RECENT PROGRESS WITH THE X-RAYS.*

SOME NEW DISCOVERIES.

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THE past year or two has seen a considerable addition to our knowledge of the Röntgen rays and their associated phenomena. Prof. Röntgen discovered in 1895 that when cathode rays impinge on solid obstacles the now famous rays which bear his name are generated. Their remarkable penetrating powers created a sensation in the scientific world, imagination was given loose play, and almost everyone of the many workers who sprang up on all sides prepared to assist in the genesis of the "new physics" had his own conception of the nature of the rays.

Röntgen at first considered the rays to be longitudinal vibrations in the ether; Jaumann modified this conception and added a transverse component; Goldhammer and others preferred to regard the new rays as extremely short transverse vibrations akin to light waves; Stokes, in 1897, put forward a theory of irregular pulses in the ether; Michelson suggested their identity with ether vortices. Lastly many physicists, including Röntgen himself, were at one time inclined to the view that the rays are flights of material particles differing only from cathode rays in the absence of an electric charge. One by one most of these theories were abandoned as experiment yielded discriminating results, until at the present time we are left with the ether-pulse theory of Stokes, which, modified and elaborated by Sir J. J. Thomson, has received almost universal acceptance, and the "neutral pair" theory to which Prof. Bragg has recently given his support.

It was soon found by many workers (Röntgen, Campbell-Swinton, Röntgen, Kaufmann, Sir Oliver Lodge, and S. P. Thompson among others) that the heavier metals make the most efficient targets or anticathodes for the cathode rays to impinge upon in a Röntgen ray tube. Platinum has been generally used for the purpose; at any rate, for the better class of tubes. Recently thorium, iridium, tungsten, and tantalum have been employed with entirely satisfactory results. Their high melting points give them an advantage in these days of focus bulbs. (Pt 1,750 degrees; Ir 2,250 degrees; W 3,080 degrees; Ta 2,910 degrees C.)

Kaye (1908) has examined the behavior of some twenty elements when used as anticathodes in a discharge tube. He has shown that the intensity or quantity of the harder or more penetrating rays is very approximately proportional to the atomic weight of the element, the conditions, of course, being the same throughout. Fig. 1 illustrates the relation graphically over a region extending from carbon to bismuth. As to the quality or penetrating powers of the rays from the different elements there is little to choose between them.

This simple atomic weight relation between intensity and atomic weight does not hold when we are dealing with the softest X-rays. The metals of the chromium-zinc group (i.e., Cr, Mn, Fe, Ni, Co, Cu, and Zn) emit radiations very rich in soft rays, and, if only on the score of expense, may well be employed in many cases, as, indeed, some of them are in the cheaper tubes, with or without a thin coating of platinum. Most of these metals have, too, the advantage of high melting points (e.g., Cr 1,490 degrees; Mn 1,200 degrees; Fe 1,500 degrees; Ni 1,430 degrees; Co 1,460 degrees; Cu 1,084 degrees C.).

It is interesting to note that, contrary to what was formerly believed, the rays from a focus bulb are not uniformly distributed. The region of maximum intensity is situated at about 60 degrees from the normal to the anticathode, in a plane containing the normal and the incident beam of cathode rays. In this plane the intensity falls off, roughly speaking, by a cosine law.

The chief defect of the induction coil from the point of view of the X-rays worker is that it does not give pure unidirectional current; the harmful reverse currents at "make" can, however, be suppressed in the Röntgen tube by joining it in series with one or more rectifiers or valve-tubes. Of these there is a number on the market: that first introduced by Villard and since modified by Sir Oliver Lodge consists of an exhausted tube with a large spiral cathode and a small narrowly-inclosed anode.

To Villard also we are indebted for the "osm-regulator," a device nowadays almost always employed to meet the "hardening" or lowering of the pressure which accompanies the continued running of a discharge tube. The regulator consists of a small platinum tube, sealed into the X-ray bulb, and closed at its outer end; its inner open end is in communication with

the interior of the bulb. On applying a small flame to the extremity of the platinum tube, hydrogen diffuses into the bulb, and thus the degree of vacuum can be regulated to a nicety.

