The Mobility of the Actinium A Recoil Atom measured by the Cloud Method.

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[Plates 15–19.]

1. *Introduction.*

This paper describes the measurement of the mobility of a single atom of actinium A immediately after it reaches the end of its recoil track.

Such a measurement is of importance for two main reasons. Firstly, it is of interest to obtain measurements of the mobility of individual atoms in order to ascertain whether the mobility has always a constant value, or whether a recoil atom possesses sometimes a mobility which is a multiple of the usually accepted value, namely, 1·56 cm./sec./volt/cm. Also, statistical experiments should give much better values of the relative numbers of recoil atoms of different mobilities than can be obtained from activity measurements as made by Erikson.*

Secondly, the present method enables one to obtain *definite* evidence when the mobility (and therefore presumably the charge) of the recoil atom is zero.

It has long been known that only a certain percentage of the recoil atoms bear a positive charge, the difference being attributed to neutral atoms. Briggs† has investigated this percentage for recoil atoms of different kinds in various gases by activity distribution methods, and it is felt that an extension of the present research should give more certain values of the percentages in question, by definite counting, than are obtainable by the activity methods; the latter involve considerable sources of possible error, since, in general, recoil atoms of more than one type are collected, while diffusion and loss of active emanations probably influence the results. Measurements of the mobility of recoil atoms have been made by Rutherford,‡ Franck,§ Erikson|| and Briggs,¶ who all agree in attributing to the recoil atom the positive mobility, approxi-

* 'Phys. Rev.,' vol. 24, p. 622 (1924); vol. 26, p. 629 (1925).

† 'Phil. Mag.,' vol. 41, p. 357 (1921); and vol. 50, p. 600 (1925).

‡ 'Phil. Mag.,' vol. 5, p. 95 (1903).

§ 'Verh. Deutsch. Phys. Ges.,' vol. 7, p. 397 (1909).

|| 'Phys. Rev.,' vol. 17, p. 400 (1921).

¶ 'Proc. Camb. Phil. Soc.,' vol. 23, p. 72 (1926).

mately 1·56 cm./sec./volt/cm., but Erikson finds the additional mobility 4·35 cm./sec./volt/cm., which value has not been assigned to any particular recoil atom.

2. *Theory of the Method.*

Suppose we have a " cloud track " chamber of the usual type which contains actininium, or thorium, emanation.

If a vertical electric field, directed upwards, exists in the chamber, then on making an expansion both sharp and diffuse tracks of α-particles will be obtained.*

For consider disintegration of a single emanation atom. If this occurs during the interval between the supersaturation and illumination, then the ions formed along the resulting α-track are immediately fixed by condensation of water vapour and photographed in their initial positions—the electric field having no effect.

If, however, the disintegration occurs before the supersaturation, the positive and negative ions in the α-track begin to move in opposite directions with constant velocities under the electric field. After a short time the result will be the presence of two parallel tracks, one containing all the positive, the other all the negative, ions. Separation will proceed either until the moment when critical supersaturation necessary for condensation on the ions is reached, with resultant destruction of mobility, or until the separated tracks are removed to the roof and floor of the chamber. We thus see that diffuse tracks may occur in parallel pairs, or in some cases singly, as when, for example, the α-track is initially formed near the roof, so that the positive ions reach the latter before the negative ions reach the floor. The diffuseness is due to self repulsion of the ions in the track, and to gaseous collisions of different kinds during the motion of the ions.

The number of diffuse tracks present is obviously inversely proportional to the strength of the electric field for a given strength of the active source.

When the emanation atom disintegrates, giving an α-track, the actinium A atom produced recoils only a short distance—and is therefore approximately at the origin of the α-track referred to at the instant of its formation. This enables one to determine the mobility of the A atom. If the photographs are taken through the side of the chamber, *i.e.*, in a direction perpendicular to the direction of the electric field, we shall obtain three main types of records of " double " disintegrations, that is, cases in which both the emanation α-track

* Wilson, ' Proc., Camb. Phil. Soc.,' vol. 21, p. 405 (1923).

and the α-track formed by the disintegration of the resulting A atom are present.

Case (*a*).—The emanation atom and the resulting A atom both disintegrate during the time interval between the production of the supersaturation and the occurrence of the illuminating spark.

Case (*b*).—The emanation atom disintegrates before the supersaturation, and the resulting *A* atom after the supersaturation and before the illuminating spark.

Case (*c*).—Both the emanation atom and the resulting *A* atom disintegrate before the supersaturation.

We shall consider these cases separately.

Case (*a*).—In this case no information as to the mobility of the A atom can be obtained.

If we consider the case of actinium emanation, for which the mean life of the A recoil atom is 1/350 second, we see that in general, since the interval between the supersaturation and the illuminating spark is of the order 0·1 second, double disintegration will appear as two α-tracks starting from the same point. The A track is distinguished by a separation of its origin, giving the track the appearance of a "crutch." This is due to the absence of sufficient water vapour, the latter having been absorbed by the origin of the emanation track, so that the positive and negative ions in the origin of the A track moved under the electric field applied to the chamber into a region where there was sufficient water vapour to condense on the ions and reduce their mobility to zero. In the paper by Prof. C. T. R. Wilson referred to, a good photograph of this event is given.

Case (*b*).—Fig. I shows a vertical cross-section of an expansion chamber in which there is a vertical electric field as illustrated.

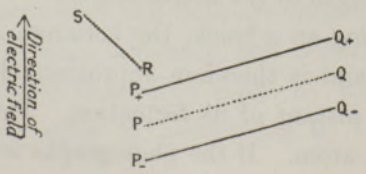

FIG. I.

P_+Q_+ and P_-Q_- are two parallel diffuse tracks formed as described previously—the emanation α-track being initially formed in the position PQ, at an instant previous to the production of the supersaturation. We here suppose that $P_+P = P_-P$, that is, that the positive and negative air ions have the same mobility under the experimental conditions—the correctness of this assumption is shown later.

Now during the time that the emanation α-track was being separated in this

way, the recoil atom of actinium A has moved to some point R in the vertical line $P_- P_+$ (supposing it to be positively charged) and its mobility is given by $(PR/PP_+) \times$ the common mobility of the positive and negative air ions under the experimental conditions. At this instant the supersaturation is supposed to have occurred and fixed all the ions and the recoil atom in the positions shown. (In reality the expansion which produces the supersaturation increases all the vertical linear dimensions in a fixed ratio, but this effect can be neglected in the present discussion.)

If during the interval between this instant and the passage of the illuminating spark the *A* atom at R disintegrates, we shall obtain a sharp α-track whose origin is at *R*.

