A STUDY OF THE POLARIZATION OF THE LIGHT FROM HYDROGEN CANAL RAYS

By K. L. Hertel

Abstract

Polarization of light from hydrogen canal rays and its rate of decay.—Light from hydrogen canal rays (principally Hβ) was found to be partially polarized, with the electric vector of the stronger component in the direction of motion of the particles. The amount of this polarization varied over a considerable range: the maximum polarization observed was about 10 percent. Measurements of the polarization at different positions along the canal ray bundle show that the polarization dies away more rapidly than does the intensity. Its half-value time is about one-third that for the intensity.

Effect of a transverse electric field on the polarization of light from hydrogen canal rays.—When an electric field at right angles both to the canal ray bundle and to the direction of observation is applied to the canal rays the polarization changes rapidly (in less than 10^{-9} sec.) at the points of entry to and exit from the field. The change is in the same direction at both entry and exit and is such that the component of the electric vector perpendicular to the direction of motion is increased relative to the parallel component. The change increases with the strength of the field up to 300 or 500 volts per cm after which the increase is small. In a weak uniform field (less than 200 volts per cm) the polarization appears to die out at about the same rate as with no field. In stronger uniform fields there is a tendency for the light to become polarized with the stronger component of the electric vector in the direction of motion. There is some evidence of periodicity in the polarization as the particles pass through a uniform field.

WHILE studying the effect of an electric field upon the radiating atom, Stark[1] observed qualitatively that the light from the canal rays of hydrogen was partially polarized. In 1915 Stark and Luneland[2] studied this polarization quantitatively, and found that the light from the moving particles was polarized, while that from the particles at rest was not polarized. They expressed the polarization as the ratio of the component vibrating in the direction of motion to that vibrating at right angles to it, and this ratio varied from 1.20 to 1.35 for the series lines of hydrogen. If these canal rays are allowed to pass through a small hole in the cathode and into a chamber where the pressure is maintained as low as possible, the intensity of the bundle dies out with distance from the hole. This rate of dying out has been studied by Wien[3] and Dempster.[4]

It would be expected from the observations of Stark and Luneland that the light from the bundle entering the high vacuum chamber used by Wien

[1] Stark, Verh. d. D. Phys. Ges. **8**, 104 (1908); J. Stark u. H. Kirschbaum Ann. d. Physik **43**, 1002 (1914).

[2] Stark and Luneland, Ann. d. Physik **46**, 68 (1915).

[3] Wien, ibid. **60**, 597, 1919; ibid., **66**, 230, (1921); ibid., **73**, 483, (1923).

[4] Dempster, Phys. Rev., **15**, 138, (1920); Astro. Jour., **57**, 193, (1923).

and Dempster would be partially polarized. Rupp[5] recently observed qualitatively that this light was partially polarized, showing that the polarization observed by Stark and Luneland persisted. The problem attacked in this series of experiments was a study in more detail of the polarization of the light from this bundle in high vacuum. It is to be noted that in this high vacuum chamber the particles are neutral, excited, moving with a high velocity, and disturbed very little by collisions with other particles. If now, these particles are subjected to an electric field or a magnetic field and an orientation is produced, it might be expected that the polarization would be changed, and since the particles have a high velocity, a "history" of the effect could be obtained by observing the polarization at various points along the path of the particles. The results of the experiments discussed here show that the light from the hydrogen canal rays at low pressure is partially polarized, and that this polarization dies out with distance from the cathode. They show further that polarization effects are produced by electric fields at right angles to the motion of the particles.

Experimental

The method used in producing the hydrogen canal rays in high vacuum was similar to that used by Wien and Dempster. Purified hydrogen was allowed to flow from a reservoir, through a capillary tube and liquid air trap into the discharge tube. Rectified current was sent through the discharge tube to produce the canal rays, which then passed through a small hole (0.48 mm diam.) in the cathode into the observation chamber. Here the bundle was photographed through a calcite crystal and the two images measured on a microphotometer. The gas that passed through the hole with the canal rays was pumped out by a rapidly acting pump, and in this way the pressure was kept low in the observation chamber.

