Some Recent Researches on X-Rays: the J-Phenomenon.¹

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A FEW years ago there appeared to be two, and only two, X-ray phenomena—scattering and fluorescence. One was due to the tremor, the forced vibration, set up in electrons when matter was traversed by X-rays; the other was due to the ejection of electrons from certain atoms and the subsequent free vibration of electrons within those atoms. One was governed by classical laws, the other by quantum laws.

For some years now, what is apparently a third phenomenon has been coming to light. This phenomenon has many of the characteristics of fluorescence (with the emission of characteristic X-rays). As it was found to occur at frequencies higher than those associated with the K-radiations, it was called the J-phenomenon. It has also frequently a close association with scattering, an association which led to what has been called a quantum theory of scattering. The phenomenon is, however, neither X-ray scattering nor X-ray fluorescence, as these terms have been understood; and it seems undesirable to use either term to denote what is quite distinct from both. It is almost certainly governed by quantum laws, and it is possible that its investigation will lead to some solution of the whole problem of the quantum relationships.

THE J-PHENOMENON.

The effects described as the J-phenomenon are briefly these:

As the frequency of an X-radiation gradually increases, though there is in general an increase in the penetrating power of the radiation, under certain conditions the absorption in a given substance exhibits a discontinuity, rising abruptly to a higher level, and afterwards diminishing as previously with increasing frequency of the radiation. This is very similar to the rise in the absorption in a substance accompanying the emission by that substance of a characteristic radiation.

This absorption discontinuity occurs at higher frequencies (higher penetrating powers) the higher the atomic number of the absorbing element. The discontinuities have been observed in carbon, nitrogen, oxygen, aluminium, sulphur, copper, gold, and platinum.

The sudden increase in the absorption of the rays is accompanied, when the absorbing substance is in the gaseous state, by a sudden increase in ionisation in that substance. When in the solid state, the absorbing substance emits an additional corpuscular radiation. The ejected electrons are apparently slowly moving electrons.

All these phenomena are suggestive of the emission of characteristic radiations of another series, the J series.

There are, however, a number of characteristics which distinguish the J-phenomenon very clearly from the phenomena associated with the emission of characteristic radiation of the now well-known K, L, M series. These may be briefly summarised:

1. The phenomenon is conditional on some unidentified factor or factors (possibly of intensity or superposition), whereas the only condition essential to X-ray fluorescence as previously known is that expressed by Stokes's fluorescence law.

¹ A summary of the Silvanus Thompson lecture delivered before the Röntgen Society on April 1.

2. The sudden changes in absorption and in ionisation appear to be absolutely abrupt, even when a *heterogeneous* primary beam is used.

3. The point at which the discontinuity occurs appears to be more closely connected with the rate of absorption of energy than with a critical wave-length (though the former, of course, depends upon wave-length).

4. The series of critical wave-lengths in the various elements cuts right across the well-known K series.

5. The change of critical frequency with atomic number is very small.

EXPERIMENTAL EVIDENCE.

The experimental facts illustrating 3 (above) are so remarkable and so entirely new, that they are worthy of description even in a short summary.

(a) Two beams proceeding from the same X-ray tube at the same time in different directions may have different penetrating powers. (There are various possible reasons for this; though it may be suggested that the obvious ones are not necessarily correct.) As the tube hardens up, the discontinuity in the absorption of each beam occurs, not when a particular state of the tube is reached, but when each beam, independently of the other, reaches the critical penetrating power for the substance used as the absorber.

(b) A heterogeneous beam direct from an X-ray tube in some cases shows no absorption discontinuity as the tube becomes harder, whereas when the same radiation is filtered and so brought to a higher average penetrating power, the discontinuity in absorption occurs at the correct critical penetrating power for the absorbing substance used. Thus the absorption of a complex beam is not the sum of the absorption of its constituents.

(c) Again, in some experiments, if the radiation is passed through a thin filter, as the tube hardens the absorption discontinuity does not appear; whereas when a thicker filter is used, the absorption of the transmitted radiation shows a well-marked discontinuity, and at the correct critical penetrating power.

(d) Further, and confirming the above, in some experiments the absorption discontinuity does not appear when *thin* absorbing sheets (absorbing only a small fraction of the radiation) are used; whereas the discontinuity appears when the absorption is measured by means of *thick* absorbing sheets.

(e) Transmission of a given heterogeneous radiation through successive very thin sheets of absorbing material, shows (as might be expected from the above results) that at a certain critical thickness there is an abrupt drop in the intensity of the transmitted beam; that is, the exponential law of absorption evidently breaks down and there is a sudden extinction of the primary beam. After this the absorption differs little, if at all, from what is normally expected. Whether or not the transmitted beam is truly transformed is not shown by these experiments; in experiments of another kind, however, when the sudden extinction occurs, the transmitted beam is definitely of a more absorbable type than previous to the abrupt change.