Thus a photograph of this type (obtained by a camera pointing horizontally through the side of the chamber) gives at once the mobility of the actinium A atom in terms of the common mobility of the positive and negative air ions under the experimental conditions. It does not, however, give the life of the A atom, namely, the time between the two disintegrations, since we cannot tell what interval elapsed between the occurrence of the supersaturation and the disintegration of the actinium *A* atom.

In order that photographs of this type shall be obtained frequently it is necessary that the electric field shall be of such a magnitude as to give an easily recognisable, but not too large, separation of the positive and negative ions of the emanation track in a time approximately equal to the mean life of the actinium A atom. It is obvious that the emanation atoms which disintegrate in a time before the supersaturation shorter than this value and whose A recoil atoms have lives greater than this value give doubles of this nature, since the time interval between the supersaturation and the illuminating spark is much greater than the mean life ; or, in other words, the occurrence of the tracks P_+Q_+, P_-Q_- will almost invariably be accompanied by the tracks RS, provided PQ was due to an emanation atom.

Case (*c*).—It is also obvious that an emanation atom which disintegrates at a time before the supersaturation which is greater than the mean life of the recoil atom will, in general, give rise to a recoil atom which also disintegrates before the supersaturation—the result being that the track RS also undergoes separation.

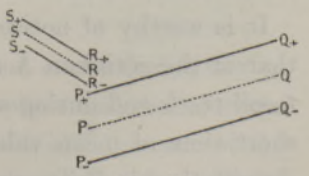

FIG. II.

Fig. II shows the general type of record to be expected in this case. Such a record will give both the mobility of the A recoil atom in terms of the common mobility of the

positive and negative air ions under the experimental conditions, and the time interval between the two disintegrations, that is, the life of the A atom. An easy calculation shows that—

(1) The mobility of the recoil atom

$$= \frac{2 \cdot PR}{(P_- P_+ - R_- R_+)} \times \text{the mobility of the positive air ion under the experimental conditions.}$$

(2) The time interval between the two disintegrations is equal to the time taken for an air ion to travel a distance $= \frac{(P_- P_+ - R_- R_+)}{2}$ under the experimental conditions.

In this case it is to be noticed that the origins of the tracks again lie in a vertical line, the electric field being as before. The parallel pair of diffuse tracks due to the α-particle from the emanation atomic disintegration will naturally be more widely separated than the parallel pair due to the α-particle emitted in the disintegration of the resulting A atom. The former pair will also be more diffuse than the latter.

It has already been stated that the field applied to the chamber has to be adjusted to give a convenient separation of the emanation α-track in the mean life of the A atom.

The accuracy of determination of both the mobility of the A atom and its life is limited by the diffuseness of the tracks. This diffuseness is dependent upon the life of the A atom and is therefore not under control. The error introduced by the diffuseness could doubtless be diminished by the use of a deeper expansion chamber permitting the use of stronger electric fields, when the separations of the tracks would be greater.

On account of this diffuseness experiments with actinium A (mean life = 0·0029 second) are much more satisfactory than those with thorium A (mean life = 0·20 second), whilst the long life of radium A makes similar measurements with it impossible.

Plate 15, figs. 1 and 2, show the great advantage which lies in the use of actinium.

It is worthy of notice that in these experiments the mobility measured is that of the actinium A atom immediately after it has reached the end of its recoil track and during an interval equal to the life of the atom, *i.e.*, during a short time of mean value 1/350 second. The conditions are therefore more definite than in Erikson's experiments, where the recoil atoms, which were not all of one type, had first to pass through a region of dense ionisation before being affected by the electric field. In the experiments of this paper the

recoil atom, if charged, was rapidly removed from ions of the opposite sign—if neutral, both positive and negative ions were rapidly removed from its neighbourhood.

3. *Apparatus and Experimental Method.*

The original expansion chamber used by Prof. C. T. R. Wilson in taking the photographs published in 1912 and 1923 was used in this work.* The illumination was by a Leyden-jar discharge through mercury vapour, and was oblique, photographs being taken through the side of the chamber with a stereoscopic camera.

The timing of the events—supersaturation and production of the illuminating spark—was effected by pendulums of adjustable period, as described in Prof. Wilson's 1923 paper on X-rays.

The interval between the two above events was made as short as possible (consistent with obtaining good tracks) to reduce the number of tracks formed after the expansion. Air was used in the chamber, at a pressure always less than atmospheric ; the data for the photographs published are given in Section 7.

The field, applied by an annular ring of tinfoil fastened to the under side of the glass roof, was usually of the order of 30 volts/cm., but was adjusted so that the separation of the positive and negative ions of an emanation track in the mean life of the A atom (which depends also on the air pressure) was of a convenient magnitude.

The upper plate was always kept negative, this being convenient, since the emanation atoms are more numerous near the floor, and the positive tracks, which are the more important, are thus more probably caught.

The lenses were Beck Isostigmars—f. 8·0 being the aperture usually employed. Imperial Process Plates were used. Some difficulty was experienced in the introduction of the emanation. The method described by Prof. C. T. R. Wilson in a previous paper,† namely, laying a line of the radioactive source across a diameter of the floor of the chamber normal to the axis of the camera, and covering by a sheet of paper to cut off the direct α-tracks, proved unsatisfactory for actinium.

It was evident that a great number of the emanation atoms (mean life = 5·6 seconds) disintegrated while passing through the paper and shot α-tracks out into the chamber. These were separated by the field, and the ratio of the number of emanation tracks originating in the chamber to the total number of

* ' Roy. Soc. Proc.,' A, vol. 87, p. 277 (1912) ; vol. 104, pp. 1 and 192 (1923).

† ' Proc. Camb. Phil. Soc.,' vol. 21, p. 405 (1923).

tracks present was very small. A number of methods were tried, the one finally adopted being the introduction of a small glass tube, about 1 mm. diameter and 1 cm. long, containing a thin layer of the radioactive source.* This tube was fastened horizontally to the gelatine floor of the chamber, on the diameter perpendicular to the axis of the camera, and close to the glass wall of the chamber. The open end of the tube pointed towards the centre of the chamber and faced a small vertical screen of copper about 1 cm. square.

By this means it was found possible to ensure that very few α-tracks starting near the mouth of the tube entered the central part of the chamber: this is, therefore, nearly free from all tracks except those due to emanation atoms which disintegrate in positions convenient for observation.

At fairly low pressures—about 0·25 atmosphere—the required event was then obtained with definition on nearly every plate exposed.

The depth of focus was about 2·0 cms., *i.e.*, tracks which were formed in that portion of the chamber bounded by two vertical planes at this distance apart were distinctly shown on the photographs. The diameter of the chamber perpendicular to the camera axis was, of course, equidistant from these planes. The magnification factor of the camera for vertical distances distributed over this depth of focus is, of course, not constant. The maximum error thus introduced is approximately 2 per cent. and was allowed for where appreciable. It was naturally impossible to prevent the formation of a number of tracks outside this depth of focus, but on examination of the plates with a stereoscope the different tracks were readily disentangled, and there was very little difficulty in interpreting the " rôle " of each track present.

