The Adaptation of the Cauchois Spectrograph to Artificial Radioactive Sources

J. E. EDWARDS, M. L. POOL, AND F. C. BLAKE
Mendenhall Laboratory, Ohio State University, Columbus, Ohio

(Received January 8, 1945)

The transmission (Cauchois) type curved crystal spectrograph has been found to be a practical instrument for photographing characteristic x-rays associated with radioactive decay. A photograph of x-rays associated with the decay of 6.7-hour $Cd^{107,109}$ is shown. X-rays emitted during the decay of 2.7-day In^{112} and 12.8-hour Cu^{64} have also been identified.

INTRODUCTION

MANY radioactive atoms are known to emit characteristic x-rays in the process of disintegration. An accurate knowledge of the wave-length of these x-rays often helps to reveal the nature of the decay process. Such x-ray information is most useful when it is sufficiently accurate to enable one to distinguish radiations characteristic of two neighboring elements.

If x-rays are associated with the disintegration of an atom of atomic number Z, the x-rays will have wave-lengths characteristic of one or more elements having atomic numbers Z, $Z-1$, or $Z+1$. To distinguish these three possibilities the method used for studying the x-rays must be sensitive enough to distinguish wave-lengths characteristic of neighboring elements in the region Z. Absorption methods are generally successful in detecting the presence of x-rays charactersitic of the general region Z. However, absorption methods are sometimes not easily applied to distinguish x-rays characteristic of two neighboring elements, especially when radiation characteristic of both elements appears in the same chemical fraction.

Accepted x-ray methods in general have not been used to measure the wave-lengths of x-rays from radioactive materials because of the low intensity available. Even the present high intensity radioactive sources emit x-rays which are too feeble to make the ordinary slit type spectrographs of practical value. However, there are two types of curved crystal spectrographs, the reflection type and the transmission type, which may be used with present x-ray intensities. The reflection type curved crystal spectrograph has been used by Abelson[1] for wave-lengths extending from about 1.5A to 0.6A. The present work was carried out to explore the possibility of using the transmission (Cauchois) type curved crystal spectrograph for photographing the shorter wave-length x-rays emitted by radioactive sources.

[1] P. Abelson, Phys. Rev. **56**, 753 (1939).

THE CURVED CRYSTAL SPECTROGRAPH

The spectrograph adopted for this work is the type used successfully by Cauchois[2,3] with crystals of mica and gypsum. Quartz crystals have also been effectively adapted to this type of spectrograph by DuMond and others.[4,5,6] Although such instruments are capable of rather high resolving power, the speed factor is much more important in photographing feeble radioactive sources.

Figure 1 shows the arrangement of the spectrograph for radioactive sources which might contain high energy beta- and gamma-rays in addition to the x-rays. The strength of the magnetic field is increased until a Geiger counter between the crystal and the film shows no appreciable beta counts. Blocks of lead are placed outside the spectrograph and inside the cylinder carrying the film to shield the film from gamma-radiation at the point where a line is to be formed. Low energy beta-rays are absorbed sufficiently by the crystal to prevent the scattered electrons from fogging the film. For low energy gamma-rays the brass in the plates which hold the crystal and the iron in the spectrograph usually provide sufficient shielding.

In practice, highest efficiency is obtained by

[2] Mlle. Y. Cauchois, J. de Phys. **3**, 320 (1932).
[3] Mlle. Y. Cauchois, J. de Phys. **4**, 61 (1933).
[4] J. W. M. DuMond and B. B. Watson, Phys. Rev. **46**, 316 (1934).
[5] Bernard B. Watson, Rev. Sci. Inst. **8**, 480 (1937).
[6] J. W. M. DuMond and H. A. Kirkpatrick, Phys. Rev. **52**, 419 (1937).

