than temperature.   Likewise, the β and γ refractive indices are relatively close together in magnitude.   The extremely high birefringence is somewhat at variance with his condition requiring weak double refraction in order to produce "wide separation of the optic axes in the two planes for the two ends of the spectrum."   The crossed axial plane dispersion of the metastable modification is slightly less than in Brookite[6] but much greater than that of saccharine,[6] the lactone or anhydride of saccharic acid, although both of these substances have a considerably smaller birefringence. The occurrence of this type of dispersion in the present case is probably explained by the dispersions of the β and γ refractive indices which are probably sufficiently great to compensate for the wide separation of α and γ.

Summary

1.   Optical crystallographic data for two crystalline modifications of acetaldehyde 2,4-dinitrophenylhydrazone have been determined.

2.   The stable form has been found to exhibit strong inclined dispersion of the bisectrices amounting to about 2.5° at room temperature.

3.   The crossed axial plane dispersion of the metastable modification has been studied in greater detail.   The wave length of uniaxiality was found to be near 5440 Å.

4.   Contamination with small amounts of the corresponding propionaldehyde derivative was found to have a marked effect upon the magnitude of the optic axial angle.

A Study of the Isotopes of Cobalt by the Magneto-optic Method

BY T. R. BALL AND STANCIL S. COOPER

As a reference substance for setting the fixed trolley of a newly installed magneto-optic apparatus, so that all subsequent readings would correspond to those recorded by Dr. Fred Allison[1] and his co-workers in their numerous publications, cobalt chloride seemed to be an ideal salt to use. Cobalt has been reported by both Aston[2] and Allison and Murphy to have only one atomic mass.   The latter authors, using the magneto-optic apparatus, reported a single point of minimum light transmission for cobalt chloride at 20.15 on their scale.   Nickel, which is always present in cobalt salts, was reported to show minima at 20.30 and 20.40, when present as the chloride.   By using a solution of cobalt chloride containing about one part

(1) Allison and Murphy, THIS JOURNAL, **52**, 3796 (1930); Allison, *J. Chem. Education*, **10**, 71 (1933); Allison and co-workers in numerous articles in *Phys. Rev.* since 1927.

(2) Aston, *Nature*, **112**, 449 (1923); *Phil. Mag.*, **47**, 385 (1924).

in 10^{11} of water, the nickel impurity should be present at a concentration below the sensitivity of the apparatus and the only minimum observable should be the one at 20.15. Thus by adjusting the position of the fixed trolley until the minimum was shown at this scale reading for the movable trolley, all subsequent readings should correspond with those reported by Allison. When this was attempted, however, more than one minimum was observed in this region, indicating that cobalt exists in isotopic forms. After having calibrated the apparatus by other reference points, the present study was undertaken.

Experimental

Materials and Solutions.—Baker cobalt ammonium sulfate, with a maximum nickel content of 0.03%, was ignited to the simple salt in platinum at 500°. The loss of water and ammonium sulfate raised the nickel content of the residual salt to about 0.10%. A solution of this salt was made by dissolving 0.0775 g. (1 milliequivalent) in 100 ml. of water which was slightly acidified with hydrochloric acid. The water was freshly distilled from an all-glass (Pyrex) still and had been tested for minima in the ranges of cobalt sulfate and chloride. The addition of hydrochloric acid made it possible to read both sulfate and chloride minima from the same solution. Successive hundred-fold dilutions of this stock solution yielded a series of solutions containing one equivalent of cobalt sulfate in 10^7, 10^9, 10^{11} and 10^{13} grams of water. Observations were made on each of these solutions.

Observations.—The solutions containing one equivalent in 10^7, 10^9 and 10^{11} showed minima at 14.33, 14.42, 14.52, 14.60 and 14.66 in the cobalt and nickel sulfate ranges. Minima were also observed for the chlorides at 20.04, 20.09, 20.15, 20.30 and 20.40. In each case, the positions of the minima were determined by averaging the scale readings grouped about the peaks of the curves of Fig. 1. In these curves, a total of 454 scale readings at which minima were observed, are recorded. The scale readings are plotted against the number of times they were observed. The upper curve is that of cobalt and nickel sulfates, and the lower that of the chlorides. These readings were taken by observing a diminution of light intensity when the trolley passed a critical point on the wire path. Because of the physiological time lag in stopping the motion of the trolley, there is a tendency to over-run the minimum, but by approaching it from both directions, there is a fairly equal distribution of readings on each side. Moreover, the minima are a few millimeters wide and settings may be made on either edge. With a large number of readings, the average of those grouped about a given peak should approximate the position of the center. The comparatively small number of readings in the valleys of the curves may be accounted for by an excessive over-running of the minima or by an occasional deceptive spark flicker. The actual linear distances on the scale are 15 cm. per major unit, and each cross-hatching on the plot corresponds to 0.05 of 15 cm. or 7.5 mm. An analysis of the data shows that 81% of all the readings fall within 0.02 of a scale division (3 mm.) of

some peak. Since these readings were taken in a dark room by three different observers,[3] using four different solutions, there can be little doubt as to their accuracy.