The hydrogen was taken from a commercial steel tank and purified by slowly passing it through activated charcoal immersed in liquid air. The gas was then stored in a reservoir and introduced into the discharge tube as needed. In order to adjust the pressure in the discharge tube, it was necessary to adjust the rate of inflow of the gas. This was accomplished by using a capillary tube 20 cm long, having a bore of 0.5 mm, and inserting in the bore a glass rod slightly tapered and a little smaller than the bore. The glass rod was made by drawing down larger rod until the proper size was obtained. The piece of iron *F*, Fig. 1, was fastened to the large end of the glass rod so that it could be moved by means of a magnet from the outside. By adjusting the glass rod the resistance to the flow of gas could be changed to give any discharge-tube pressure desired. Using a reservoir pressure of 25 cm of mercury, the pressure in the discharge tube was changed from 0.14 mm to 0.07 mm of mercury when the rod was moved 8 cm.

As shown in Fig. 1, the discharge tube *D* was separated from the observation chamber *O* by the cathode (Fig. 2) resting on the ground joint *G*. The discharge tube proper was 55 cm long and 2.3 cm in diameter. Two different

[5] Rupp, Ann. d. Physik **99**, 1 (1926).

observation chambers were used in these experiments. The first was a cylindrical tube of Pyrex glass about 4.4 cm in diameter and the bundle observed through the cylindrical wall of the tube. The second observation chamber (*O*, Fig. 1) was designed to reduce to a minimum any polarization that might be introduced by the glass wall. It had a large tube extending in the direction of the camera and a good piece of plate glass fastened to the end of it with wax. The calcite crystal *C* which had been recently polished was properly oriented and cemented to this plate with Canada balsam, thus leaving only one reflecting face to introduce polarization. The lens of the camera was placed near the calcite crystal and the glass plate, so that any polarization introduced by strains in the glass plate would not be localized in the image.

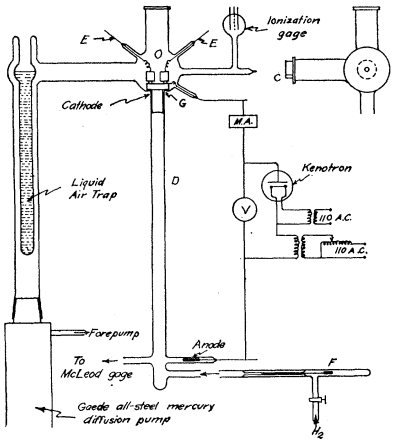

Fig. 1. Diagram of apparatus.

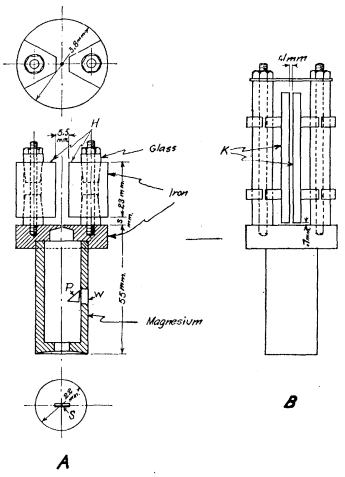

Fig. 2. Diagrams of cathodes.

The pressure in the discharge tube was measured by a MacLeod gage and in the observation chamber it was measured by an ionization gage which had been calibrated with the MacLeod gage. The current for the discharge tube was furnished by an alternating current transformer, rectified with one kenotron, and thus giving only one-half of the cycle. The current was measured by the direct current milli-ammeter M.A. and the voltage across the tube measured by the Braun voltmeter *V*.

The cathodes used in these experiments are shown in Fig. 2. The lower part, which extended down into the discharge tube, was made of magnesium to eliminate sputtering. *P* was a totally reflecting prism which reflected the light from the slit *S* through the opening *W* into the slit of a spectroscope for observing the Doppler effect. This magnesium cup was fastened to the cathode proper which in turn rested on the ground joint. In the center of the cathode was a hole 0.48 mm in diameter which allowed the canal rays to pass into the observation chamber. Cathode "*A*" was used to apply either a magnetic or an electric field to the bundle, the poles *H* acting either

as magnetic poles or as condenser plates. When a magnetic field was used the magnet was placed just outside the walls of the tube. On cathode "*B*" the condenser plates were made adjustable and set close together and near the cathode as shown in Fig. 2. The condenser plates were joined to the leads *E* (Fig. 1) which were in turn connected to a potentiometer for applying the field. Care was always taken to adjust the potential so that the potential of the cathode (which was grounded) was midway between that of the two plates *K*.