The measurements of the plates were made by a travelling microscope. The magnification factor of the camera was determined by obtaining photographs of reticules placed in the chamber.

The main experiments were made with actinium, but a few preliminary trials were made using thorium.

4. *Results.*

Examination of the photographs obtained showed that five classes of associated tracks were obtained.

A large number of the pairs of type (*a*) were noticed.

The remaining four classes are discussed separately below; each can be accounted for theoretically by taking particular cases of the general theory (*b*) and (*c*) given above.

* The actinium source used was kindly lent by Dr. Chadwick.

Class (1). *Single separation. Mobility = that of the positive air ion under the existing conditions.*—Fig. III shows the nature of the group of tracks in this instance. This is obviously a particular form of *case* (*b*), given previously, corresponding to equality of the mobility of the actinium A atom with that of the positive air ion under the experimental conditions. The track RS was sharp—usually showing rays—the parallel tracks were diffuse.

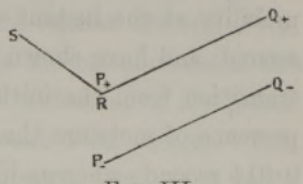

FIG. III.

Twenty photographs of cases of this nature were obtained—for typical plates see Plate 15, fig. 2, and Plate 18, fig. 8. In general the actinium A track was observed to start from the centre of the origin of the emanation α-track—or rather from the end of the positive ions of the recoil track. It is to be noticed that in the preceding discussion we neglected the length of the recoil track. This was about 0·5 mm. at the pressures used.

It is clear that the *ends* of the separated actinium A recoil tracks should be in the same vertical line as the *common origin* of the α-track from the actinium A atom and of the recoil actinium B track. This was in general found to be the case—but the great self-repulsion of the ions in the deeply ionised recoil tracks often masked this effect. In future, for convenience, we shall not refer to this effect, but it was taken into account in making the measurements of the plates. We may, therefore, conclude from these photographs that the mobility of the actinium A recoil atom in air saturated with water vapour is, in some cases, equal to the mobility of the positive air ion under similar conditions. It will be seen shortly, however, that the positive air ion in question is the *initial* short-lived positive air ion.

Class (2). *Double separation. Mobility = that of positive air ion under the existing conditions.*—Fig. IV shows the record obtained in this case. It is obviously a particular form of *case* (*c*), discussed previously, corresponding to the same mobility of the actinium A atom as in (1) above, and to a time interval between the two disintegrations equal to that required for the air ions to travel a distance $\frac{1}{2}$(P_R_).

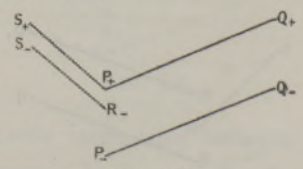

FIG. IV.

Fifty-six photographs of this type were obtained—for typical plates see Plate 17, fig. 6; Plate 18, fig. 7; Plate 19, fig. 9. The time intervals between the two disintegrations, *i.e.*, the lives of the A atoms, were calculated in a manner shown later.

It is of interest here to discuss the assumption we have made that the

positive and negative air ions have equal mobilities under the conditions of these experiments. In a recent paper Tyndall and Grindley* have confirmed a result obtained by Erikson,† namely, that the positive air ion has a higher mobility at the instant of its formation than after an interval of about 0·02 second, and have shown in addition that the presence of moisture retards the transition from the initial to the final positive ion. They found that in the presence of moisture the positive ions are nearly all in their initial state after 0·014 second, whereas in dry air a considerable amount of transformation has occurred in 0·007 second. In these experiments the age of the positive ions *when the actinium A atom disintegrates* is never greater than 0·006 second, so that it must be the *initial* positive air ion which is effective in the cases described. Now Tyndall and Grindley found that in dry air the mobility of the initial positive ion equals that of the negative ion, namely, 2·15 cm./sec./volt/cm.—and both are affected by water vapour in the same way—tending to the value 1·60 for air with a saturation water-vapour pressure of 16·5 mm. This latter value is, therefore, the mobility of the positive air ion in the experiments of this paper.

Since the occurrence of groups of tracks belonging to classes (1) and (2) above fixes the mobility of the actinium A recoil atom as identical with that of the positive air ion under the experimental conditions, the mobility of the actinium A atom in air saturated with water vapour is in such cases equal to + 1·60 cm./sec./volt/cm.

In reality, as will be seen later, the mobility measured is that of the A atom in air for supersaturations less than the critical value for condensation upon the ions. The experiments of Tyndall and Grindley indicate, however, that this mobility will not differ much from the value for air saturated with water vapour. This is close to the value obtained by Erikson in ordinary air which had not been dried, and was probably also unsaturated, and suggests that the actinium A atom is not influenced by water vapour to the same extent as a negative or initial positive air ion.

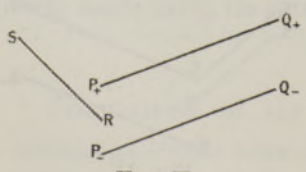

Fig. V.

Class (3). *Single separation. Mobility* = 0.—See fig. V. This, again, is a particular form of case (*b*) in the earlier part of the paper.

Four examples of this phenomenon were obtained. See Plate 15, fig. 3; Plate 16, fig. 4; and Plate 17, fig. 5.

* 'Roy. Soc. Proc.,' A, vol. 110, pp. 341 and 358 (1926).

† 'Phys. Rev.,' vol. 24, p. 502 (1924).

Although the positive and negative air ions have equal mobilities under the experimental conditions, we should not expect the distances RP_+ and RP_- to be exactly equal, for the critical supersaturations for the positive and negative ions are not attained simultaneously owing to the finite time of descent of the piston. The exact manner in which this time affects the calculations of the mean lives of the A atoms is shown later. The time of descent of the piston was approximately determined and found to be about 0·02 second. This corresponds to an interval of about 0·003 second between the instants at which critical supersaturations are reached for the negative and positive ions and to a further interval of the same amount between the latter instant and the attainment of the final supersaturation for which $v_2/v_1 = 1{\cdot}37$. The difference $(P_+R - P_-R)$ which would be obtained if the instants of occurrence of critical supersaturation and destruction of mobility for an ion were identical is about 3·0 mm. The experimental value obtained for this distance was never greater than 0·3 mm., and in two of the four cases it was approximately zero. It is to be expected that the time during which an ion is in the free state decreases very rapidly as the supersaturation increases beyond the critical value, and since the greater final supersaturation is reached in a very short time after the attainment of critical supersaturation, it is seen that the value for $(P_+R - P_-R)$ of 3·0 mm. is an upper limit, and that any value less than this magnitude is possible experimentally. For this and other reasons it has been assumed that destruction of mobility occurs at the same instant for positive as for negative ions.

