflict with our measurements.)

VARIATION OF ABSORPTION WITH ALTITUDE.

Since the origin of the rays was still uncertain, with indications in favour of some cosmic source, Dr. Russell Otis and myself felt that the next step was to find out how penetrating the rays were; and since they were weaker at the surface than higher up, we went to the top of Pike's Peak in the summer of 1923, carrying up 300 pounds of lead and a big 6 ft. $\times$ 6 ft. $\times$ 6 ft. water tank for the sake of making absorption measurements on such rays as were found at that altitude.

We found that though our electroscopes discharged twice as fast on Pike's Peak as at the altitude of Pasadena, the rays were cut down so fast by our absorbing screens that it was certain that the greater part of them were not much, if any more, penetrating than the ordinary gamma rays emitted by radium. We found, further, that the rate of discharge of our electroscope was decreased by 10 per cent. by a heavy snowstorm which occurred during the week in which we were on the peak. This showed conclusively that the chief part, at least, of the rays with which we were experimenting on the peak were of local origin, and that they might be due to radioactive matter which in some unknown way got into the upper regions of the atmosphere.

The search for the cause of the increase with altitude in the intensity of these soft gamma-like rays became, therefore, quite as interesting as the question of the existence of a very penetrating radiation of cosmic origin, since this latter would produce at the most but a fraction, and no large fraction either, of the observed increase between Pasadena and Pike's Peak. Mr. Harvey Cameron and I therefore planned experiments for the summer of 1925 which were designed (1) to

settle definitely the question of the existence or non-existence of a small, very penetrating radiation of cosmic origin, and (2) to throw light on the cause of the variation with altitude of the softer radiation of the gamma ray type which we had found more than twice as intense on Pike's Peak as at Pasadena.

HIGH PENETRATING POWER.

To bring to light the very penetrating radiation, if it existed, it was necessary to find at very high altitudes very deep snow-fed lakes, for any radioactive contamination of the water through its seepage through the earth would vitiate the results obtained by sinking electroscopes to different depths beneath the surface of the lake.

We chose for the first experiment Muir Lake (11,800 feet high), a beautiful body of water hundreds of feet deep just under the brow of Mount Whitney, the highest peak in the United States. Here we worked for the last ten days in August, sinking our electroscopes to various depths down to 60 feet. Our experiments brought to light altogether unambiguously a cosmic radiation of such extraordinary penetrating power that the electroscope reading kept decreasing down to a depth of 45 feet below the surface. The atmosphere above the lake was equivalent in absorbing power to 23 feet of water, so that we had found rays, coming into the earth from outer space, so penetrating that they could pass through 45 plus 23 equalling 68 feet of water, or the equivalent of 6 feet of lead, before being completely absorbed. This represents rays much harder (more penetrating) than any which had before even been imagined. The most penetrating X-rays which we produce in our hospitals cannot go through half an inch of lead. Here were rays originating somewhere out in space at least a hundred times more penetrating than these.

Further, high penetrating power means, according to modern physics, simply high frequency or short wave-length. Our experiments indicate, then, that there is a region of frequencies as far up above the X-ray frequencies as are these latter above the frequencies of light waves. They show quite definitely, too, that these highest frequency rays are not homogeneous, but have a measurable spectral distribution, the shortest waves which we observed being a little less than twice the frequency of the longest, for the rays which we actually observed in Muir Lake changed hardness or frequency as they were filtered through greater and greater thicknesses of water, just as X-rays are successively hardened by passing through successive layers of lead. The experiments with the sounding balloons indicate that the frequencies of these cosmic rays do not extend over into the X-ray region of frequencies, else we should have obtained larger discharges in the experiments with sounding balloons when nine-tenths of the atmosphere had been left beneath us.

Further, we obtained good evidence that these cosmic rays shoot through space in all directions, this evidence being found in the fact that we could observe no change whatever in their intensity throughout day or night.

All the results obtained in Muir Lake were checked with wonderful completeness by another set of observa-

tions in another snow-fed lake—Arrowhead Lake—300 miles away from Muir, 7000 feet lower, and equally deep, where the Arrowhead Lake Development Company kindly put all their facilities at our disposal. Indeed, the absorbing power of the atmosphere between the elevations of Muir and Arrowhead Lakes is the equivalent of about two metres of water, and as a matter of fact, every reading in Arrowhead was practically identical with one taken in Muir at a depth two metres lower.

ORIGIN OF HIGH FREQUENCY RAYS.