It was necessary in these experiments to keep the pressure in the observation chamber as low as possible in order that the number of collisions of the moving particles with the "rest" gas be reduced to a minimum. This was accomplished by connecting a Gaede all-steel mercury diffusion pump to the observation chamber with large tubing and using the special liquid air trap shown in Fig. 1. The total distance from the cathode to the mouth of the pump was about one meter. In this way the ratio of the pressures on the two sides of the cathode could be maintained up to 330 to 1. With wax joints in the system, this ratio was reduced a little.

Method of Photometry

The luminous bundle was studied by photographing it at right angles both to the direction of motion of the particles, and to the direction of the field. The photographs were taken with an ordinary camera through a calcite crystal 1 cm thick. The crystal was oriented so that one image was produced by the light vibrating in the direction of motion of the particles, while the other was produced by the light vibrating at right angles to it. A 0.7 mm slit made of bakelite was placed 8 mm in front of the bundle and parallel to it, to prevent the two images from overlapping as the bundle became diffuse. The images were about 0.5 mm apart on the photographic plate, and the blackening could be easily measured with a microphotometer. Beyond the bundle another piece of roughened bakelite was placed so that no light could be reflected through the slit into the camera. Cramer Hi Speed plates were used and developed with Cramer Contrast Developer. Exposure times of 10 to 20 minutes were found to give the right density to be used on the microphotometer. The microphotometer was of the thermopile type, having a Coblentz thermopile and a Leeds and Northrup high sensitivity galvanometer.

In order to convert the microphotometer readings into relative intensities a series of intensity spots were placed on every photographic plate and a calibration curve made for each plate. The intensity spots were formed on the plate by allowing light from a uniformly illuminated screen to pass through holes of various sizes and to fall on the plate 7 cm away. There was a velvet lined tube leading from each hole to the plate so that the light falling upon any one part of the plate came through only one hole. The relative intensity with which the plate was illuminated at any one point was directly proportional to the area of the hole through which the light passed, and from the relative areas of the holes the corresponding relative intensities were

determined. A gas-filled tungsten light was used to illuminate the screen after it was found by test to give the same density curve as the light from the region just in front of the cathode. In the microphotometer the slit of the instrument was vertical and was adjusted to less than half the width of the image of the bundle which was also placed vertical. The plate was placed on a horizontal slit 0.6 mm wide, so that only 0.6 mm of the image was measured at a time. This represented from 0.9 to 1.1 mm of the bundle since the reduction of the camera was 1.5 to 1.85 times. In measuring a plate, the intensity spots were first placed over the horizontal slit and moved horizontally past the instrument; in this way the average deflection for each intensity spot was obtained. The two images of the bundle to be measured were then placed across the slit and the deflection for the maximum density of each image was observed. These data were taken at 1 mm intervals along the length of the image. The deflections for the intensities giving the calibration curve for the plate, and from this calibration curve the deflections for the image were changed into relative intensities. Using this method of photometry, the images and comparison are placed on the same plate, exposed for the same length of time to the same quality of light, and developed in the same developer at the same time. Also the microphotometer readings of the two images were taken as near the same time as practical. In this way the photographic plate with the microphotometer acted as a medium for comparing intensities, and consequently the accuracy depended primarily upon the uniformity of both the photographic plate and the microphotometer measurements.

Data and Results

The data in Figs. 3 and 4 were taken with the cylindrical observation chamber and the cathode "*A*" (Fig. 2), and for the data in Figs. 5, 6 and 7 the observation chamber shown in Fig 1 with cathode "*B*" were used. The set of curves shown in each figure was made from the data taken from one photographic plate. I_p was the intensity of the light whose electric vector was vibrating parallel to the direction of motion of the particles, and I_n the intensity of light whose electric vector was vibrating at right angles to this. The ratio I_p/I_n was plotted against the distance along the bundle. Several plates were discarded because of their non-uniformity.

