

## STUDIES OF URANIUM MINERALS (XIII): SYNTHETIC URANOSPINITES

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### ABSTRACT

Compounds having the formula  $A(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , where  $A = \text{Ca}, \text{H}_2, \text{Na}_2$ , or  $(\text{NH}_4)_2$ , have been synthesized, the last two by base exchange with hydrogen-uranospinite,  $\text{H}_2(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ . Synthetic calcium-uranospinite and hydrogen-uranospinite crystals are thin tablets flattened on {001} with {010} and {110}. X-ray single crystal study by the Weissenberg method indicated tetragonal symmetry and gave the space group  $\text{P4/nmm}$ , if holohedral symmetry is assumed. Calcium-uranospinite has cell dimensions  $a_0$  7.19 Å,  $c_0$  8.81 ( $a_0:c_0 = 1:1.225$ ). Specific gravity 3.65 (calc.). Color lemon yellow. Perfect cleavage {001}. Optically anomalously biaxial negative (–) with  $\alpha$  1.591 (nearly colorless),  $\beta$  1.619 (pale lemon yellow),  $\gamma$  1.621 (pale lemon yellow);  $2V$  variable,  $0^\circ$ – $5^\circ$ ;  $r > v$ , moderate. Hydrogen-uranospinite has cell dimensions  $a_0$  7.16 Å,  $c_0$  8.80 ( $a_0:c_0 = 1:1.230$ ). Specific gravity 3.55 (meas.), 3.55 (calc.). Color lemon yellow. Perfect cleavage {001}. Optically uniaxial negative (–) with  $\omega$  1.612 (pale lemon yellow),  $\epsilon$  1.584 (nearly colorless). Sodium-uranospinite has cell dimensions  $a_0$  7.12 Å,  $c_0$  8.70 ( $a_0:c_0 = 1:1.222$ ), obtained by the powder method. Specific gravity 3.80 (calc.). Optically uniaxial negative (–) with  $\omega$  1.617 (pale yellow),  $\epsilon$  1.586 (colorless). Ammonium-uranospinite has cell dimensions  $a_0$  7.21 Å,  $c_0$  8.85 ( $a_0:c_0 = 1:1.227$ ), obtained by the powder method. Specific gravity 3.60 (calc.). Optically uniaxial negative (–) with  $\omega$  1.611 (pale yellow),  $\epsilon$  1.601 (colorless). All fluoresce bright lemon yellow in long-wave ultraviolet light and less brightly in short-wave ultraviolet light. Natural troegerite, supposedly  $(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 12\text{H}_2\text{O}$ , is a member of the metatorbernite group and probably has the composition  $\text{H}_2(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ .

### INTRODUCTION

Uranospinite, a hydrated arsenate of calcium and uranium,  $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot n\text{H}_2\text{O}$ , was originally found in 1871 at the Weisser Hirsch mine at Neustädtel, near Schneeberg, Saxony, Germany, and was first named and described by Weisbach (1873). The mineral occurred there in association with other secondary uranium minerals—zeunerite, walpurgite, uranospherite, and troegerite. Since then the mineral has been reported from only one other locality—near Pahreah, Kane County, Utah (Butler, *et al.*, 1920).

The only available analysis of the Schneeberg material, made by Winkler (1873), established the composition at that time as  $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , though Church (1877) states that Winkler's analysis does not conclusively prove it to contain only 8 molecules of water and suggests that the water may correspond to 10 molecules instead of 8.

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Winkler (Weisbach, 1873) successfully obtained minute yellow crystals of uranospinite by adding a solution of uranyl nitrate to a solution of lime in excess arsenic acid. His analysis of this synthetic material showed it to be in close agreement with the Schneeberg uranospinite (Table 3).

Uranospinite from Schneeberg was described by Weisbach (1873, 1877) as siskin green in color, occurring in thin tabular crystals {001}, square to rectangular in outline. Cleavages {001} perfect, {100} distinct; hardness 2-3; specific gravity 3.45; pearly luster on {010}. On the basis of the biaxial optical character Weisbach considered the mineral to be orthorhombic, but possessing pseudo-tetragonal symmetry. The forms  $c\{001\}$ ,  $q\{1.0.10\}$ ,  $y\{102\}$ ,  $r\{101\}$ , and  $x\{012\}$  were identified by goniometric measurements by Weisbach (1877) who obtained, as a result, the axial ratio  $a:b:c=1$  (approx.):1:2.9123.