Class (4). *Double separation. Mobility* = 0.—Fig. VI shows the modification of fig. II necessary to explain the photographs of this class. All four tracks are diffuse in this case. Eleven photographs of this type were obtained (see Plate 19, fig. 9). In general the distances between the two positive tracks and between the two negative tracks were not quite equal, but taking all the photographs the mean of the former was equal to the mean of the latter.

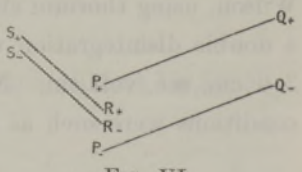

FIG. VI.

This equality would be expected even for a comparatively large time between two critical supersaturations, since in this case the distances P_+R_+ and P_-R_- are determined completely by the velocity of the positive and negative ions and the interval between the two disintegrations.

Photographs of the α-tracks produced by the use of actinium emanation in an expansion chamber have also been taken by Kinoshita and Ikeuti.* In their

* 'Nagaoka Anniv.,' 1925.

experiments the axis of the camera coincided with the direction of the electric field, making it extremely difficult to examine the relative positions of the origins of the tracks since separation occurred in the line of sight. No mention of neutral recoil atoms is made—the object of the study apparently being the determination of the relative numbers of the pairs " sharp-sharp," " sharp-diffuse," " diffuse-diffuse " with a view to the determination of the decay constant of actinium A.

5. *Rare Occurrences.*

The above four classes, together with the double disintegrations which occurred between the supersaturation and illumination, embrace nearly all the cases experimentally observed.

In two cases photographs were obtained which apparently corresponded to a mobility of the actinium A atom higher than the value given in Classes (1) and (2) above. Unfortunately, in both of these cases the separation of the emanation track was very small, making the error due to diffuseness considerable. The distance of the origin of the actinium A track in these cases from the centre of the ions at the end of the positive separated track is, moreover, of the same order as the deviations occurring in the inequalities of positive and negative separations in Class (4) above, and it therefore seems unjustifiable to attribute these cases to a higher mobility than the value 1·60 but rather to assume that in these cases the A atom suffered greater gaseous diffusion than the average ion. One photograph was obtained which corresponded to the recoil atom being negatively charged of mobility 1·60. Little certainty is felt about this photograph—the origin was in a part of the chamber which was denser than the average with other tracks. Among the photographs taken by Prof. C. T. R. Wilson, using thorium emanation in the expansion chamber, there is a record of a double disintegration which apparently corresponds to a negative mobility 3·6 cm./sec./volt/cm. No such record was obtained in these experiments; conditions were such as to render its detection rather improbable.

6. *Experiments with Thorium.*

Only a few photographs were taken using thorium emanation. Plate 15, fig. 1, shows a typical case and emphasises the great advantage lying in the short life of actinium A.

The diffuseness of the separated tracks makes it impossible to give any value for the mobility of the thorium A atom.

Three cases in which the mobility was equal to that of the positive air

ion, and one case of zero mobility, were obtained, in each of which only the emanation track was separated.

7. *Description of Plates.*

Plate 15.

Fig. 1.—Final pressure = 39 cms. of mercury.
Electric field = 1·5 volts/cm.

$$v_2/v_1 = 1{\cdot}36.$$

This figure shows an example of Class (1) for thorium. The sharp track is, by chance, almost parallel to the initial emanation track.

Fig. 2.—Final pressure = 28 cms.
Electric field = 35 volts/cm.

$$v_2/v_1 = 1{\cdot}37.$$

This photograph belongs to Class (1) for actinium, showing the smaller diffuseness of the parallel pair of separated tracks.

In all the following cases actinium emanation was in the chamber.

The magnification given below each figure indicates the ratio of the linear dimensions of the picture to those of the original object.

Fig. 3.—Final pressure = 26 cms.
Electric field = 34 volts/cm.

$$v_2/v_1 = 1{\cdot}37.$$

This stereoscopic pair shows an example of Class (3). The enlarged "heads" of the tracks, due to the great ionisation produced by the recoil atoms, are clearly visible.

Plate 16.

Fig. 4.—An enlargement of the left-hand photograph of Plate 15, fig. 3.

Plate 17.

Fig. 5.—Final pressure = 28 cms.
Electric field = 35 volts/cm.

$$v_2/v_1 = 1{\cdot}37.$$

This stereoscopic pair shows another example of Class (3).

Fig. 6.—Final pressure = 27 cms.
Electric field = 35 volts/cm.

$$v_2/v_1 = 1{\cdot}37.$$

An example of Class (2) is shown ; the life of the A atom was 0·0016 second, Also near the roof there is a pair of sharp tracks with the same origin due to a double disintegration which occurred after supersaturation.

Plate 18.

Fig. 7.—Final pressure = 17 cms.

Electric field = 23 volts/cm.

$$v_2/v_1 = 1{\cdot}39.$$

Three records of double disintegrations are present on this stereoscopic pair. The three enlarged " heads " in a vertical line near the centre correspond to an example of Class (2). The more widely separated pair of parallel tracks are due to the α-particle from the emanation atom. This example also shows the effect previously discussed in Section 4, namely, that the *ends* of the separated actinium A recoil track are in the same vertical line as the common origins of the separated α-track from the A atom, and of the recoil actinium B track. The life of the A atom in this example was 0·0007 second. Above this, on the left, is seen a record of a double disintegration corresponding to a very short life of the A atom, certainly less than 0·0002 second. Near the bottom of the photograph there is an example of a double disintegration which occurred after the critical supersaturation had been reached.

Fig. 8.—Final pressure = 28 cms.

Electric field = 36 volts/cm.

$$v_2/v_1 = 1{\cdot}36.$$

The horizontal pair of parallel diffuse tracks correspond to an example of Class (1). The sharp track originating at the beginning of the positive separated track shows a crutch at its origin, due to want of water vapour at this point. The inclined pair of parallel diffuse tracks belong to an example of Class (2). The α-track from the A atom is, by chance, vertical ; so that the motion in opposite directions of the positive and negative ions in this track gives rise to separation only at the origin. This is visible, and combined with the diffuse character of the track justify the inclusion of this example in Class (2) rather than Class (1). On the left of each stereoscopic photograph there is a record of a double disintegration which occurred after the supersaturation. On the right of the right-hand photograph there is another example of the same type, but somewhat out of focus. The diffuse spot in each photograph is not a small cloud but an optical image of the source due to successive reflection by the glass cylinder.