In Fig. 3 *A*, the solid line shows the dying out of the partial polarization with distance from the opening in the cathode, and the broken line shows the dying out of the total intensity. It is seen that the partial polarization decreases at a faster rate than the intensity itself and becomes practically zero by the time the total intensity has reached half value. The remaining curves of Fig. 3 show the effects of various electric fields upon the polarization. The notation "field applied" show the distance over which the field was applied and is the 23 mm distance of cathode "*A*" Fig. 2. The polarization of the light as the particles are entering the observation chamber is approximately the same as with no field, but this changes quite rapidly as the particles enter the field, the light becoming polarized in

the opposite direction by the time the particles are in the uniform field. In this uniform field the polarization dies out at about the same rate as

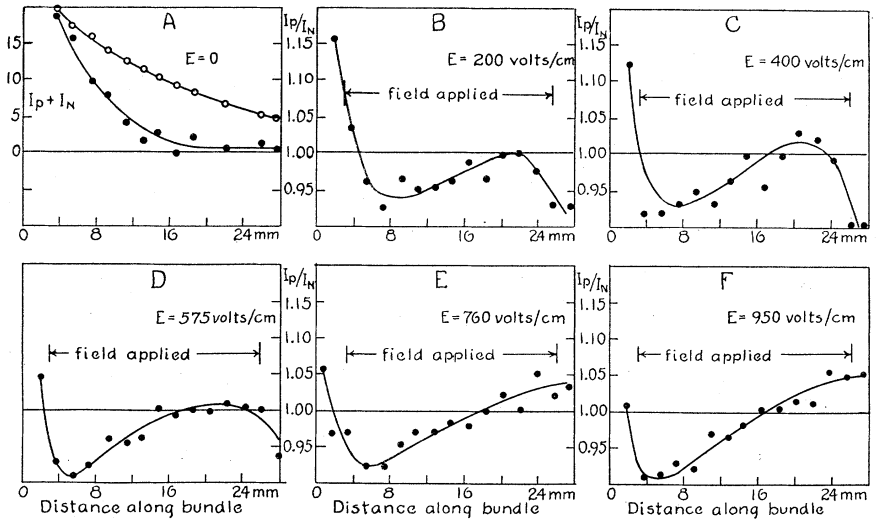

Fig. 3. Showing the variation of intensity and state of polarization of the light along the canal ray bundle. $P=0.097$ mm, $p=0.00029$ mm, $V=5000$ volts, $I=9.0$ m.a., $S=5.4$ 10^7 cm/sec.

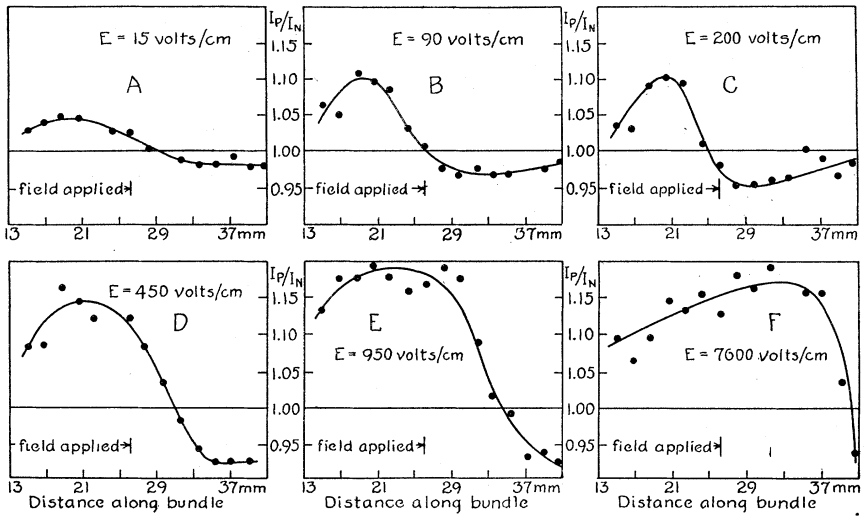

Fig. 4. Showing the variation of the state of polarization of the light along the canal ray bundle. $P=0.100$ mm, $p=0.00030$ mm, $V=4200$ volts, $I=9.5$ m.a.

with no field at all, and in the stronger fields I_p again becomes greater than I_n. When the particles pass out of this uniform field another change in the

polarization takes place. This change is similar to the change that occurred as the particles entered the field, and I_n again becomes the stronger. It is