placing the source at the most favorable angle for diffraction from an appropriate set of internal planes according to the familiar Bragg law: $n\lambda = 2d \sin \theta$. This is done with the aid of a divided circle on the back of the spectrograph having angles marked with respect to the center of the crystal. Sources such as those frequently encountered after chemical separations in radioactivity can be extended over an area of a few square centimeters to reduce self-absorption of the radiation without impairing the efficiency of the spectrograph. The position of a spectral line is to a slight extent a function of the position of the source. In the molybdenum region the maximum shift in the lines due to movement of the source is 0.004A with crystal planes having a "d" value of 2.56A. Thus an extension of the source tends to broaden the lines but the shift of a line is not important when comparing wave-lengths of two neighboring elements. The separation of the $K\alpha$ doublets of Ag and Cd is 0.024A or about 6 times the maximum displacement which could be produced in the lines by movement of the source. The displacement can be virtually eliminated by careful alignment of the source with the center of the crystal at the correct Bragg angle.

Two sizes of spectrographs were used, one having a crystal radius of 8 inches, the other a crystal radius of 15 inches. Mica and quartz crystals were employed in both spectrographs. The set of planes used in the mica has a "d" value of 2.56A and the x-ray lines are obtained in first order. This is the same set of planes employed by Cauchois[3] and reported by Favejee[7] to produce very intense reflection in powder photographs. The most suitable mica crystal thickness was found to range from about 0.15 mm to 0.5 mm. The quartz crystals were cut perpendicular to the 310 planes then ground to a thickness of .2 mm and polished. The 100, 110, and 310 planes were thus made available, all producing strong lines.[7] These planes have "d" values of 4.246A, 2.451A and 1.178A respectively.

The spectrographs were investigated with various x-ray wave-lengths to determine the optimum spectrograph size and type of crystal for greatest speed commensurate with adequate resolving power. Characteristic K lines of several elements ranging from chromium to tungsten were photographed in first order with fluorescent or direct emission radiation. In general the quartz crystals are more efficient for longer wave-lengths from 0.7A to 2.3A while the mica is more efficient at shorter wave-lengths from 0.8A to 0.2A. Highest speed was obtained with the 8 inch (crystal curved to a radius of 8 inches) quartz spectrograph in the Cu region, the 8-inch mica spectrograph in the Mo region, and the 15-inch mica instrument for shorter wave-lengths.

RESULTS

Cu^{64}

Metallic copper activated by high energy deuterons exhibits a strong 12.8-hour activity assigned to Cu^{64} by Van Voorhis.[8] Beta-rays, positrons and x-rays are associated with the decay of this activity. Abelson[1] has shown these x-rays to be characteristic of nickel by use of a reflection type spectrograph equipped with a rock salt crystal. The nickel $K\alpha$ doublet arising

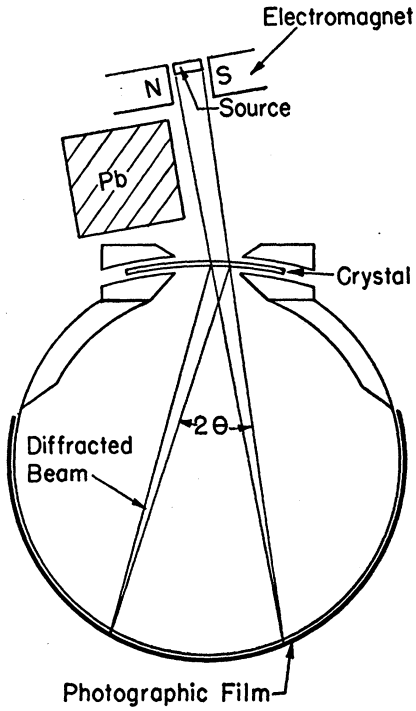

FIG. 1. Transmission type curved crystal spectrograph.

[7] T. Ch. L. Favejee, Zeits. f. Krist. **100**, 425 (1938).

[8] S. N. VanVoorhis, Phys. Rev. **50**, 895 (1936).

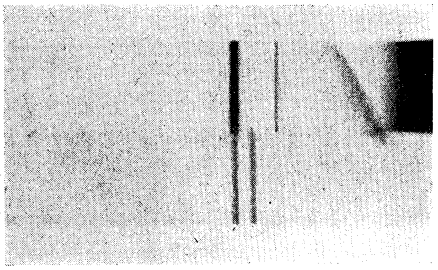

FIG. 2. Upper half—$K\alpha$, $K\beta$, and $K\gamma$ lines of Ag emitted during decay of 6.7-hour $Cd^{107,109}$. Lower half—Ag and Cd calibration lines.

from this activity was photographed in an 8-inch quartz spectrograph using the 110 planes.