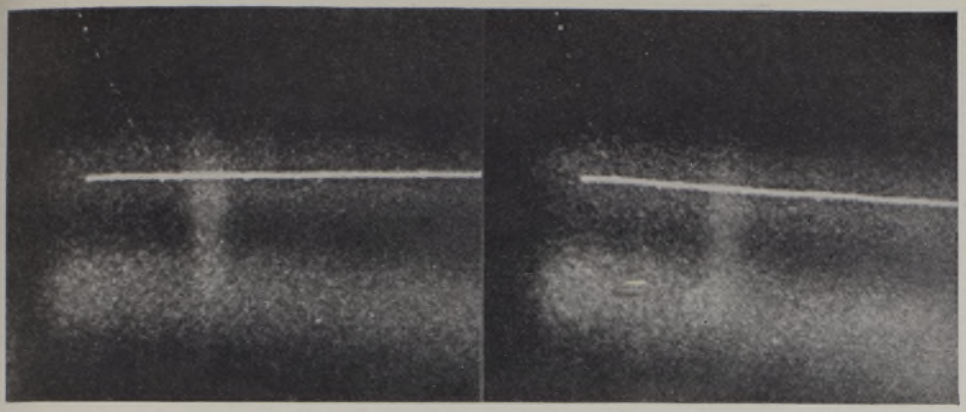

FIG. 1. (× 2.)

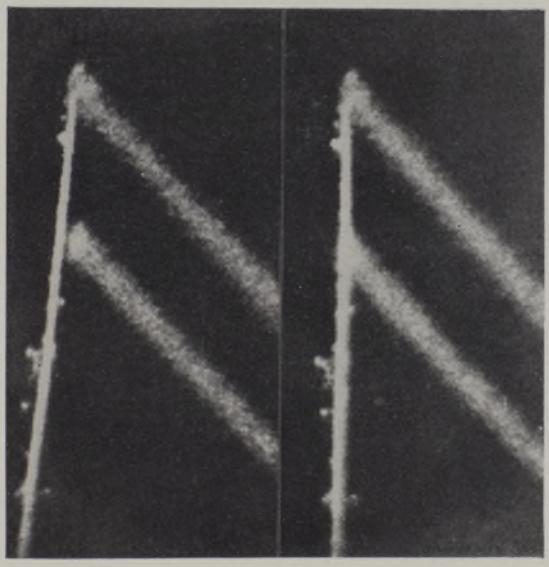

FIG. 2. (× 3.)

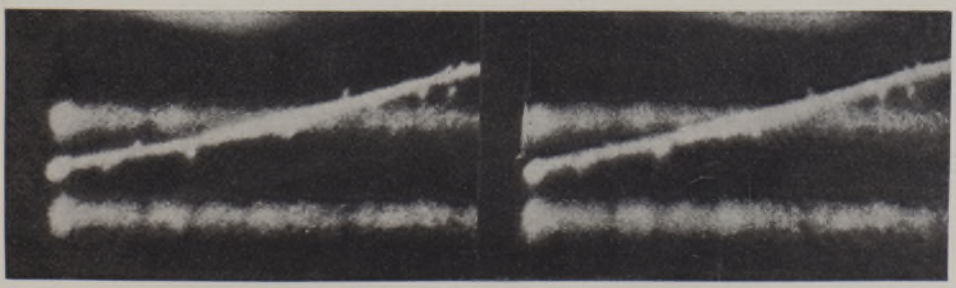

FIG. 3. (× 3·5.)

(*Facing p.* 676.)

FIG. 4. (×2·5.)

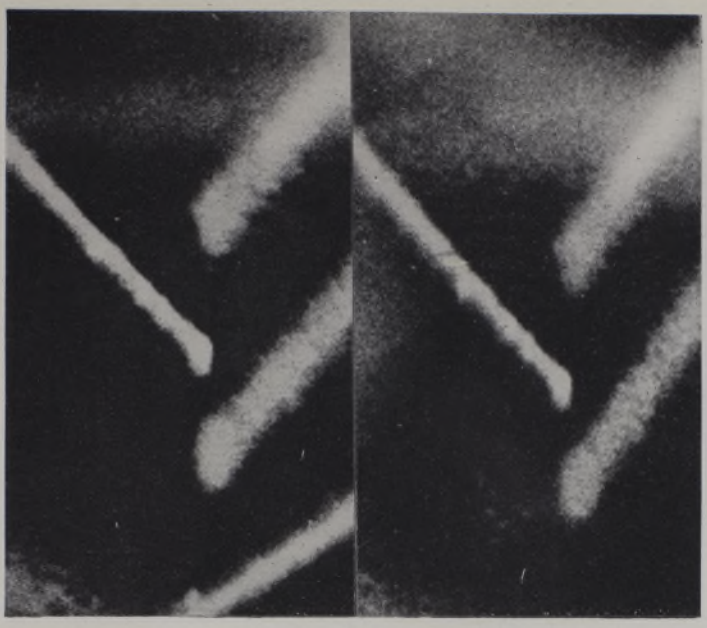

FIG. 5. (× 7.)

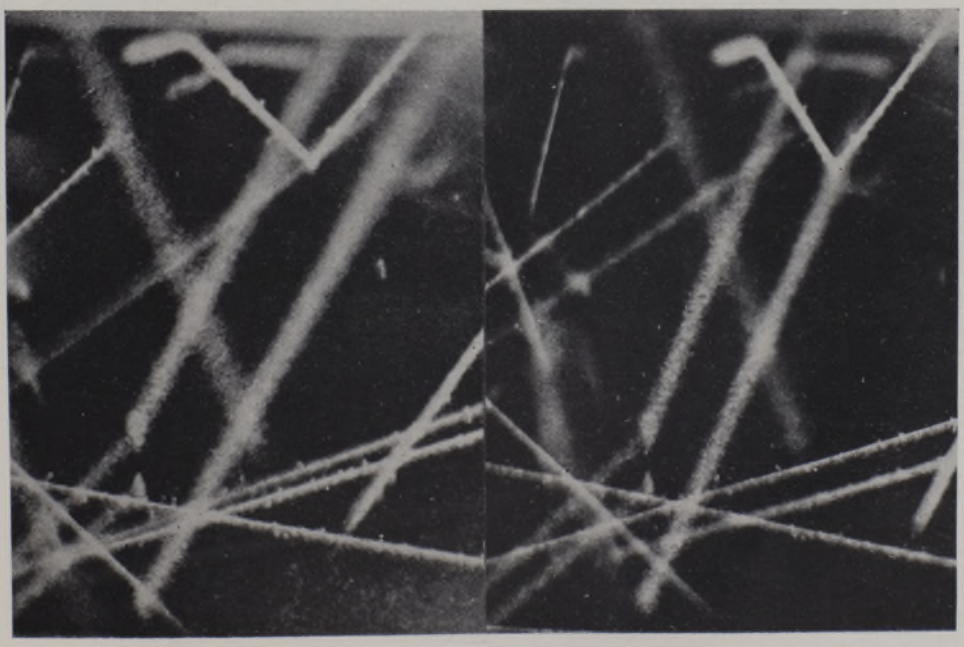

FIG. 6. (× 2·8.)