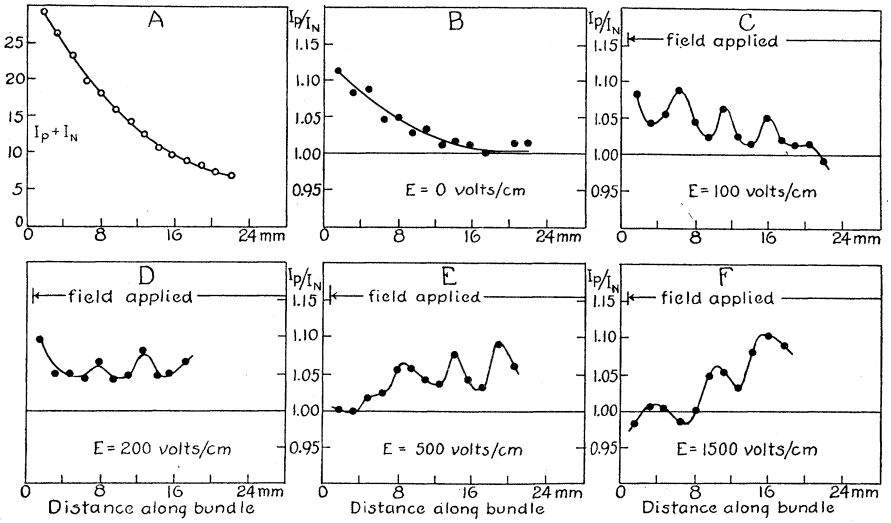

Fig. 5. Showing the variation of intensity and state of polarization of the light along the canal ray bundle. $P=0.080$ mm, $p=0.00034$ mm, $V=6300$ volts, $I=8.0$ m.a., $S=4.1$ 10^7 cm/sec.

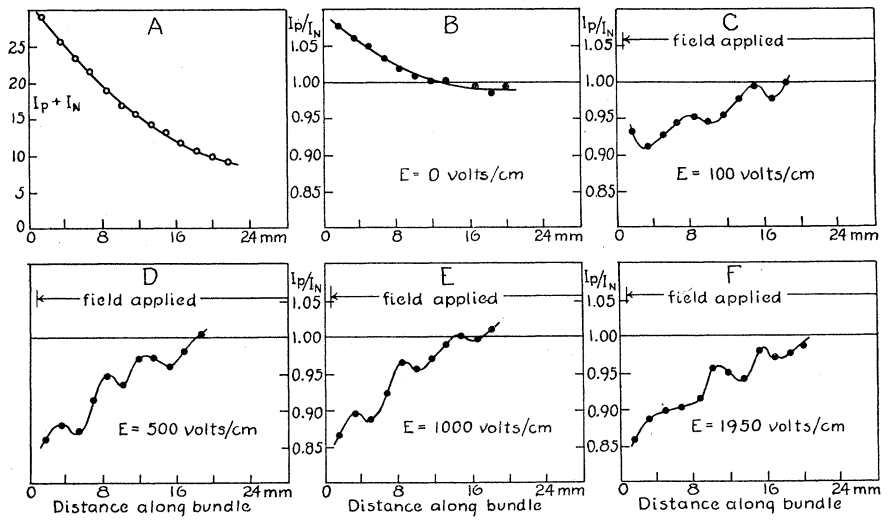

Fig. 6. Showing the variation of intensity and state of polarization of the light along the canal ray bundle. $P=0.0925$ mm, $p=0.00034$ mm, $V=6000$ volts, $I=9.5$ m.a., $S=5.2$ 10^7 cm/sec.

seen that as the field was increased this last change took place later and later, and in the last two curves (E and F) it did not occur at all. In a similar

way the change that took place as the particles entered the field seemed to occur a little earlier with the stronger fields.

In order to confirm the conclusion that a sudden change in the polarization occurred as the particles passed out of the field, a series of photographs were taken of this region of the bundle. The results obtained are shown in Fig. 4 with the field varied from 15 to 7,600 volts per cm. In every case a change occurred, and in general the change occurred later for stronger fields. For the field of 7,600 volts per cm the change took place about 1 cm beyond the end of the condenser plates. In the two curves B and C of Fig. 4 there is evidence that after this sudden change took place in the polarization, the polarization once more decreased.