FIG. 1.

The vibrating hammer interrupter fitted to induction coils has, owing to the demand for short exposures, practically fallen into disuse for medical work. A great variety of motor-driven interrupters have been contrived, many of them employing a mercury jet operated centrifugally in methylated spirit, paraffin, or compressed coal gas. For heavy hospital work, induction coils and Wehnelt interrupters have lately been constructed to work at large amperages for use directly on direct-current supply mains at potentials up to 200

FIG. 2.—BENOIST'S RADIOCHROMOMETER.

volts. With an alternating-current supply no interrupter is necessary, but some form of rectifier (e.g., the synchronous mercury-jet interrupter, the modified Wehnelt interrupter, the aluminium rectifiers, etc.) is inserted in the primary circuit which will transmit only one phase of the alternating current. The coil is thus used merely as a step-up transformer, and in the secondary circuit the Röntgen tube is shunted with a high-potential rectifier arranged so as to provide an easy path for those impulses which are in the wrong direction.

FIG. 3.

A, Radiator; B, maximum intensity of secondary rays; C, minimum intensity of secondary rays; D, primary X-rays; E, cathode rays; F, anticathode; S, slit.

The output of an X-ray tube has to be specified from the standpoints of both intensity and hardness. A rough notion of the intensity may be obtained by measuring with a milliammeter or thermo-galvanometer the actual current passing through the tube. But in practice the usual methods for measuring intensity depend on one or other of the properties of the rays—

ionization, heating, fluorescing, photographic, or chemical. Owing to the delicacy and convenience of ionization methods, most recent workers have taken advantage of this property of the rays. The heating effects are small, and require sensitive detectors such as bolometers or radiomicrometers. In medicine various chemical reactions brought about by the rays have been suggested and employed as aids to dosage; for instance, the discoloration of various alkaline salts (Holzknecht, 1902), the liberation of iodine from a solution of iodoform in chloroform (Freund, Bordier, and Galimard), the darkening of a photographic plate (Kienböck), the browning of pastilles of barium platino-cyanide (Sabouraud and Noiré, Bordier), and the precipitation of calomel from a mixture of ammonium oxalate and mercuric chloride solutions (Schwartz). Recently the lowering of the electrical resistance of selenium, when exposed to the rays, has also been suggested for the same purpose.

An indication of the hardness of a beam of rays is afforded by the potential difference between the terminals of the tube; this may be measured by some form of high potential electrostatic voltmeter, such as Bergonié's, capable of reading up to 100,000 volts or more. Or, failing this, the length of the alternative spark gap may be noted. In air, at atmospheric pressure, each centimeter of a spark gap between brightly polished balls is equivalent to about 28,000 volts. For general all-round photographic work a useful spark length is about 15 centimeters. The most accurate way of determining hardness is to measure the absorption due to a definite thickness of metal sheet (preferably of low atomic weight), or, perhaps, better to note the thickness of sheet required to reduce the intensity of the beam to half value. Among radiographers Benoist's radiochromometer enjoys extensive use as a hardness measurer. It consists of a thin silver disk surrounded by a dozen aluminium sectors in order of increasing thickness. The Röntgen rays are sent through the instrument, and the observations consist merely in matching on a fluorescent screen or photographic plate the images cast by the silver disk against one of those from the aluminium plates; the thickness of the matching sector increases, of course, with the hardness of the rays. The chromometer is illustrated in Fig. 2. As will be gathered, the instrument is rapid in action, but from a quantitative point of view its readings may easily be misinterpreted.

It was formerly assumed that the absorbing powers of different elements for the Röntgen rays are, roughly, proportional to their densities. However, Benoist has shown that the elements of high atomic weight are a good deal more absorbent, weight for weight, than the lighter-atomed elements. For example, to quote the results of one experiment with hard X-rays in which all the plates had equal masses and the same area, lead was 22, tin 15, and copper 8 times as absorbent as aluminium. It should, by the way, be noticed in passing that a similar relation holds for the soft γ rays from radium; for hard γ rays a density law holds, and the absorption of unit mass per unit area is a constant for all elements; in other words, these very penetrating rays altogether ignore atomic structure.