Goldschmidt (1899), on the other hand, considered the mineral as possessing tetragonal symmetry as a result of optical studies he made on Winkler's synthetic uranospinite and Weisbach's natural uranospinite. Winkler's material was found to be uniaxial negative; the Schneeberg material, anomalously biaxial negative. Neither Goldschmidt nor Weisbach, however, recorded the indices of refraction for the natural or synthetic uranospinite. Goldschmidt (1923) observed the forms  $c\{001\}$ ,  $q\{105\}$ ,  $d\{011\}$ , and  $r\{021\}$  on uranospinite crystals and obtained, as a

TABLE 1. OPTICAL PROPERTIES AND UNIT CELL DIMEN-

	Synthetic Hydrogen-uranospinite	Synthetic Calcium-uranospinite (C. Frondel)			
	Air-dried at room temp.	Air-dried at room temp.	Heated to 110°	Heated to 1000°	Hydrated in H <sub>2</sub> O for 1 week
Anal. No.	2	5			
Sign	(-)	(-); anomalously biax.	(-)	(-)	(-)
Indices					
$\alpha$ or $\epsilon$	$1.584 \pm 0.003$	$1.591 \pm 0.003$	$1.615 \pm 0.003$	$1.765 \pm 0.003$	$1.562 \pm 0.003$
$\beta$		$1.619 \pm 0.003$			
$\gamma$ or $\omega$	$1.612 \pm 0.003$	$1.621 \pm 0.003$	$1.637 \pm 0.003$	$1.778 \pm 0.003$	$1.589 \pm 0.003$
Opt. Orient.	X=c	X=c	X=c	X=c	X=c
Dispersion		r>v, moderate			
Pleochroism					
X or E	nearly colorless	nearly colorless	nearly colorless	pale yellow brown	nearly colorless
Y		pale lemon yellow			
Z or 0	pale lemon yellow	lemon yellow	pale lemon yellow	yellow brown	pale lemon yellow
2V	0°	variable, 0°-5°	0°	0°	0°
Space Group	P 4/nmm	P 4/nmm			
$a_0$	$7.16 \text{ \AA} \pm 0.02$	$7.19 \text{ \AA} \pm 0.02$			
$c_0$	$8.80 \pm 0.02$	$8.81 \pm 0.02$			
$a_0:c_0$	1:1.230	1:1.225			

result, the axial ratio  $a:c=1:1.4561$ , which is one-half the  $c$  value obtained by Weisbach (1877).

Numerous specimens labelled uranospinite and troegerite from Schneeberg, Saxony, were examined by means of optical and  $x$ -ray methods in the attempt to identify the presence of these two uranium minerals. A wide variation in optical data and  $x$ -ray powder patterns was obtained for materials supposedly uranospinite and troegerite. Since in every instance the limited amount of material on the specimens precluded the possibility of chemical analysis as a certain means of identification, it was decided to pursue the problem with the use of synthetic materials.

## SYNTHESES OF URANOSPINITES

Crystals of synthetic uranospinite,  $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , prepared by Dr. Clifford Frondel, were available for study. At the same time, because of the possibility that material labelled uranospinite and troegerite might actually be the hydrogen, sodium, or ammonium analogues of  $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , crystals of these compounds were synthesized. Hydrogen-uranospinite,  $\text{H}_2(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , was the first to be prepared, by the method described below; sodium- and ammonium-uranospinite were obtained by base exchange with hydrogen-uranospinite.