There are five distinct peaks in each curve, indicating a total of five isotopes of cobalt and nickel. Upon diluting the cobalt sulfate solution to one equivalent in 10^{13} g. of water, the 14.60 and 14.66 minima for the sulfate disappeared, but the other three remained. Similarly, the 20.30 and 20.40 minima disappeared in the chloride range. At this dilution, the cobalt sulfate would be present to the extent of 0.77 g. in 10^{11} of water. If the
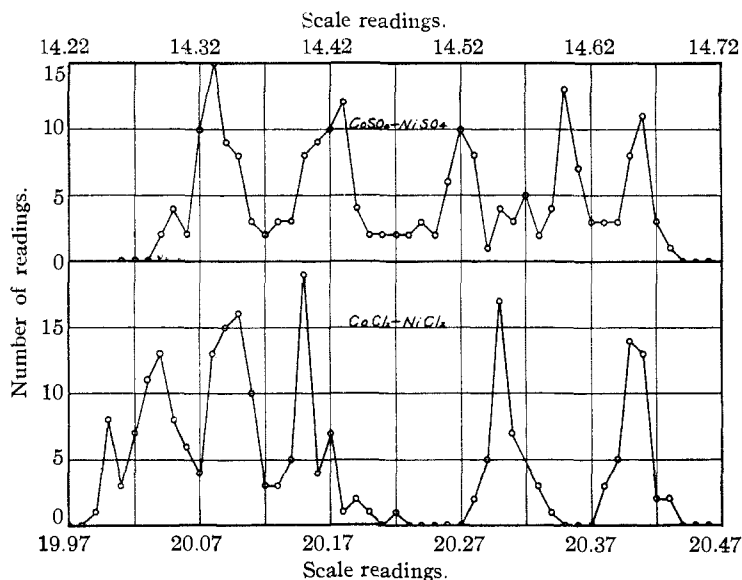

Fig. 1.—Distribution of scale readings for cobalt and nickel sulfates and chlorides.

nickel were present as an impurity even up to 1%, its concentration would be of the order of 0.77 g. in 10^{13} of water. Since all previous work by the magneto-optic method has indicated a limit of sensitivity at a few parts in 10^{12}, the nickel would not be expected to show up. Therefore, the conclusion is warranted that the two highest scale readings in both the chloride and sulfate ranges correspond to the two known isotopes of nickel and the remaining three to isotopes of cobalt.

Allison and Murphy's results for the isotopes of nickel in the chloride series are confirmed by the 20.30 and 20.40 readings. However, they report the minima for nickel sulfate at 14.52 and 14.66. The present investigation shows that the 14.52 minimum belongs to cobalt and that the two nickel minima are at 14.60 and 14.66.

(3) We are indebted to Mr. Keith D. Crane for checking some of these observations.

Relative Abundance of Cobalt Isotopes.—In a series of isotopes, the one of highest mass is detected at the lowest point on the scale. Therefore the 14.33 and 20.04 readings in the sulfate and chloride series, respectively, are those of the heaviest isotope. It was, therefore, necessary to determine the relative abundance of the three isotopes to ascertain whether Aston's 59 value represents the one of highest mass. A solution was prepared containing 0.775 g. of cobalt sulfate in 10^{10} g. of water, to which a few drops of hydrochloric acid was added. Thirty milliliters of water was placed in an observation cell and successive portions of the above solution were added from a micro-buret until all three minima were observed for both the chloride and sulfate. The results are shown in Table I. A minus sign $(-)$ indicates that no minimum was observed, a question mark $(?)$, doubtful, and a plus sign $(+)$, an unmistakable minimum.

TABLE I

RELATIVE ABUNDANCE OF COBALT ISOTOPES

Scale Rdg. CoSO₄	Concentration of CoSO₄ (g. in 10^{12})								
	0.00	3.56	3.81	3.93	4.22	4.35	4.44	4.55	4.71
14.33	−	−	?	+	+	+	+	+	+
14.42	−	−	--	−	−	−	?	+	+
14.52	−	−	--	−	−	?	+	+	+
CoCl₂									
20.04	−	−	?	+	+	+	+	+	+
20.09	−	−	--	−	−	−	?	+	+
20.15	−	−	--	−	−	?	+	+	+

The heaviest isotope is evidently the most abundant, since it was observed at a lower concentration than the other two. Assuming Aston's value of 59 to be correct and to represent the predominating isotope, the other two must be of lower mass. Because of the uniform spacing of the minima, as shown on both curves of Fig. 1, it is concluded that the new isotopes have masses of 57[4] and 58. The 57 isotope is second in abundance and the 58 third. These orders are in keeping with the value 58.94 for the atomic weight of cobalt.

Summary

1. Two new isotopes of cobalt have been observed. They are lighter than the 59 isotopes reported by Aston and probably have masses of 57 and 58.

2. The 59 isotope is by far the most abundant and the 57 and 58 follow in order.

3. Allison and Murphy's 14.52 scale reading for nickel sulfate has been shown to belong to cobalt sulfate and a new one for nickel has been observed at 14.60. Their other readings for nickel salts have been confirmed.

(4) Bartlett, *Nature*, **130**, 165 (1932), has predicted a 57 isotope of cobalt on purely theoretical grounds.