The writer has shown that when the absorbing screen and the anticathode emitting the X-rays are of the same material, the absorption is relatively low in amount; in other words, the rays are specially penetrating to such a screen. This abnormal transparency can also be detected when screen and radiator have closely adjoining atomic weights.

As is well known, the rays from a coil-driven Röntgen bulb are heterogeneous in character. The higher penetrating power of a beam after passage through a metal sheet is usually ascribed to the removal of the softer components. However, Sagnac and, later, Walter have claimed that their experiments point to an actual transformation of the incident rays by the material of the screen. Barkla (October, 1908) has put forward a somewhat similar view. In the special case when screen and anticathode are of like metal the author has shown that in general an exponential law of absorption rules, indicative of homogeneity.

When X-rays encounter matter, two kinds of what are now known as secondary rays are the result. One of these consists of negatively-charged electrons which are emitted from the substance with a speed of about 7 by 10^9 centimeters per second (Innes, 1907). This velocity increases a little with the hardness of the rays, but does not depend upon their intensity. More of these secondary corpuscles emerge from an element of high atomic weight than from one of low.

* Knowledge.

The other class of secondary rays is of a kindred nature to the primary. With very soft primary rays most elements (especially those of low atomic weight) emit secondary rays almost identical in quality with the primary; the secondary rays may, in fact, be regarded as so much scattered primary radiation. With hard primary rays this scattered radiation disappears and is replaced by a soft homogeneous radiation specially penetrating to and characteristic of the element which emits it. The degree of hardness of the primary rays at which this transformation begins to occur depends on the material of the radiator.

The purely scattered secondary rays show a one-sidedness of polarization which Barkla first noticed in 1905. This, being interpreted, means that in a plane at right angles to the direction of propagation of the primary rays the secondary rays have a minimum intensity in a direction parallel to the cathode rays in the generating X-ray tube, and a maximum in a direction at right angles to this (see Fig. 3).

One may note that both classes of secondary radiation preponderate on the far side of a thin screen over the corresponding amounts which emerge from the near or "incidence" side.

Haga and Wind (1901), by allowing Röntgen rays to pass through a very narrow triangular slit on to a photographic plate, obtained broadenings of the slit image, which they attributed to diffraction. Walter

and Pohl have, however, very recently shown that the extent of the broadening depends on the time of exposure, and that the diffraction of the X-rays cannot be regarded as having yet been established.

Marx, in 1906, carried out determinations of the velocity of the Röntgen rays, and arrived at the result that it is equal to the speed of light. The result would be of the greatest importance if it were substantiated, but after Franck and Pohl's repetition of the experiments this year we are, however, forced to conclude that Marx's measurements cannot be relied upon to furnish the value of this constant.

The present position of the X-rays is interesting on account of the difference of opinion that prevails as to their nature. The ether-pulse theory regards them as so many individual electromagnetic disturbances, which travel outward through the ether with the speed of light whenever a charged particle has its velocity altered. In the front of each pulse are electric and magnetic forces at right angles to each other and to the direction of propagation. For a pulse to contain much energy the charged particle must be moving with a speed not far from that of light, and the alteration in its motion must be effected very suddenly.

On the neutral-pair theory the Röntgen rays consist of pairs or doublets made up of a positive and an equal negative charge, which possess rotational and a high translational velocity.

Both theories account for the penetrating abilities of the rays, their ionizing properties, the lack of deviation in electric and magnetic fields, the absence of refraction, and the other special properties with which we have dealt above. A good deal of the evidence that has been called upon depends on the different results arising out of secondary radiation; it cannot, however, yet be said that any of these results are of discriminating value. Accurate indications of velocity and diffraction would be of service, as ether pulses must travel only with the speed of light; material particles could have any speed less than this. No diffraction effects could be expected on the neutral-pair theory. However, the whole question has attracted attention, and we should not have long to wait before some crucial experiments are carried out to a successful conclusion.

