On the Falling Cloud-Chamber and on a Radial-Expansion Chamber

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On the Falling Cloud-Chamber and on a Radial-Expansion Chamber

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[PLATES 17–18]

INTRODUCTION

When cloud-track photographs are taken with the cloud-chamber fixed between the poles of a magnet, it is difficult to fulfil the conditions for maximum efficiency of either the magnetic or optical parts of the apparatus. If it were possible to remove the cloud-chamber from between the pole pieces (or from any confined space) after the expansion and then to obtain undistorted photographs of the resulting cloud-tracks, the possibilities of the cloud-chamber method might be considerably extended. The simplest method of removing the cloud-chamber from its original position would be to allow it to fall. And dropping the cloud-chamber would seem to be not only the easiest but also the best possible method of displacing it. For if the cloud-chamber is released at the moment of expansion, then so long as it is falling freely the disturbing effects of gravity will be eliminated; the droplets will not fall relatively to the gas in the chamber, and convection currents will not be set up in spite of the differences of temperature which arise in the gas owing to contact with the walls and to condensation on tracks. Thus, dropping the cloud-chamber instead of causing distortion of the tracks will tend to prevent it, if the photograph is taken while the chamber is still falling freely. The falling cloud-chamber may thus have considerable advantages quite apart from the particular application which suggested it.

Before making experiments with a falling cloud-chamber, it seemed desirable to endeavour to design one which should have both the form most suitable for insertion between the poles of a magnet and also admit of the maximum efficiency of the optical arrangements. The form of expansion apparatus which suggested itself as likely to be good for both purposes was one in which the cloud-chamber is a shallow cylinder with fixed parallel glass ends and in which the motion of the air during expansion is radial. It was decided to try a modification of the expansion apparatus described a year ago* in which the pressure remains constant after expansion, not the volume as in the older type of apparatus.

The first part of our work (and the main part) has been the construction and testing of a radial-motion expansion apparatus; the second part has been the study of the behaviour of the falling cloud-chamber. The radial-motion cloud-chamber as finally constructed has been found to work well. The advantages anticipated from allowing the cloud-chamber to fall have been confirmed.

NATURE OF THE EXPANSION IN THE RADIAL-MOTION CLOUD-CHAMBER

It is essential that the motion of the air during expansion in any cloud-chamber used for track photography should cause no eddying or other motion persisting after expansion is completed. If this condition is satisfied the tracks of particles, which enter the chamber after expansion, will be free from distortion, except in so far as they are disturbed by subsequent local heating and the resulting convection currents. The tracks of particles which enter the chamber before expansion will, however, share in the motion of the air during expansion and it is desirable that the deformation so produced should be of a simple kind, such as uniform magnification in one, two or three dimensions. Magnification in three dimension is incompatible with illuminating and viewing the cloud-tracks. Magnification in one dimension is that aimed at in the ordinary type of chamber; a close approximation to uniform magnification in two dimension is attempted in the radial motion cloud-chamber.

Let us assume that the displacement of air on expansion in a cylindrical cloud-chamber is made to be everywhere radial. As the pressure before and after expansion will be uniform throughout the chamber, the volume expansion ratio v_2/v_1 (if adiabatic conditions be assumed) must be everywhere the same. As there is no motion parallel to the axis, there is throughout the chamber a uniform two-dimensional expansion of the air, any area in a plane at right angles to the axis being increased in the ratio v_2/v_1. Every particle of air will have its distance from the axis increased by radial displacement in the ratio $\sqrt{v_2/v_1}$. In a track system due to particles passing before the expansion all linear dimensions in directions at right angles to the axis will be increased in the ratio of $\sqrt{v_2/v_1}$, dimensions parallel to the axis remaining unchanged; there is thus uniform two-dimensional magnification. The actual motion of the

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* 'Proc. Roy. Soc.,' A, vol. 142, p. 88 (1933).

air will differ somewhat from the ideal motion which has been assumed. For at the surface of the end plates of the cylindrical cloud-chamber the radial motion will vanish, and for a short distance from the plates will fall short of the displacement corresponding to the expansion ratio. To compensate for this deficiency in the radial expansion of the layers near the plates there must be expansion at right angles to the plates; this implies for the rest of the air in the chamber compression in a direction parallel to the axis with a corresponding increase in the radial expansion. The displacements parallel to the axis will be small, and unless the chamber is a very shallow one the radial displacement except near the end plates, will differ little from that deduced from the expansion ratio. The heat received from the end plates, during or after expansion, will add to the above effect by causing expansion of the air next the plates and consequent increased radial displacement elsewhere. These effects are small and, except in the regions close to the end plates, will only result in the two-dimensional magnification of track-systems being slightly increased; the actual magnification for a given expansion ratio would be found by experiment. It should be noticed that these departures from the ideally simple displacement of the air during expansion are not peculiar to the radial expansion cloud-chamber; exactly corresponding deviations from the ideal uniform expansion everywhere parallel to the axis must occur in the usual type of cloud-chamber.