We can draw some fairly reliable conclusions as to the origin of these very penetrating and very high frequency rays. The most penetrating rays that we have known anything about thus far, the gamma rays of radium and thorium, are produced only by nuclear transformations within atoms. This means that they are produced by the change of one atom over into another atom, or by the creation of a new type of atom. It is scarcely possible, then, to avoid the conclusion that these still more penetrating rays which we have here been studying are produced similarly by nuclear transformations of some sort. But these transformations must be enormously more energetic than are those taking place in any radioactive changes which we know anything about. For the frequency of any emitted ray is, according to our present knowledge, proportional to the energy of the subatomic change which gives birth to it. We can scarcely avoid the conclusion, then, that nuclear changes having an energy value perhaps fifty times as great as the energy changes involved in observed radioactive processes are taking place all through space, and that signals of these changes are being sent to us in these high frequency rays.

The energy of the nuclear change which corresponds to the formation of helium out of hydrogen is known, and from it we have computed the corresponding frequency and found it to correspond closely to the highest frequency rays which we have observed this summer. The computed frequencies of these rays also correspond closely to the energy involved in the simple capture of an electron by a positive nucleus. It is possible that this phenomenon is actually going on all through space. This is, I think, the most probable source of these rays. It is true that the formula underlying this computation of the frequencies of these rays from their absorption coefficient is of uncertain validity. It is a formula, nevertheless, that works well in the frequency range in which we can get independent checks upon it, namely, in that of the X-ray field and the gamma ray field.

According to this formula, the wave-length of the shortest waves which we have here investigated is 0.0004 Ångströms, or but one-fiftieth of that of the hardest gamma rays heretofore known, and but one-tenth millionth that of ordinary light. The longest wave-length which we have found is about five-thirds of the shortest, or 0.00067 Ångströms.

When these extraordinarily high frequency rays strike the earth, according to the now well-established Compton effect, they should be transformed partially into soft scattered rays of just about the hardness, or the wave-length, of the soft rays which we have

actually observed on Pike's Peak and Mount Whitney. The reason these soft rays were more plentiful on the mountain peaks than at Pasadena would then be found simply in the fact that there are more than twice as many of the hard rays to be transformed at the altitudes of the peaks than at that of Pasadena. This seems to be the solution of the second of our summer's problems.

But how can nuclear transformation, such, for example, as the formation of helium out of hydrogen or the capture of an electron by a positive nucleus, be going on all through space, the resulting rays coming apparently as much from one direction as from any other, and certainly not a whit more plentifully from the direction of the sun than from that diametrically opposite to it, as evidenced by the entire equality of our midday and midnight observations? The difficulty is not so insuperable, in view of the transparency even of large amounts of matter for these hard rays, combined with Hubble's recent proof at the Mount Wilson Observatory that some of the spiral nebulae are at least a million light years away. The centres at which these nuclear changes are taking place would then only have to occur at extraordinarily widely scattered intervals to produce the intensity of the radiation observed at Muir Lake.

The only alternative hypothesis to that above presented, of high frequency rays traversing space in all directions, might seem to be to assume that the observed rays are generated in the upper layers of the atmosphere by electrons shooting through space in all directions with practically the speed of light. This hypothesis might help in interpreting the mysterious fact of the maintenance of the earth's negative charge, but it meets with insuperable obstacles, I think, in explaining quantitatively the variation with altitude of the ionisation in closed vessels. In any case, this hypothesis is, in its most important aspect, very much like the one represented above, for it, too, fills space with rays of one sort or another travelling in all directions with the speed of light. From some such conception as this there now seems to be no escape. Yet it is a conception which is almost too powerful a stimulus to the imagination. Prof. MacMillan, of Chicago, will wish to see in it evidence for the condensation into matter, out somewhere in space, of the light and heat continually being radiated into space by the sun and stars, and the psychists will be explaining all kinds of telepathic phenomena by it.

In any event, our experiments seem to point to the following conclusions:

- (1) That these extraordinarily penetrating rays exist;
- (2) That their mass absorption coefficient may be so high as 0.18 per metre of water;
- (3) That they are not homogeneous, but are distributed through a spectral region far up above X-ray frequencies—probably 1000 times the mean frequencies of X-rays;
- (4) That these hard rays stimulate, upon striking matter, softer rays of about the frequency predicted by the theory of the Compton effect;
- (5) That these rays come into the earth with equal intensity day and night and at all hours of the day or night, and with practically the same intensity in all directions.