For a fuller treatment of these and many other associated points the reader is referred to—

Sir J. J. Thomson, "Conduction of Electricity Through Gases," 2nd edit. (Camb. Univ. Press), 1906.

N. R. Campbell, "Modern Electrical Theory" (Camb. Univ. Press), 1907.

Sir Oliver Lodge, "Electrons" (Bell), 1907.

G. W. C. Kaye, "Röntgen Rays" ("Science Progress," October, 1908).

C. G. Barkla, "On Secondary Röntgen Rays" (Jahrbuch der Rad. und Elekt., V. 3, p. 346, 1908).

EARTHQUAKE FORECASTS.—I.*

FUTURE POSSIBILITIES.

BY G. K. GILBERT.

PLACE.

LET us consider first the possibility of scientific forecast as to place, and in so doing let us assume the point of view of the resident. The factor in which he is personally interested is the factor of danger—danger to life, danger to property, danger to the present generation. Except as a matter of curiosity, he is not concerned with faint tremors and minor shocks, nor with violent shocks likely to come after centuries of immunity. It will be convenient, at least for this day and hour, to embody our point of view in a concise term, and the adjective *mallooseismic* will be used to designate localities likely to be visited several times in a century by earthquakes of destructive violence.

Experience.—The most important of all bases for the indication of earthquake localities is experience. Where tremors have been frequent in the past, there they are to be expected in the future. This premise hardly requires discussion, for it is founded on our confidence in the continuity of the great processes concerned in the evolution of the earth. We recognize indeed that continuity may fail in any particular case, but we always assume it as far more probable than discontinuity.

Other bases for forecast are connected with our conceptions as to the origin of earthquakes. The theory of earthquakes now generally accepted ascribes them to the sudden breaking or slipping of rocks previously in a condition of shearing strain. Exception should probably be made of some of the shocks accompanying volcanic eruptions, but volcanic shocks constitute a class by themselves to which it is not important to extend the present discussion. In non-volcanic, or ordinary examples, it is believed that the strains arise in connection with those tectonic or diastrophic changes which are exhibited superficially in the deformation of the surface, and that their accumulation is gradual. Fracture occurs when and where the internal stress exceeds the strength of the rock, and a fault results. Slipping takes place when the stress along the plane of a pre-existent fault exceeds the force of adhesion. In either case it is the instantaneous character of the separation which occasions the jar.

The earthquake being thus a concomitant of tectonic change, its regions of frequency should be found in areas of diastrophic activity, and its occurrence should be rare and sporadic in areas of diastrophic sluggishness. This corollary is so well recognized that seismic activity is commonly regarded as the specific criterion of relatively rapid crustal change. Other criteria of such change are physiographic and geologic, and these may be applied in regions whose earthquake history is unknown. They may also be used, in the absence of seismic records, to give approximate indication of mallooseismic localities.

Bold and High Ranges.—It was pointed out by

Powell that, because erosion is greatly stimulated by altitude and high declivity, lofty mountains must be regarded as young; and under the principle of continuity young mountains created by uplift are presumably still growing. They are, therefore, phenomena of diastrophic activity and presumably belong to mallooseismic districts. The conspicuous example is Mt. St. Elias, which rises boldly 20,000 feet from its base, which was shown by Russell to have continued its growth during the life of the existing marine fauna, and which recently has been signalized by earthquakes of the first class.

Fault Scarps.—Along the bases of block mountains the lines of their limiting faults are sometimes marked by fresh scarps demonstrating recent increase of uplift. In the Great Basin these scarps traverse the alluvium of the piedmont slopes, a surface of such simple type that their presence or absence can be observed with confidence. Their absence suggests diastrophic inactivity or sluggishness, for their effacement is a time-consuming process. Their presence suggests diastrophic activity, and the suggestion is strengthened when their relation to phenomena of weathering and erosion is such as to show that they were produced by a series of recent uplifts instead of one only.