It would be difficult to bring about the radial motion of the air by expanding the cylindrical wall of the chamber. The method used has been to let the air pass through this wall. For expansion to occur by escape of air through the cylindrical wall of the chamber this has to be perforated with suitable apertures symmetrically distributed. The expansion within the cloud-chamber is brought about by the sudden reduction of the pressure in a surrounding annular space; this fall of pressure is produced by opening communication with the atmosphere. To obtain a symmetrical escape of air all round the circumference of the cloud-chamber, it is necessary that the pressure difference in the air on the two sides of the cylindrical wall should always, during the expansion, be large in comparison with any pressure differences existing in the air in different portions of the surrounding annular space. The wire gauze, which served sufficiently well as perforated diaphragm in the apparatus described in 1933, was found to be quite inadequate for the present purpose. With the slit system, which we finally used and found to give good results, the mean velocity of the escaping air (as deduced from the rate of fall of pressure in the cloud-chamber) amounted to about 100 metres per second in the slits; a pressure difference of some centimetres of mercury would be required to produce this velocity. To maintain such a pressure difference while the pressure is falling at the very high rate observed (about 30 cm of mercury in 1/100 second) a lag in the pressure fall in the cloud-chamber behind that in the surround space of only one or two thousandths of a second is sufficient. The actual behaviour of this type of cloud-chamber, as regards speed of expansion and absence of serious distortion of the tracks is described later.

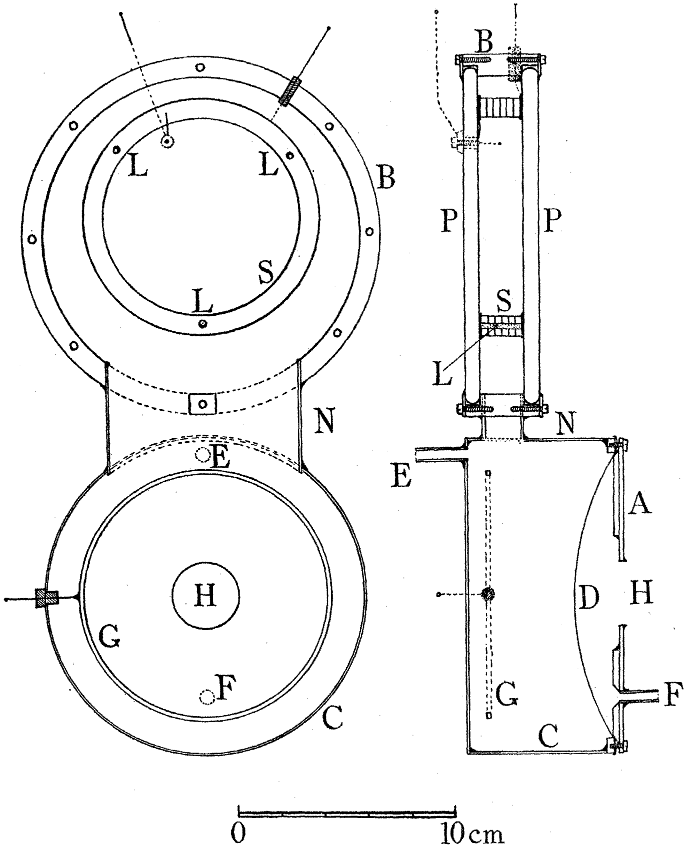

FIG. 1

CONSTRUCTION OF THE EXPANSION APPARATUS

The expansion apparatus consists of two parts connected by a wide short neck, N, fig. 1. The part which includes the cloud-chamber is a shallow cylinder of brass B. Circular plates P of selected glass fit into rebates at either end of the cylinder, and are held in position by annular brass rings bolted to the side wall. One of the glass plates is sealed in position with hard white wax, the other, which is put in place last of all, rests upon a rubber washer and is sealed with glycerine jelly. The brass neck of rectangular section connects this part with the outer chamber—a brass cylinder C in which the thin rubber diaphragm D is placed. This cylinder is closed at one end by a brass plate soldered to it, and to the open end a brass plate A is bolted: the plate A contains a circular hole H of 3 cm diameter against which a rubber bung is pressed. The thin rubber diaphragm is securely held between a lip on the cylinder C of the outer chamber and a conical surface on the inner side of the brass plate A. The parts of this vessel within and without the rubber diaphragm are connected respectively at E and F with a pressure gauge and a compression pump.