## PROPERTIES OF SYNTHETIC AND NATURAL URANOSPINITES

Natural Uranospinite (Larsen, 1921)			Synthetic Sodium- uranospinite	Synthetic Ammonium- uranospinite
Schneeberg	Schneeberg	Schneeberg	Air-dried at room temp.	Air-dried at room temp.
(-)	(-)	(-)	9 (-)	11 (-)
1.560 ± 0.003 1.582 ± 0.003 1.587 ± 0.003 X=c r > v, rather strong	1.560 ± 0.01  1.586 ± 0.003	1.55 ± 0.01 1.567 ± 0.003 1.572 ± 0.003	1.586 ± 0.003  1.617 ± 0.003	1.601 ± 0.003  1.611 ± 0.003
nearly colorless pale canary yellow pale canary yellow 46°	nearly colorless  pale yellow 0°	colorless pale yellow pale yellow 62° ± 3°	colorless  pale lemon yellow 0°  7.12 Å ± 0.02 8.70 ± 0.02 1:1.222	colorless  pale lemon yellow 0°  7.21 Å ± 0.02 8.85 ± 0.02 1:1.227

*Synthesis of Calcium-uranospinite*

Uranospinite,  $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , was precipitated at room temperature as a flocculent lemon-yellow precipitate by reaction in water solution of calcium chloride, uranyl nitrate, and monohydrogen sodium arsenate in molar ratio of 1:2:2. The precipitate was then heated in the mother solution, which had an acid reaction, for five months at 50° C. In this time the original precipitate recrystallized into thin lemon-yellow plates, square to rectangular in outline, up to 0.5 mm. on an edge.

*Syntheses of Hydrogen-, Sodium-, and Ammonium-uranospinite*

Several methods were employed in the effort to synthesize measurable crystals of hydrogen-uranospinite,  $\text{H}_2(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ . The following method yielded best results: 6.04 g arsenic acid were dissolved in 400 cc hot water and then brought to the boiling point. To this a hot solution of uranyl nitrate (10.1 g  $(\text{UO}_2)(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  in 80 cc. hot water) was slowly added. The resultant solution was allowed to boil vigorously for 20 minutes. When allowed to cool to room temperature at this stage, distinct but very small crystals averaging less than 0.01 mm. on an edge were precipitated. Large crystals, up to 1.5 mm. on an edge, were obtained by placing the boiling solution in an oven at 100° C., filtering the solution at the end of four days, then placing the filtrate in a flask sealed except for a small capillary tube set into the cork and allowing this to cool slowly by lowering the oven temperature 5° per day. When the oven temperature was lowered from 35° to 30°, large crystals were precipitated.

Sodium- and ammonium-uranospinite were synthesized by base-exchange with hydrogen-uranospinite. Sodium-uranospinite,  $\text{Na}_2(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , was obtained by immersing small crystals of hydrogen-uranospinite in a 1N water solution of sodium chloride for two weeks at room temperature. Ammonium-uranospinite,  $(\text{NH}_4)_2(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , was similarly obtained, using ammonium chloride.

## OPTICAL PROPERTIES

The optical properties of synthetic and natural uranospinites are summarized in Table 1. The indices of refraction for the air-dried synthetic uranospinites are somewhat different from those reported for natural uranospinite. It may be noted in Table 1 that the only synthetic preparation whose indices of refraction approach those of the natural material is the Ca member after it had been immersed in water at room temperature for one week. With the apparent increase in water content, there was an accompanying decrease in indices of refraction. On the other hand, the

loss of water by dehydration of synthetic  $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$  at  $110^\circ\text{C}$ . and at  $1000^\circ\text{C}$ . (Table 1) caused a considerable increase in both  $\omega$  and  $\epsilon$ . The decrease and increase in indices of refraction are consistent with the  $x$ -ray data which show changes in crystal structure at these stages in the dehydration process. Though it seems apparent that the natural material may be a higher hydrate than the  $8\text{H}_2\text{O}$  hydrate obtained by synthesis, no conclusive statement can herewith be made concerning the optical relationships between the two, since chemical analyses are lacking for the natural material described optically by Larsen (1921).