Rifts.—A third physiographic criterion is illustrated in California and was brought to general attention by the San Francisco earthquake. The slip causing that shock occurred on the plane of a fault which outcrops at the surface and has been traced for hundreds of miles. The attitude of the plane is vertical, but the displacement along it was horizontal; and there is reason to think that earlier movements on the same plane were horizontal also, for the fault does not separate a ridge of uplift from a valley of depression, but traverses both valleys and mountains. At all points it is included within a belt of peculiar topographic habit, which the investigating geologists have designated as "the rift." Within this belt, which ranges in width from a fraction of a mile to several miles, are numerous ridges and troughs, long or short, level or inclined, and approximately parallel to the trend of the belt. Each of these represents a dislocated tectonic block, and the dislocation is of so recent date that the disturbed drainage has made little progress toward the restoration of normal conditions. Lakelets are numerous, and streams wander irregularly. Without delaying to attempt a fuller and more adequate description, which may be found in the report of the California Commission,* I content myself with an assurance to physiographers that the topographic expression of the rift belt is distinctive, so that it can readily be recognized in other localities by those who have made its personal acquaintance in the field. Other belts of the same character have already

been found in California* and their discovery elsewhere may confidently be expected.

Rift topography appears to be the surface expression of a species of repetitive horizontal faulting, just as the fault scarp is the surface expression of vertical faulting, and the two types, which with present knowledge are apparently distinct, will doubtless eventually be found to intergrade. The features of the San Andreas rift—the one associated with the San Francisco earthquake—were neither created nor greatly modified at the time of that shock, but such modifications as were made were of such character as to accentuate and perpetuate the peculiarities of the belt. The belt itself would be the natural result of a long series of such events, succeeding one another with such rapidity as to dominate minor aqueous agencies in the modeling of the surface. These considerations, together with the fact that earthquakes are known to have repeatedly originated in the rift belts of California, serve to establish the rift topography as a criterion for the recognition of mallooseismic districts.

Geologic Formation.—Fault scarps and rift belts serve to indicate some of the foci of past and future earthquakes. Other foci lie wholly within the earth's crust. Whether the rupture occurs above or below, its jar is propagated through the crust in all directions and affects a large area of the surface. Within this area the intensity of the shock varies primarily with distance from the origin, but it varies also with the character of the geologic formation at the point of emergence. The variation with formation has less range than the variation with distance, but is not less important to the resident and the sojourner, the architect and the engineer—that is to say, it is equally important in forecasting areas of dangerous energy. The portion of San Francisco most intensely racked by the shock of 1906 stood farther from the fault line than the portion least affected, but it stood on less coherent soil. Wood has carefully mapped the distribution of intensity in the San Francisco peninsula, as evidenced by the injury to buildings, and shown its close correlation with the distribution of underlying material;† and similar, though less detailed, correlations have been made in other regions. On the theoretic side the

* The only rift belt besides the San Andreas which has yet been traced for any distance is one which follows in a general way the western base of the Berkeley Hills. In the vicinity of Oakland its position is indicated by a trough among the lower hills two or three miles back from the piedmont plain. At Haywards it coincides with the western base of the hills, and at Irvington, with the western base of a projecting spur. In Berkeley also its line follows the base of the hills, but a little northward it climbs to the summit of the first ridge. The principal fault occasioning the earthquake of 1868 was in this rift belt, running from Haywards southward, and it is probable that some of the earlier recorded earthquakes were associated with the same belt. The fault of 1868 is described, and the rift belt is mentioned, in the "Report of the California Earthquake Commission," Vol. I., Part II., pp. 434-5 and 447.

† Report of the California Earthquake Commission, Vol. I., Part II., pp. 220-45, and atlas, maps 17-19.

* Abstracted from Presidential address to the American Association of Geographers.

* California earthquake of April 18, 1906; report of the State Earthquake Investigation Commission; published by the Carnegie Institution, Washington, 1908, pp. 25-52.