Without further modification, the motion of air in the cloud-chamber would be irregular. The motion in the central region of this part on expansion is rendered radial by the introduction of a cylindrical slit system S, completely enclosing it. The form of slit system finally adopted consisted of a pile of annular slate rings about 0·3 cm thick and 1·0 cm wide, separated by distance pieces of mica of appropriate thickness. The rings were turned in a lathe from sheets of a fairly soft slate, and were ground flat and to a suitable thickness on a glass plate with fine carborundum. No difficulty was encountered in obtaining in this manner the requisite degree of uniformity of width of the separating slits. The rings were afterwards well washed by prolonged boiling in distilled water. Relative slipping of the rings is prevented by means of three glass pegs L, which pass through the whole pile. Without these pegs there is danger of the middle rings of the pile becoming displaced by the large accelerations encountered in stopping the chamber when it is used falling. The slit system is held in position by the pressure of the glass ends through a compressible ring of filter paper at either end. The slit system is placed eccentrically, as shown in fig. 1, since the annular space outside the cloud-chamber acts merely as an air channel, and in the part remote from the neck the amount of air flowing at the time of expansion will be less than that flowing in the part near the neck. This position of the ring system is not essential, and for some purposes the central position will be superior.

The usual electrostatic clearing field for ions is applied between copper rings at either end of the pile of slate rings. In the experiments described, a potential of 60 volts was maintained between these two rings. An additional electrode G is placed within the outer chamber C, for all this part of the chamber is electrostatically shielded from the normal clearing field, and unremoved ions in this region would otherwise develop after an expansion into permanent nuclei for drop condensation.

All the metal walls within the apparatus are coated with moist gelatine, the slate rings of the slit system appear readily to hold a surface layer of water, and the filter paper rings at the ends of the slit system are also moistened before the chamber is closed. With this provision, the cloud-chamber seems always to remain sufficiently nearly saturated with water vapour. As the expansion apparatus is at present constructed, the final pressure in the chamber is always atmospheric. The hole H is closed with a rubber bung which is held in position by a catch operated by a simple electromagnet mechanism, and air is pumped in at F until the pressure gauge connected at E shows a suitable excess pressure within the chamber. The expansion is made by breaking the circuit of the electromagnet and releasing the bung from the hole H.

Much work has been directed to attaining suitable motion of the air in the cloud-chamber. The escape of air from the ring system must be uniformly distributed over its circumference, so that the motion of the air in the cloud-chamber may be radial. This requires that the slate rings shall be ground flat, and that the distance pieces used shall all be of equal thickness. Experiments were made with slit widths of 0·007 cm, 0·004 cm and of 0·002 cm. With a slit width of 0·007 cm, the air motion in the cloud-chamber was always irregular. A slit width of 0·004 cm has been generally adopted as most satisfactory. For this slit width the expansion in the cloud-chamber is always free from irregular air motions. Variations in the thickness of the filter paper compression rings at the ends of the pile of slate rings give rise to slight departures from exactly radial motion. These may be removed by small alterations of the thickness of the compressing rings at suitable points. Deviations from radial motion of this type are detected by examination of the diffuse tracks of α-particles which have passed through the chamber before expansion. A source of α-particles in the centre of the chamber is used, and except when the motion of air at expansion is radial, the apparent point of origin of these old tracks is displaced.

The cloud-chamber can be brought into a clean condition, which indicates that the slate used for the cylindrical wall is a suitable material for chamber construction. In the apparatus as at present constructed the cleaning of the chamber by means of small expansions after condensation on ions is less efficient than in the normal type of chamber.