These results naturally suggest such inquiries as the

following: Are we really measuring the intensity of the radiation? Is a certain portion of the ionisation (used as a measure of intensity) produced by a method distinct from the remainder, and are all the phenomena above described due to this special ionisation? Is a fraction of the observed effect of the X-rays due to the combined action of a number of radiations differing in wave-length? Is a certain portion of the ionisation due to short-range electrons as distinct from the bulk of the ionisation taken as a measure of intensity?

An answer to these and many other questions is given by the results of experiments in which various methods of measuring intensity were adopted. Ionisation in air, in sulphur dioxide, and in hydrogen produced by the emission of high-speed electrons from an aluminium plate in the path of the X-rays, and ionisation produced by the high-speed electrons ejected from copper, were all used as measures of intensity. The discontinuity was observed by each method, and at the same critical penetrating power. The phenomenon thus appears to be independent of the particular method of measuring the X-radiation. We must therefore assume that the phenomenon is one in the X-rays themselves, for our only measure of X-rays is obtained from such effects.

These phenomena have been observed with radiations from many different tubes and with different anticathodes; with strong and with very feeble radiations; with narrow pencils and with wide beams; with polarised and with unpolarised radiations; with heterogeneous and approximately homogeneous radiations; with primary radiations, scattered radiations, and characteristic radiations.

APPLICATIONS TO THE SCATTERING OF X-RAYS.

The results recorded above have many important applications, notably to the phenomenon of scattering of X-rays.

Röntgen radiation which is scattered from light elements is exactly like the primary radiation in its penetrating power (and hence its wave-length) over a long range of wave-lengths. The polarisation, distribution, and intensity of this radiation are all accounted for by the classical theory of radiation. There is no shadow of the quantum in the phenomenon. The appearance under certain conditions of a secondary radiation differing from the primary indicated the probability of the emission of a fluorescent radiation of the J series by these light elements. Compton has recently called this transformed radiation "scattered radiation." It appears that this transformed radiation is neither a fluorescent radiation nor a scattered radiation, as these terms have been understood.

The transformation observed by us is the transformation associated with what is described above as the J-phenomenon. For some reason (possibly connected with intensity), the scattered radiation appears more susceptible to the J-phenomenon than the primary radiation. The following brief statement of results obtained from experiments on scattering show that the true phenomenon of scattering may be completely masked by the J-phenomenon as described above; the results are precisely those to be expected from the application to the scattered radiation of the laws governing the J-phenomenon. They are all contrary

to Compton's hypothesis. (Most of the following results were obtained in collaboration with Dr. S. R. Khastgir.)

1. As the wave-length of a primary radiation diminishes, the scattered radiation remains exactly like the primary (measured by its absorptivity) over a long range of wave-lengths. There is nothing even approaching the difference between primary and scattered required by Compton's hypothesis.

2. An apparent change—a difference between scattered and primary radiation—appears quite abruptly as the frequency of the radiation is increased. It is a change of the order of five or more times the error of experiment. There is no mistaking it. This well-marked difference in penetrating powers of scattered and primary radiations persists for all shorter wave-lengths. (This phenomenon seemed at first to confirm the indications of an emission of characteristic rays of the J series.)

3. Further sudden changes in the scattered radiation appear as the wave-length of the primary radiation is diminished, the difference between the secondary and primary radiations becoming greater at certain critical, though not accurately definable, wave-lengths. There are several well-marked discontinuities.

4. Using various substances to measure the absorptivity of the primary and secondary radiations, the above-mentioned discontinuities occur not at the same but at slightly different wave-lengths.

5. When *thick* absorbing sheets are substituted for *thin* ones to test the character of the radiations, the discontinuity—the sudden appearance of or increase in the difference between the primary and the secondary radiations—appears earlier; that is, when the primary is of greater wave-length than is the case when thin absorbing sheets are used.

6. The wave-length at which the difference appears (the discontinuity) depends to a certain extent both upon the *material* and upon the *thickness* of the radiating substance.

7.² In certain selected cases, we can identify the thin layer of absorbing material in which the change occurs. Thus as primary and secondary radiations are transmitted through an increasing thickness of absorbing material, the absorptions up to a certain thickness are exactly alike (unmodified scattering). A further thin layer makes all the difference between the two. Afterwards the scattered radiation is the more absorbable. Thus we have curves showing quite definitely that an unmodified scattered radiation becomes suddenly modified by transmission through material quite outside the scattering substance. It is, of course, only by proper selection of the radiation experimented upon that this transformation can be located in this way. But this fact alone shows that the transformation is not necessarily or essentially in the process of scattering.

The importance of this result is little affected by the fact that in numbers of experiments in the Laboratory at Edinburgh as elsewhere, long series of observations show a persistent difference between primary and secondary radiations without a suggestion of equality of wave-length or of the abrupt changes referred to above.