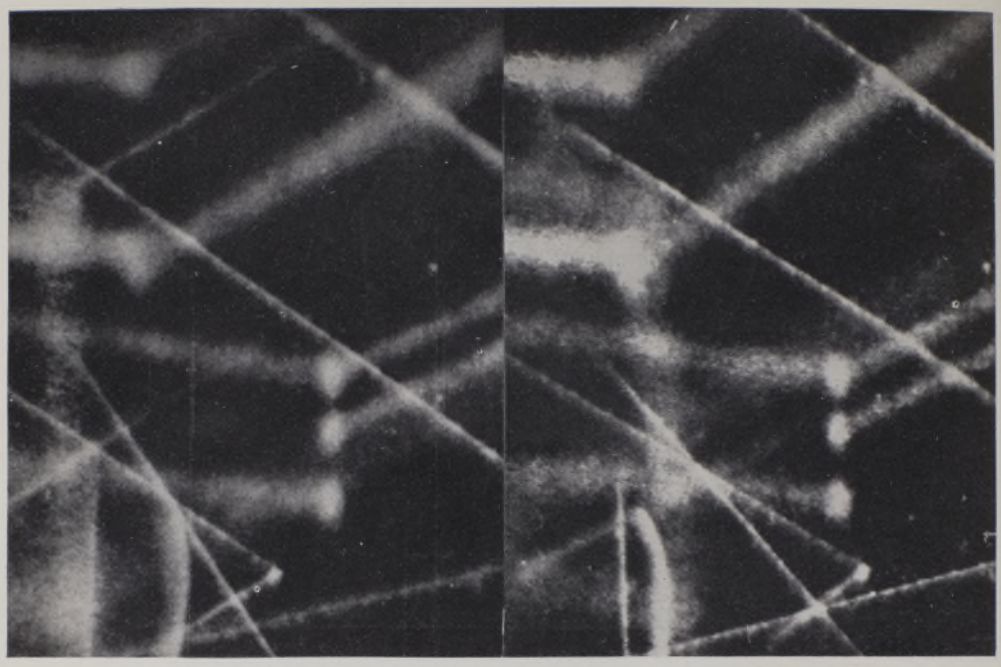

FIG. 7. (× 4.)

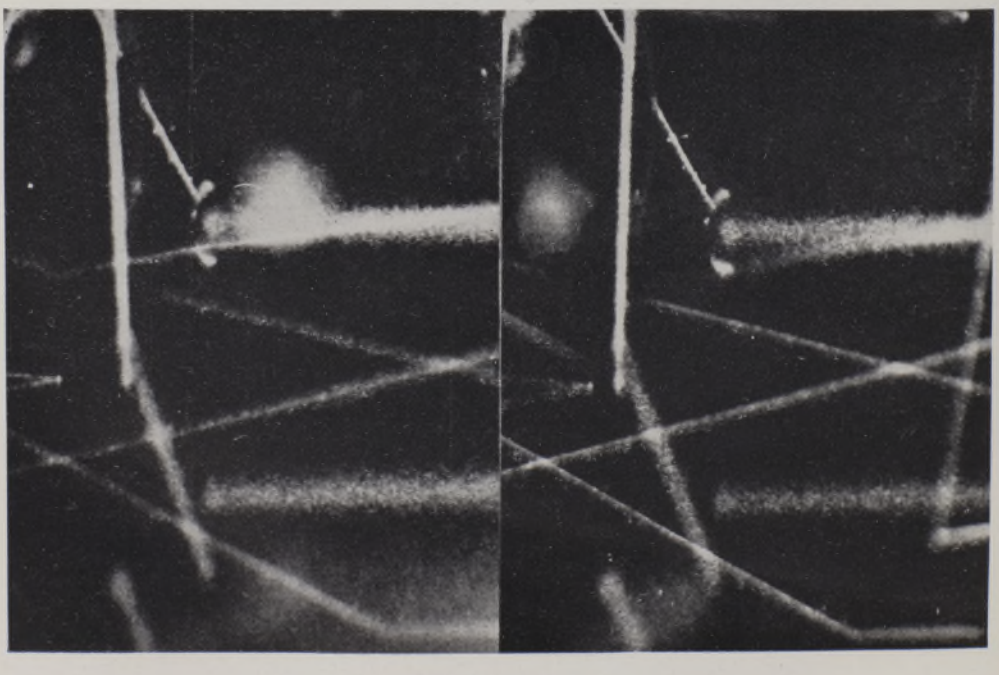

FIG. 8. (× 2·5.)