Speed and Character of Pressure Fall

Records have been obtained of the pressure changes in the cloud-chamber during expansion by means of the capillary manometer which was used in experiments on the pressure variations in the old type of expansion apparatus by P. I. Dee and one of us (C. T. R. W.). The manometer consists of a small air bubble imprisoned in a fine closed capillary tube by means of a short column of sulphuric acid, the length of this column being chosen to attain critical damping. The open end of the capillary is connected to the cloud-chamber, and the variations of length of the air bubble are projected on to a rotating drum carrying sensitive paper. The pressure change in the cloud-chamber at an expansion from an excess initial pressure of 30 cm, corresponding to an expansion ratio of about 1·27, is shown in fig. 2. When a slit width of 0·004 cm is used, the expansion is completed in less than 0·01 sec and the final oscillation is negligible. For a similar expansion using a slit width of 0·002 cm, the pressure change is much slower, and the time taken to complete the expansion is about 0·03 sec.

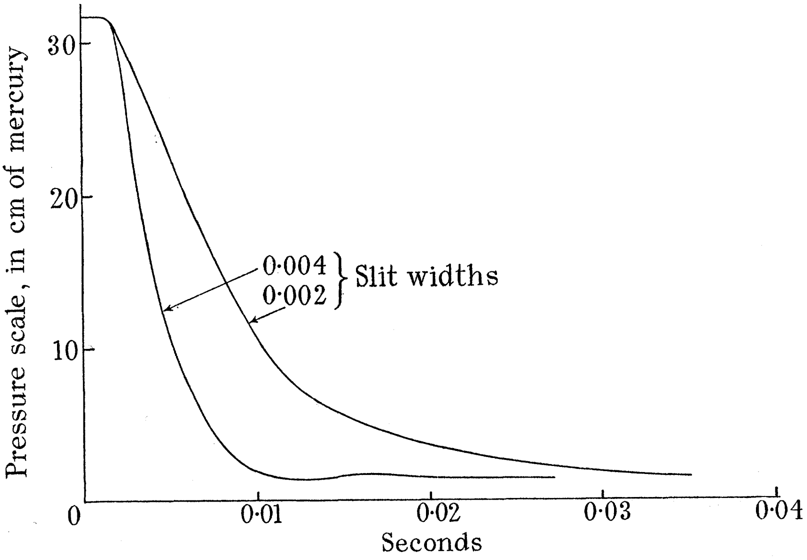

FIG. 2—Pressure fall in cloud-chamber at expansion

ILLUMINATION

The form of the cloud-chamber, with parallel glass faces, allows great freedom in the manner of illumination. The method which has been used employs the usual condenser spark in mercury vapour at atmospheric pressure in a quartz tube. Two vertical lamps are used, in the same horizontal level as the chamber and symmetrically placed relative to the axis of the chamber and of the camera, each with a condensing lens to give a parallel beam. The illuminating beams make an angle of about 17° with the axis of the chamber and of the camera. A plan of the illuminating system is given in fig. 3.

COMPARISON OF THE STATIONARY AND FREELY FALLING CHAMBER

The arrangements which have been used to study the effect of dropping the expansion apparatus are of a very simple kind. Guides are used to prevent the apparatus from turning while it falls, but the motion is made as nearly as possible free. The expansion chamber, C, fig. 1, is bolted in a squared wooden framework, which slides very freely in four smooth wooden guides. The apparatus is held vertically, with the cloud-chamber above the expansion chamber. The apparatus is held until the moment of expansion by means of two electromagnetic catches, attached to the framework carrying the guides, which enagage with brass lips on the expansion apparatus, at points in a vertical plane containing the centre of gravity of the whole moving mass. These catches are included in the circuit operating the release attached to the expansion apparatus, and also in the circuit is a small electromagnet supporting a brass ball which, on falling, completes the illuminating circuit. The distance through which this ball is adjusted to fall before causing the illuminating discharge to pass, is that through which the chamber will fall before it is photographed. After it has passed the position in which it is photographed, the expansion apparatus is brought to rest in a manner which, as far as possible, avoids the imposition of large accelerations. It is allowed to fall upon an air cushion mounted on a wooden table which is carried by four spiral springs. This device is by no means dead-beat, but the whole motion of the expansion apparatus after the photograph has been taken is unimportant. Photographs have been taken of α-particle tracks with an interval between expansion and illumination of