Numerous specimens labelled uranospinite and troegerite were examined optically during the course of this study. Only two specimens contained material whose optics were in close agreement with those reported for uranospinite by Larsen (1921). The crystals on both specimens were siskin green in color, rectangular in outline, and fluoresced bright lemon yellow in long-wave and short-wave ultraviolet light. The optical data for these are as follows (all values  $\pm 0.003$ ):

	"Troegerite" Schneeberg, Saxony (C 4394)	"Uranospinite" Spanish Fork, Utah (USNM 94665)	Pleochroism		
$\alpha$	1.560	1.560	X	nearly colorless	Biaxial neg. (-)
$\beta$	1.581	1.584	Y	pale lemon yellow	$2V \sim 45^\circ$
$\gamma$	1.585	1.586	Z	pale lemon yellow	$r > v$ , moderate

The  $x$ -ray powder patterns of the two specimens, however, differed from each other. The unanalyzed "troegerite" from Schneeberg gave a pattern identical with the meta-I hydrate of the torbernite group, while the unanalyzed "uranospinite" from Spanish Fork, Utah, corresponded to the fully hydrated phase. However, in neither case was sufficient material available for quantitative or qualitative analyses. Several other specimens labelled uranospinite and troegerite were later proven to be saléite and novacekite. Some still remain unidentified.

Qualitative analyses were made by Forrest A. Gonyer on eight specimens labelled troegerite. Four of these were reported to contain As and P together with Mg. These were subsequently proven by chemical analyses to be saléite and novacekite (Fron del, 1951b). The other four were reported to have an excess of As over P but without either Ca or Mg. It was hoped that these might prove to be hydrogen-uranospinite, believed to exist in nature as troegerite. The optical data for these four samples are as follows (all values  $\pm 0.003$ ):

	Schneeberg (H 15781)*	Schneeberg (H 665)*	Schneeberg (Y 1016)†	Joachimsthal (H 977)*	Pleochroism
Sign	(-)	(-)	(-)	(-)	
$\alpha$	1.600	1.600	1.600	1.584	X nearly colorless
$\beta$	1.629	1.628	1.628	1.620	Y pale lemon yellow
$\gamma$	1.631	1.630	1.630	1.623	Z pale lemon yellow
Opt. Orient.	X=c	X=c	X=c	X=c	
Dispersion	r>v, mod.	r>v, perc.	r>v, mod.	r>v, perc.	
2V	0°-40°	~15°	~30°	~20°	

\* Harvard specimen number.

† Yale specimen number.

They show three to be in close agreement with each other while the fourth (Joachimsthal) is in fair agreement with the data listed by Larsen (1921) for troegerite.

The x-ray powder photographs of the three specimens of "troegerite" from Schneeberg are very similar to those of sabugalite, an aluminum-autunite (Fron del, 1951a) and resemble but are distinct from both fully-hydrated autunite and meta-autunite. Qualitative analyses and optical data, however, eliminate this mineral (sabugalite) as a possibility. The Joachimsthal specimen afforded a pattern similar to that of novacekite; the optical data are in good agreement. However, the qualitative analysis eliminates this mineral as novacekite.

#### CRYSTALLOGRAPHY

Only the crystals of synthetic hydrogen-uranospinite were large enough to afford accurate goniometric measurements. Examination of numerous crystals indicated the presence of two habits; the smaller crystals were, for the most part, square in outline with only the forms {001} and {010} present; the larger crystals, on the other hand, were eight-sided with {001} and {010} truncated by {110}. Because of the absence of inclined forms, it was impossible to derive a linear axial ratio based on the morphology.

The morphological development of the synthetic Ca, Na, and (NH<sub>4</sub>) compounds was observed only under the microscope. The forms noted were the same as found on the crystals of synthetic hydrogen-uranospinite.

Single crystal x-ray work was done on the synthetic calcium-uranospinite and hydrogen-uranospinite crystals. The x-ray rotation and Weissenberg films conclusively proved that both synthetic compounds possess tetragonal symmetry. The space group established by the diffraction effects is P 4/nmm, if holohedral symmetry is assumed. Unit cell dimen-

TABLE 2. X-RAY POWDER SPACING DATA FOR SYNTHETIC URANOSPINITES  
Copper radiation, nickel filter, in Å ( $\lambda=1.5418$ )