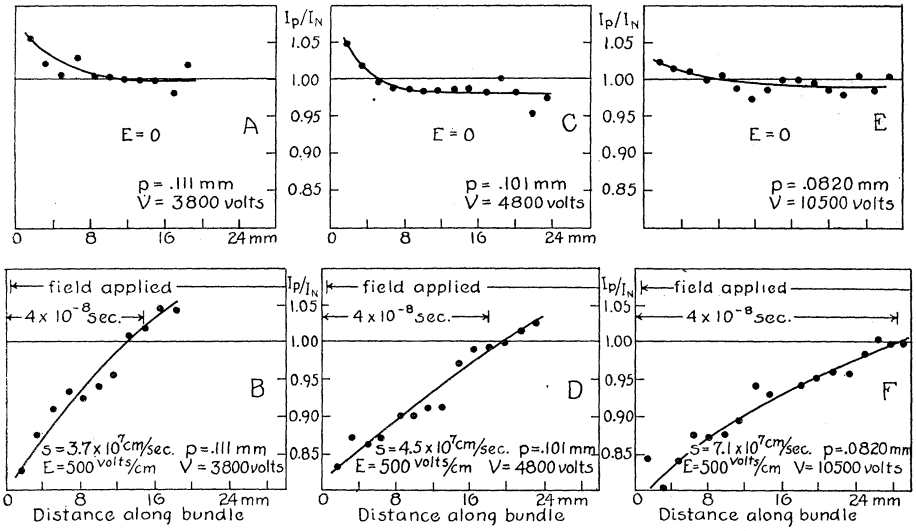

Fig. 7. Showing the variation of the state of polarization of the light along the canal ray bundle for various pressures and potentials in the main discharge tube. $p = 0.00035$ mm, $I = 8.5$ m.a.

The data shown in Figs. 5, 6 and 7 were taken with cathode "B" and the observation chamber shown in Fig. 1. The dying out of the polarization is shown in curve B of Fig. 5 with no field applied, and A is the total intensity curve of the data from B. The total intensity was taken as the sum $I_p + I_n$. A smooth curve through the points in B gives some idea of the accuracy of the data. If a smooth curve had been drawn through the points in C it is plainly seen that the points would be much farther from the curve than in B. It is for this reason that a curve was drawn directly through the observed points. When this was done the curve took on the appearance of a "wave" with a certain regularity. In the same way the rest of the curves were drawn directly through the observed points. In the case of F another "wave" appears but with a longer wave-length than C, and starting in the opposite phase. The curve E suggests a combination of two waves, and

when C and F are combined, with the phase in both of them reversed, a curve almost identical with that of E results. The curves in Fig. 6 are drawn just as those in Fig. 5, A being the total intensity curve of B, and B being the polarization curve with no field. Similarly the rest of the curves represent the polarization with various electric fields. If the wave-lengths of C in Figs. 5 and 6 are converted into periods of time, 5 C gives a period of 1.2×10^{-8} seconds, and Fig. 6 C gives 1.3×10^{-8} seconds, the field being 100 volts per cm in both cases. From these data there seems to be some evidence for a periodicity in the polarization in a uniform field, yet the effect is too near the limit of accuracy of the experiment to make the evidence conclusive.

In Fig. 7 the electric field was kept at 500 volts per cm and the pressure in the discharge tube varied to give particles of different velocities. It was found that in the case of the slow moving particles the polarization decreased to zero in a shorter distance than for the faster particles. Since the velocity of the particles was known in each case, the time required for the polarization to reach zero could be calculated. It was found to be about 4×10^{-8} seconds in each case. In these curves the change of polarization produced as the particles entered the field had evidently all taken place before the curves started. This means that the change took place in less than 2×10^{-9} seconds.

When the various photographic plates were compared it was found that the initial polarization appearing in the bundle was not the same for the various plates. No definite reason can be given for this, but it may be due to the presence of small amounts of some impurity like mercury, for it is known that the presence of mercury changes the character of the hydrogen canal rays. The amount of polarization produced as the particles entered an electric field depended upon the strength of the field, increasing rather rapidly with the field until 300 to 500 volts per cm was reached, but after this the increase was small. The amount of polarization introduced also seemed to be independent of the velocity of the particle or the amount of initial polarization.

The bundle was also subjected to a small magnetic field but there was no effect that could be detected.

In conclusion the writer wishes to thank Dr. A. J. Dempster, who suggested the problem, for his interest and helpful suggestions during the investigations.

RYERSON PHYSICAL LABORATORY,
UNIVERSITY OF CHICAGO,
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