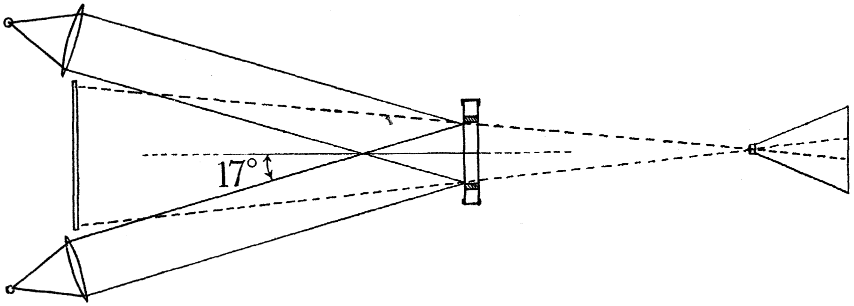

FIG. 3

1/5 sec. In this time the chamber, when falling freely, moves a distance of 20 cm.

Distorting processes in the chamber arise from uneven heating up of the cooled air; this heating is due to conduction from the walls and to condensation of water vapour into drops. Rapid heating, therefore, occurs in a layer of gas close to the walls, and in regions of heavy condensation. For times of the order of 1/5 sec, the distortion due directly to the expansion of the heated gas is very slight; the secondary effect, arising from convection currents due to the temperature inequalities, is much larger; in a chamber of the dimensions described it becomes serious within 1/5 sec, and it is this source of distortion which is absent when the chamber is allowed to fall after expansion.

Photographs taken with the cloud-chamber stationary and falling, in both cases 1/5 sec after expansion, are shown for purposes of comparison in figs. 4–7, Plates 17–18. In figs. 4 and 5, Plate 17, α-particles from a source of actinium active deposit have been used, and have been allowed to reach all parts of the chamber. In fig. 4, Plate 17, taken while the chamber was stationary, both of the causes of convection currents mentioned above have been effective. In fig. 5, Plate 17, in which case the chamber was used falling, these distortions are not observed: even in the case of tracks passing obliquely to the glass faces, only a distortion of the extreme end is present. For figs. 6 and 7, Plate 18, a polonium source of α-particles was used, and the α-particles were confined as far as possible to the central plane of the chamber. In the stationary photograph, fig. 6, Plate 18, there is not now the extreme distortion encountered near the glass face, but nearly every track is found to be more or less distorted by convection currents. In a corresponding photograph taken while the chamber was falling freely, fig. 7, Plate 18, there is no noticeable distortion. Absence of distortion by the radial expansion itself (other than two-dimensional magnification) is perhaps more strikingly shown by tracks which do not radiate from the axis of the chamber than by those, as in figs. 5 and 7, Plates 17 and 18, which radiate from the axis. Photographs with the falling chamber have been taken in which an α-particle source is placed near the cylindrical wall of the chamber: the tracks are uniformly straight, whether the direction of the length of the track passes near the axis of the chamber or not.

GENERAL CONCLUSIONS

1. *The Radial Expansion Cloud-chamber*—The cloud-chamber which has been described would appear to have distinct advantages over apparatus of the usual type for many purposes in addition to that for which it

was specially designed. One advantage is the ease with which the whole contents of the chamber can be illuminated and photographed with the camera looking along the axis of the chamber.

The air motion during expansion being zero on the axis and being radial and very small for points near the axis, objects such as sources or targets may be inserted in this position without causing appreciable disturbanace of the air on expansion. A specially useful arrangement would be an axial tube, traversing both glass plates and open at the ends, into which sources of radiation, primary or secondary, could be placed. This would cause no disturbance of the air on expansion. If the chamber were not going to be dropped, the horizontal position, *i.e.*, with the axis vertical, would for many purposes be the more convenient.

2. *Advantages of Dropping the Chamber*—Apart from its usefulness for removing the cloud-chamber from a confined space, such as that between the poles of a magnet, before photographing, dropping the cloud-chamber has distinct advantages. The time interval between making the expansion and taking the photograph may be greatly extended without any risk of distortion of the tracks by the fall of drops or the setting up of convection currents. This increased time interval may be useful both for increasing the number of tracks photographed and for increasing the amount of water condensed in each track. If the camera is dropped with the cloud-chamber it becomes possible to increase the time of exposure, and the use of continuous sources of illumination (instead of spark discharges) has now considerably greater possibilities than when the chamber is fixed.