Hydrogen-uranospinite		Calcium-uranospinite				Sodium-uranospinite		Ammonium-uranospinite	
d(meas.)	I*	Air-dried		Heated to 1000°		d(meas.)	I*	d(meas.)	I*
		d(meas.)	I*	d(meas.)	I*				
8.59	10	8.85	10	7.20	2	8.42	10	9.26	10
5.50	7	5.57	6	6.46	2	5.44	7	5.72	7
5.04	4	5.10	7	5.10	7	5.01	6	5.14	4
4.35	7	4.40	2	4.82	8	4.27	5	4.54	6
3.79	9	3.74	5	4.06	7	4.09	$\frac{1}{2}$	4.30	$\frac{1}{2}$
3.56	6	3.59	9	3.58	10	3.93	$\frac{1}{2}$	3.86	9
3.30	8	3.34	8	3.29	9	3.63	9	3.60	6
3.14	$\frac{1}{2}$	3.02	4	2.96	2	3.55	7	3.36	8
2.99	5	2.81	1	2.87	1	3.27	8	3.20	$\frac{1}{2}$
2.76	2	2.68	1	2.77	6	2.97	6	3.04	5
2.70	7	2.55	5	2.69	3	2.74	2	2.80	7
2.59	3	2.44	4	2.53	5	2.64	6	2.63	5
2.53	6	2.29	3	2.42	5	2.56	4	2.55	3
2.43	5	2.20	2	2.23	6	2.52	4	2.46	6
2.30	2	2.16	2	2.15	3	2.49	5	2.33	2
2.26	3	2.10	2	2.12	4	2.41	5	2.28	7
2.19	7	2.00	1	2.01	5	2.29	4	2.22	7
2.16	4	1.945	1	1.933	3	2.27	4	2.18	2
2.10	5	1.845	$\frac{1}{2}$	1.863	5	2.18	4	2.14	4
2.01	7	1.804	5	1.841	1	2.14	5	2.07	7
1.931	3	1.755	1	1.821	3	2.08	5	1.961	2
1.873	2	1.704	1	1.784	5	1.977	6	1.928	1
1.845	3	1.642	3	1.749	5	1.926	3	1.890	3
1.807	4	1.608	3	1.667	5	1.834	4	1.863	1
1.787	4	1.575	3	1.629	1	1.797	4	1.828	6
1.752	4	1.499	$\frac{1}{2}$	1.600	5	1.781	4	1.801	3
1.705	1	1.414	$\frac{1}{2}$	1.568	4	1.740	3	1.770	3
1.685	$\frac{1}{2}$	1.384	$\frac{1}{2}$	1.499	4	1.722	2	1.713	7
1.658	7	1.361	$\frac{1}{2}$	1.453	2	1.692	1	1.670	3
1.643	2			1.433	4	1.670	$\frac{1}{2}$	1.633	3
1.613	3			1.397	3	1.626	7	1.608	7
1.598	3			1.377	2	1.598	4	1.589	3
1.576	7			1.365	2	1.561	6 (broad)	1.518	3
1.541	$\frac{1}{2}$			1.347	2	1.517	$\frac{1}{2}$	1.486	4
1.508	$\frac{1}{2}$			1.337	3	1.495	1	1.456	3
1.492	1			1.288	2	1.478	2	1.422	8
1.473	$\frac{1}{2}$			1.278	2	1.453	1	1.401	$\frac{1}{2}$
1.462	1			1.251	2	1.421	$\frac{1}{2}$	1.373	4
1.437	4			1.222	3	1.408	5	1.361	2
1.427	4			1.188	4	1.384	1	1.321	$\frac{1}{2}$
1.388	6			1.148	4	1.370	5	1.304	2

\* Intensities estimated visually.

sions for the synthetic uranospinites are cited in Table 1; those given for sodium- and ammonium-uranospinite were obtained by indexing the powder photographs in terms of the hydrogen-uranospinite cell. X-ray powder spacing data are given in Table 2.

The  $x$ -ray ratio for calcium-uranospinite ( $a:c=1:1.225$ ) and the morphological ratio obtained by Goldschmidt (1923) on natural crystals ( $a:c=1:1.4361$ ) are not in good agreement. The unit of the  $x$ -ray cell for hydrogen-uranospinite ( $a:c=1:1.230$ ) differs from the morphological unit of Goldschmidt (1899) on natural troegerite in that the  $c$ -axis is halved ( $a:c=1:2.16$ ); the agreement in ratios is not close.