² Results under section 7 were obtained in April 1924, shortly after the lecture before the Röntgen Society.

The experiments only *appear* to indicate a change of wave-length produced by scattering. It is possible that, of these cases, the J transformation occurs at the birth in the scattered radiation. But facts of much greater significance are these :

As the frequency of the X-radiation increases we can, in many cases, observe the quite abrupt transition from an unmodified scattered radiation to the modified scattered radiation. There is a gulf between the two which makes the identification unmistakable and shows that some special condition is essential to the production of the modified scattered radiation. We can, in selected cases, take the unmodified scattered radiation and transform it into the modified scattered radiation, even identifying the thin sheet of absorbing material which affects the transformation—quite outside the scattering substance.

These are not isolated results, nor are they of the hazy, indefinite kind which some seem to suspect. The changes are of a magnitude several times the magnitude of the possible error. The phenomenon has all the characteristics of the J-phenomenon as observed originally in primary radiations, and as briefly indicated above.

It is not intended here to discuss either the process or even the nature of the transformation involved, for though many experiments have been made, many more are necessary before we can get a secure foundation for any theory. The phenomenon is not scattering nor is it fluorescence with the emission of characteristic radiation as generally understood ; it is a new—a third X-ray phenomenon. Without committing oneself to an opinion, it may be stated that there is the appearance of a sudden absorption of the beam followed by a re-emission of radiation of somewhat greater wave-length proceeding in the original direction of propagation. Absorption laws break down ; methods of comparing intensities of radiation are no longer applicable. This needs to be borne in mind in experiments upon penetrating radiations. It seems highly probable, for example, that in experiments on the absorption of penetrating X-rays and γ -rays, the transmitted beams produce far too much ionisation for their energy, and thus appear not to be absorbed so strongly as they really are. For we have observed sudden

increases of ionisation of so much as 100 per cent. due to a very slight diminution in wave-length. Thus there seems little doubt that when penetrating X- and γ -rays are transmitted through thick layers of absorbing material, the ionisation coefficient is suddenly increased at certain points (under certain conditions the change may be gradual), and the transmitted radiation then produces a greater effect than is accounted for by intensity alone. It appears more penetrating than it really is.

CONCLUSIONS.

The broad conclusions are that under certain conditions not yet identified, but apparently depending on the rate of energy absorption, discontinuities occur in the absorption of X-radiation accompanied by corpuscular emission from the absorbing substance and ionisation when that substance is in the gaseous state. The transmitted primary radiation behaves as a transformed radiation.

No direct evidence of the emission by the absorbing substance of a characteristic X-radiation (of J series) has been obtained. If it exists it must be very feeble. What originally appeared to be a fluorescent radiation (and to others a modified scattered radiation) has been found in some cases to be merely the scattered radiation transformed by transmission through matter after its production. The radiation when observed is neither characteristic nor scattered, but is the scattered radiation after having been transformed by the J process (a process similar in many ways to fluorescence with the emission of characteristic X-rays). The necessity for critical conditions suggests obedience to the quantum laws in some form. The well-known laws of X-ray absorption break down when the critical conditions are reached.

Though it is realised that some of the results here recorded will possibly need re-statement or modification when they are tested by experiments extending over a wider range of conditions, the results already obtained are so absolutely new, so remarkable, that they seem to justify publication before a solution of the whole problem has been found. Further investigation of the subject promises to lead to some of the most interesting and important generalisations.

Historical Tradition and Oriental Research.¹

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IT has often been remarked that the outstanding trait of the untrained mind is credulity. The rationalisation of man's views of the world has been a very slow process and it is still very far from a completed process. It has commonly been thought to have begun with the Greeks, but its origin must be sought in the Orient in a period long before Greek civilisation had arisen. The Edwin Smith Medical Papyrus, acquired in 1906 by the New York Historical Society, discloses the inductive process of scientific investigation already in operation in the seventeenth century before Christ. For example, this document contains the earliest occurrence of the word "brain" anywhere appearing in surviving records of the past. The word is unknown in Old Testament

Hebrew, in Babylonian, Assyrian, or any of the ancient languages of Western Asia. The organ itself therefore was evidently discovered, and the recognition of its various functions was begun, for the first time by these physicians of early Egypt in the thousand years preceding the seventeenth century B.C. The observations recorded in the Edwin Smith Medical Papyrus show that its author had already observed that control of the members and limbs of the body was localised in different sides of the brain ; and the recognition of localisation of functions in the brain, mostly the work of modern surgeons and others within the past generation or two, had already begun in the seventeenth century B.C., at a time when all Europe still lay in savagery or barbarism.

There is in existence part of an original transit

¹ From a paper communicated to the National Academy of Sciences, Washington, on April 29, and published in the Proceedings of the Academy for July, vol. x. No. 7, 1924.