Three photographs were made starting 40 minutes after bombardment. A decay curve was obtained while the exposures were in progress. The first exposure extended over 4 hours during which time the intensity of the 38.5-minute Zn^{63} dropped to 1/100 the intensity of the 12.8-hour Cu^{64}. This exposure showed no lines. The nickel lines appeared on the second photograph which was exposed for 36 hours. The third exposure of 40 hours showed no lines. Copper calibration lines were placed on half of the film by use of fluorescent radiation.

2.7-Day In^{112}

A 2.7-day activity in indium produced by deuteron bombardment of cadmium has been reported by Cork and Lawson.[9,10] The activity consists of x-rays and low energy electrons caused by two internally converted gamma-ray energies. The identification of the x-ray as characteristic of Cd by critical absorption together with the absence of positrons suggested the probability of K-capture.[10]

Photographs of Cd activated by deuterons were obtained with a 15-inch mica spectrograph. The first exposure extending over 16 hours starting immediately after bombardment showed no lines. A second exposure of 8 days gave a strong Cd $K\alpha$ line. These Cd x-rays are presumed to be caused by the 2.7-day In activity since no other isotopes have been reported which would emit strong Cd x-rays 16 hours after activation.

6.7-Hour $Cd^{107,109}$

A 6.7-hour cadmium activity has been produced by bombardment of Ag with protons[11] and by the well known Ag(d, $2n$)Cd reaction.[12] It is known to emit K and L conversion electrons,[13,14] x-rays characteristic of silver,[11,14] and a 40 second half-life has been identified in the silver fraction.[15] At one time the x-rays were thought to be characteristic of cadmium[12] but the spectrograph confirms the presence of x-rays characteristic of silver.

The photograph shown in Fig. 2 was obtained with a 15-inch mica spectrograph. The upper half of the film shows the $K\alpha$, $K\beta$, and $K\gamma$ lines of Ag resulting from the decay of $Cd^{107,109}$ produced by deuteron bombardment of Ag. The lower half shows Ag and Cd calibration lines obtained by fluorescence. The exposure to the radioactive source was carried through 4 half-lives. No cadmium lines or general radiation were detected. The Ag $K\alpha$ doublet is resolved on the original film.

The authors are grateful to Dr. DuMond for the loan of a curved crystal spectrograph which was used in preliminary experiments. It is a pleasure to acknowledge the support received from Mr. Julius F. Stone, The Ohio State University Development Fund and from The Ohio State University Research Foundation.

[9] J. M. Cork and J. L. Lawson, Phys. Rev. **56**, 291 (1939).
[10] J. L. Lawson and J. M. Cork, Phys. Rev. **57**, 982 (1940).
[11] L. A. Delsasso, L. N. Ridenour, R. Sherr, and M. G. White, Phys. Rev. **55**, 113 (1939).
[12] R. S. Krishnan and D. H. T. Gant, Nature **144**, 547 (1939).
[13] G. E. Valley and R. L. McCreary, Phys. Rev. **56**, 863 (1939).
[14] A. C. Helmholz, Phys. Rev. **60**, 415 (1941).
[15] L. W. Alvarez, A. C. Helmholz, and E. Nelson, Phys. Rev. **57**, 660 (1940).

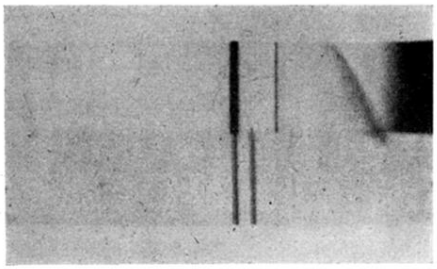

FIG. 2. Upper half—$K\alpha$, $K\beta$, and $K\gamma$ lines of Ag emitted during decay of 6.7-hour $Cd^{107,109}$. Lower half—Ag and Cd calibration lines.