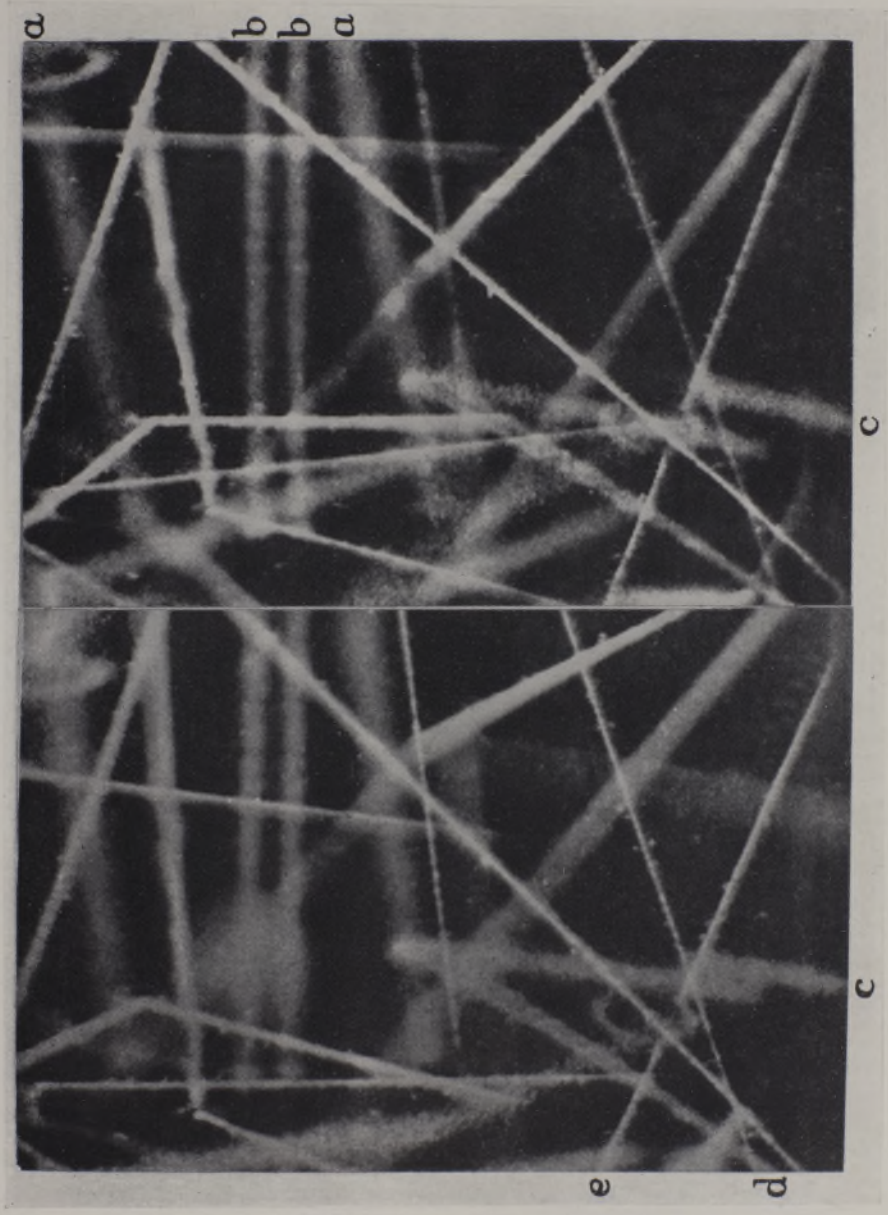

FIG. 9. (× 3·5.)

Plate 19.

Fig. 9.—Final pressure = 28 cms.

Electric field = 34 volts/cm.

$$v_2/v_1 = 1{\cdot}37.$$

This photograph contains a much greater number of tracks than was customary.

The four diffuse tracks, *aa*, *bb*, correspond to a double disintegration of Class (4), the life of the A atom being 0·0032 second. The tracks, *c*, *d*, belong to a record of Class (2); the α-track from the A atom is only slightly separated; the life of the A atom was 0·0032 second. Two double disintegrations which occurred after the expansion are also visible, one showing the crutch at the common origin of the two α-tracks. A similar effect is seen in the loop on the sharp track *e*.

8. *Calculations and Rough Statistics.*

The factor 0·40 was obtained for the magnification effect of the camera—vertical distances measured on the plates have to be multiplied by 2·50 to give the actual magnitude of vertical distances in the chamber.

The average number of tracks originating in the gas was, neglecting doubles of case (*a*), which are readily recognisable, about 3 per plate, so that the chance of records of the above classes being produced by the disintegrations of unrelated atoms is very small. It is realised that in the above method the actinium atom of mobility 4·35 as found by Erikson, even if due to actinium A, would in many cases escape capture owing to its greater separation from the emanation tracks, but in *32* cases of the total number (91) of double disintegrations (other than those of case (*a*)) which were recorded the position of the emanation track was such that had the A atom possessed the high mobility value it would have been detected.

The total number of positively charged recoil atoms of actinium A observed was *76*, the total number of neutral atoms was *15*, giving the value 84 per cent. of actinium A recoil atoms positively charged in air at the end of their recoil tracks.

This agrees well with Briggs's value 82 per cent. obtained for thorium A and radium A in air, since it is to be expected that these elements give the same percentage as actinium A, the three elements being isotopic, and this percentage depending only upon the nature of the atom and of the gas in which the recoil occurs, and not upon the velocity of recoil. Briggs has shown that isotopic elements do give identical percentages in the same gas, and using the value

82 per cent. for actinium A in air has explained Lucian's* results for the distribution of active deposit of actinium emanation.

By assuming that the whole separation occurs before the expansion commences, and that the latter occurs in an infinitely short time, it is possible to prove that the life of the actinium A atom is given by

$$\frac{2{\cdot}5\ \mathrm{D}\,.\,v_0 v_1}{\mathrm{K}\mathrm{V}v_2}\left\{(\mathrm{B}-p)+\frac{pv_1}{v_0}\right\}1/76\ \text{sec.},$$

where

D cms. = the measured distance on the plates ½(P_R_) for Class (2), (P_R_) for Class (4).

K cm./sec./volt/cm. = the mobility of the negative air ion for the water-vapour pressure in question, and for total pressure = 76 cms.

B cms. of mercury = Barometric height.

V = Voltage applied to chamber.

v_0 cms. = depth of the cloud chamber at barometric pressure.

v_1 cms. = depth of the cloud chamber just before the expansion.

v_2 cms. = depth of the cloud chamber after the expansion.

p cms. of mercury = the water-vapour pressure.

The expansion, however, does not occur in an infinitely short time. Calculation shows that the whole separation which occurred took place after the piston had started to move. The equations giving the separation of the tracks for a life L seconds of the A atom were obtained and it was found that, if the electric field in the chamber remains constant during the expansion, the equation for the separation of the negative tracks where the piston is moving whilst the whole double event occurs was exactly the same as the equation obtained on the assumption of an infinitely fast expansion after the whole event has occurred at the pressure just before the expansion. The field remains constant during the expansion because the time of the latter is very much shorter than the time taken for the electric charge on the glass roof to diminish by leakage across the roof to the smaller value which corresponds to the smaller field, *i.e.*, to the field which corresponds to the greater depth of the chamber and the same applied voltage. By experiments with a gold leaf electroscope it was shown that the time taken for the leakage of the excess charge off the roof was certainly greater than 0·3 second, whilst the time of descent of the piston is of the order 0·02 second.

* 'Phil. Mag.,' vol. 28, p. 761 (1914).

The equality of the two cases can be seen in a simple manner as follows :—

Consider the motion of an ion under the electric field during the descent of the piston.

Let s = the *displacement* of the ion at the time t; that is, its distance from the gas molecules which were in its immediate neighbourhood at $t = 0$.

Then the increase of this, due to the mobility of the ion, in time dt is equal to

$$\mathrm{KF}\frac{v}{v_0}\,dt \text{ (assuming } v_0 \text{ corresponds to 76 cms. pressure),}$$

where

v = depth of the chamber at time t,

F = the constant field during the expansion $\left(= \frac{V}{v_1}\right)$,

K and v_0 being as given above.

The final contribution of *this* separation to the final displacement of the ion

$$= \mathrm{KF} \cdot \frac{v}{v_0} \cdot dt \cdot \frac{v_2}{v}$$

$$= \mathrm{KF}\frac{v_2}{v_0}\,dt.$$

Thus the final displacement

$$= \mathrm{KF} \cdot \frac{v_2}{v_0} \cdot t,$$

where t = the time interval between the production of the ion and the instant when *its* mobility is destroyed by condensation.