Our thanks are due to Lord Rutherford and Professor Stratton for the facilities given us at the Cavendish Laboratory and at the Solar Physics Observatory. A considerable part of the apparatus used in these and previous experiments with the cloud-chamber at the Solar Physics Observatory was obtained with the aid of a gift from the Caird fund of the British Association made to one of us (C. T. R. W.) some years ago. One of us (J. G. W.) is indebted to the Department of Scientific and Industrial Research for a grant.

SUMMARY

The advantages of removing a cloud-chamber from a confined space such as that between the poles of a magnet by letting it fall, and photographing the tracks while the chamber is falling freely, are pointed out.

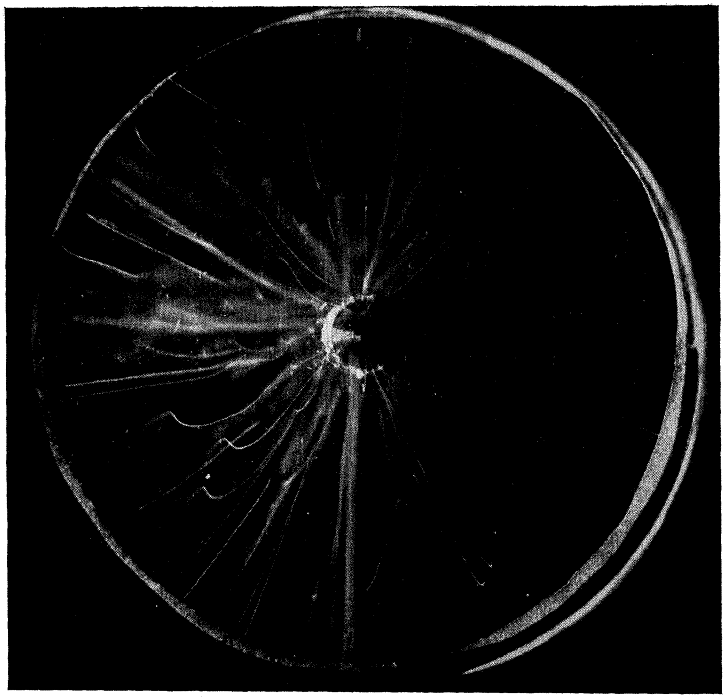

FIG. 4—Stationary

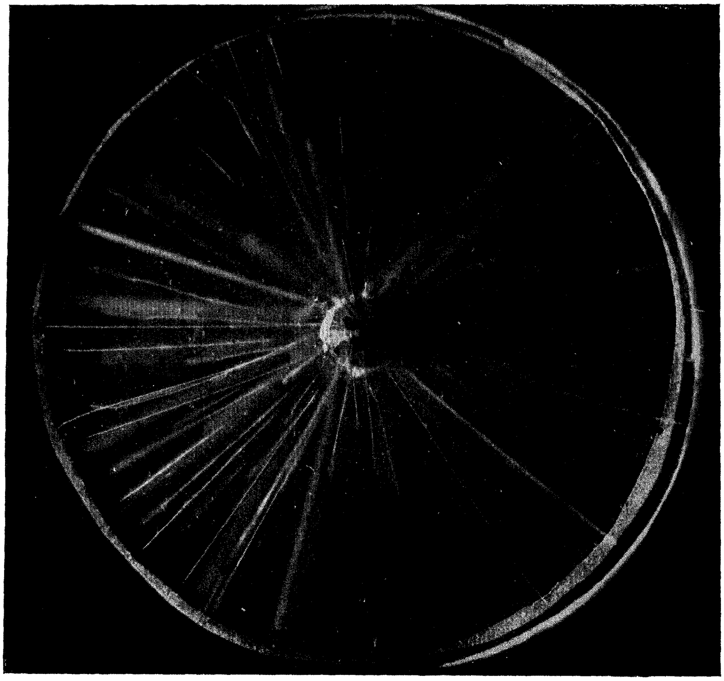

FIG. 5—Falling

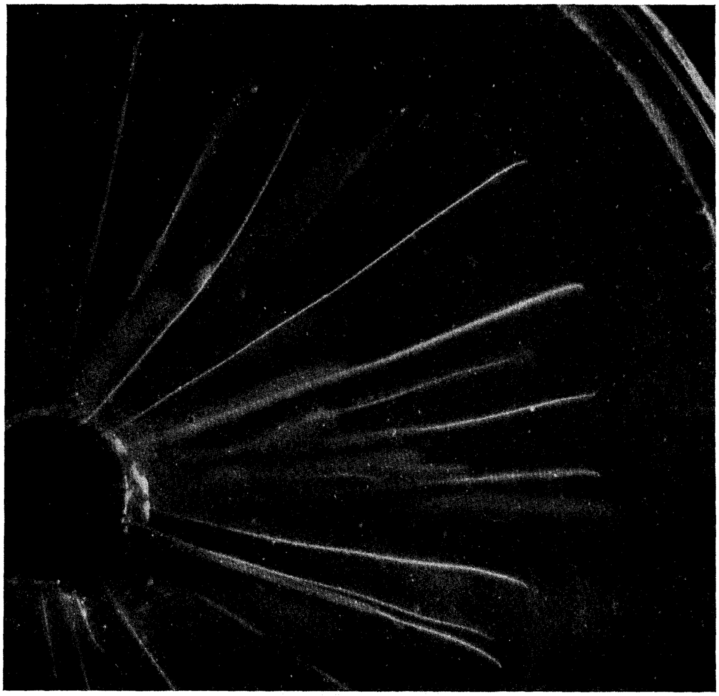

FIG. 6—Stationary

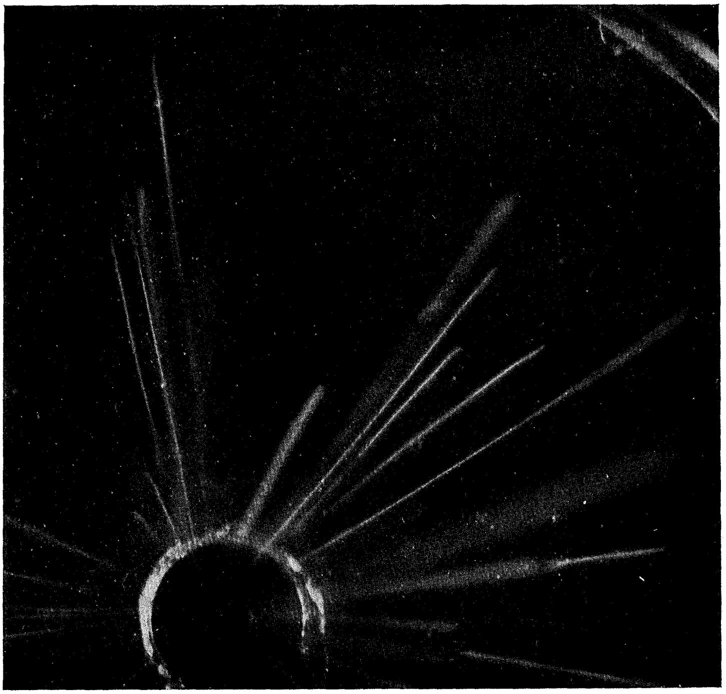

FIG. 7—Falling

A new type of cloud-chamber is described which has the form of a shallow cylinder with plane glass ends and in which the motion of the air during expansion is radial. Experiments show that this type of chamber gives good results. It is found, as anticipated, that dropping the cloud-chamber and photographing while it is falling freely enables undistorted track pictures to be obtained (by eliminating gravity) when the interval between expansion and illumination is prolonged to such an extent that, with the cloud-chamber stationary, distortion by convection currents has become serious.

The Emission of Electrons under the Influence of Chemical Action

Part V—The Theory of the Chemical Electron Emission and its Application to Certain Reactions Involving Haloids

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§ 1—Introduction

The chemical electron emission studied[†] is that of the electrons emitted from the liquid alloy of sodium and potassium, K_2Na, when it is acted on by different chemically active gases, such as the halogens, at very low pressures of the order of 10^{-5} mm of Hg. The electron emission is looked upon as an immediate result of a bombardment, by free metallic electrons, of the unstable (excited) chemical bonds formed on the metal surface during collisions of the gas molecules with the metal. When an electron collides with an excited bond, the latter reverts spontaneously through an electronic rearrangement to the normal polar state and the available energy of the electronic rearrangement is simultaneously transferred to the electron which is thus enabled to escape from the metal. The fundamental physical problems underlying the observed phenomena, on this view, relate to (1) collisions of the second kind between free

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[†] See 'Proc. Roy. Soc.,' A, vol. 132, p. 22 (1931), Part I; vol. 144, p. 46 (1934), Part II; vol. 145, p. 18 (1934), Part III; vol. 146, p. 524 (1934), Part IV.