Now on the elementary theory that the expansion occurs in an infinitely short time we have for this displacement $\left(\mathrm{KF}\frac{v_1}{v_0}t'\right)$ before the expansion—giving a final displacement

$$= \mathrm{KF}\frac{v_1}{v_0}t' \cdot \frac{v_2}{v_1},$$

$$= \mathrm{KF}\frac{v_2}{v_0}t',$$

t' in this case being the interval between the production of the ion and the instant of expansion. It may also be seen that the final result for the displacement is as if the motion occurred at the *final* pressure for a time t given above.

For the determination of the life of the A atom we need only consider the distance between the negative tracks, so that the correct result is obtained by considering the motion of the ions from the instant of their production to the instant of attainment of critical supersaturation for the negative ion.

Using the equation on p. 678 and substituting the values of all the different quantities for each case, the lives of the actinium A atoms were obtained in 47 cases of the total number of cases (67) in which the double separation occurred. The lives in the other 20 cases were not calculated as all the origins did not appear on the plate—this, however, did not prevent the recognition of these cases, as in general only a small length of the separated negative emanation track was missing.

The mean life of these 47 actinium A atoms was 0·0018(5) second. The highest life recorded was 0·0053 second, and in two of the cases the separation of the origins of the negative separated tracks was too small to be measured, the life being shorter than 0·0001 second. If we calculate the mean life to be expected for an infinitely large number of actinium A atoms, whose lives are all shorter than 0·0053 second, we obtain the value 0·0019 second. The agreement is better than would be expected, since the mean life thus calculated varies rapidly with change in the maximum value adopted.

The distribution of the lives was compared with that to be expected theoretically for A atoms whose lives are all shorter than 0·0053 second.

Life in seconds.	0–0·001.	0·001–0·002.	0·002–0·003.	0·003–0·004.	0·004–0·0053.
Calculated No.	17	11	8	5	5
Observed No.	18	13	8	3	5

The relative numbers of the three types of records, " sharp-sharp," " sharp-diffuse," " diffuse-diffuse," agreed approximately with the calculated numbers.

9. *The High Mobility Recoil Atom.*

It is very probable that the mobility 4·35 cm/sec./volt/cm. is due to one particular type of recoil atom. In Erikson's experiments about equal activities were found for the groups of atoms possessing mobilities 1·56 and 4·35 respectively, and the two groups were *B* products a short time after collection when their activities were measured. It is well known that emanation recoil atoms are all neutral. The agreement of my value 84 per cent. of actinium A atoms positively charged in air, combined with the fact that in a large number of cases the high mobility would have been observed had it been present, makes it improbable that more than a small percentage of the A atoms have the high mobility. This suggests that the high mobility recoil atoms obtained by Erikson were B atoms.

Summary.

A method is described by which the mobility of *individual* actinium A recoil atoms is measured at the instant of their reaching the ends of their recoil tracks. Photographs of four main types of grouped tracks were obtained, corresponding to the double disintegration—actinium emanation $\xrightarrow{\alpha}$ actinium A $\xrightarrow{\alpha}$ actinium B. The relative positions of the origins of these tracks gave the mobility and, in some cases, the life of the A atom. Results obtained for actinium A agree with the usually accepted value for the mobility, namely, 1·56 cm./sec./volt/cm. The method also gives *direct* evidence that some of the recoil atoms at the end of their recoil track are uncharged, and the percentage of such neutral recoil atoms agrees with Briggs's value, found by activity distribution methods. The lives of the actinium A atoms were deduced for 47 cases, and the rough statistics were satisfactory.

No cases of the mobility 4·35 found by Erikson for recoil from an active source were obtained. The method is well suited to a study of the percentages of actinium A and thorium A recoil atoms positively charged in different gases.

The above method was suggested by Prof. C. T. R. Wilson, to whom I am also indebted for valuable advice during the course of the work.

The research was carried out with the original apparatus installed by Prof. C. T. R. Wilson at the Solar Physics Observatory, Cambridge. I wish to thank the Director, Prof. Newall, for the use of all the facilities of the laboratory. I wish also to thank Mr. Manning for making the photographic enlargements.

Appendix.

Before the work described above was undertaken, Mr. Hamshue and I had repeated Briggs's* experiment on the mobility of recoil atoms from a mesothorium source. The method was that of deflection of the recoil atoms in an electric field and air blast acting at right angles. The method adopted is that fully described in the paper referred to with a few slight modifications.

The air velocity was measured by Pitot tubes connected to the apparatus—one facing the blast and one fitting in flush with the side wall of the box so that the air stream blew tangentially across its mouth. The pressure difference recorded was measured by a Chattock gauge.

The mobility calculated from the "peak" values of the photometer curves was ($1·50 \pm 0·04$), which agrees with Erikson's and Briggs's values.

It is of interest to note that Briggs failed to obtain evidence of the 4·35

* 'Proc. Camb. Phil. Soc.,' vol. 23, p. 73 (1926).

mobility recoil atom and suggested as the main point of difference between his experiment and Erikson's the fact that Erikson used fields of the order of 1,000 volts/cm. compared with his own field of about 140 volts/cm.

We used fields of the order 750 volts/cm., and in one case 1,000 volts/cm., but obtained no evidence of the high mobility recoil atom.

Further Measurements on Wireless Waves received from the Upper Atmosphere.

By R. L. Smith-Rose, D.Sc., Ph.D., and R. H. Barfield, M.Sc.,

(Communicated by Admiral of the Fleet Sir Henry Jackson, F.R.S.—Received October 1, 1927.)

1. *Introductory.*

In previous papers* the authors have described the development of experimental methods of measuring the directions and relative intensities of both the electric and magnetic forces in wireless waves received at the earth's surface from a distant transmitting station. In this work it was seen that the detection of the arrival of waves deflected from the upper atmosphere, and polarised with their electric force in a horizontal plane, was rendered difficult owing to the relatively great reflecting power of the earth resulting from its high conductivity. By a suitable choice of wave-length and careful attention to detail in the design and construction of the apparatus, however, the methods employed enabled measurements to be made on both vertically and horizontally polarised waves. The results of such measurements enabled a direct proof to be given of the fact that the fading of wireless signals on a vertical aerial and the variations of bearings experienced on the closed-loop type of wireless direction-finder are due to the reception respectively of vertically and horizontally polarised waves deflected from the upper atmosphere in their passage from the transmitter to the receiver. On arrival at the receiver, these indirect or atmospheric waves interfere with the direct or ground waves, in a manner determined by their relative magnitude and phase, and produce the intensity and apparent directional variations mentioned above. The results of such interference phenomena

* 'Roy. Soc. Proc.,' A, vol. 107, p. 587 (1925), and vol. 110, p. 580 (1926).