#### CHEMISTRY

Chemical analyses of the various synthetic uranospinites (cited in Table 3) indicate the general formula of the compounds to be  $A(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot n\text{H}_2\text{O}$ , where  $A = \text{H}_2, \text{Ca}, \text{Na}_2$  or  $(\text{NH}_4)_2$ .

The analysis of synthetic hydrogen-uranospinite is cited in column 2. The measured specific gravity of this compound is 3.55, representing an average of five different measurements made on the Berman microbalance. Using this value as the density, the analysis of column 2, and the unit cell dimensions obtained by single crystal  $x$ -ray study, the molecular weight of the unit cell was found to be 965. The calculated cell contents approach closely the formula



The calculated specific gravity is 3.55. The analysis of troegerite, given in column 3—probably natural hydrogen-uranospinite—indicates somewhat lower water content than that of the synthetic material.

The percentage of CaO in the analysis made on C. Frondel's calcium-uranospinite (column 5, Table 3) is low as compared with that reported by Winkler for his synthetic material (column 6, Table 3). The  $x$ -ray powder photograph of Frondel's material, however, is in agreement with that given by synthetic calcium-uranospinite, prepared by Fairchild's salting-out method, furnished the writer by Mr. K. J. Murata of the United States Geological Survey, when both materials were brought into equilibrium with each other. The deficiency in calcium is probably due to a partial substitution of  $\text{H}_2$  for Ca, in a series toward hydrogen-uranospinite. A similar situation is known in synthetic meta-autunite (Beintema, 1938).

The small size and fragility of the crystals of calcium-, sodium-, and ammonium-uranospinite precluded making specific gravity measurements. Assuming  $\text{Ca}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$  as the formula for calcium-uranospinite and the cell dimensions obtained by single crystal  $x$ -ray study (Table 1), the calculated specific gravity is 3.65. Using the cell



TABLE 3. CHEMICAL ANALYSES OF URANOSPINITES

	1	2	3	4	5	6	7	8	9	10	11
CaO				5.60	3.10	5.62	5.47				
Na <sub>2</sub> O								6.15	5.90		
(NH <sub>4</sub> ) <sub>2</sub> O										5.22	5.11
UO <sub>3</sub>	59.34	59.26	63.76	57.09	58.56	59.01	59.18	56.75	58.68	57.32	59.70
As <sub>2</sub> O <sub>5</sub>	23.84	23.70	19.64	22.93	23.54	23.01	19.37	22.80	22.86	23.02	23.14
H <sub>2</sub> O	16.82	17.09	14.81	14.38	14.60	14.27	16.19	14.30	12.69	14.44	12.13
Total	100.00	100.05	98.21	100.00	99.80	101.91	100.21	100.00	100.13	100.00	100.08
G (meas.)		3.55									
G (calc.)		3.55		3.65				3.80		3.60	

1. H<sub>2</sub>(UO<sub>2</sub>)<sub>2</sub>(AsO<sub>4</sub>)<sub>2</sub> · 8H<sub>2</sub>O. Theoretical weight percentages.
2. Hydrogen-uranospinite. Synthetic (Mrose). Gonyer, analyst, 1950.
3. Troegerite. Schneeberg, Saxony (Winkler, 1873).
4. Ca(UO<sub>2</sub>)<sub>2</sub>(AsO<sub>4</sub>)<sub>2</sub> · 8H<sub>2</sub>O. Theoretical weight percentages.
5. Uranospinite. Synthetic (C. Frondel). Gonyer, analyst, 1950.
6. Uranospinite. Synthetic (Winkler, 1873).
7. Uranospinite. Schneeberg, Saxony (Winkler, 1873).
8. Na<sub>2</sub>(UO<sub>2</sub>)<sub>2</sub>(AsO<sub>4</sub>)<sub>2</sub> · 8H<sub>2</sub>O. Theoretical weight percentages.
9. Sodium-uranospinite. Synthetic (Mrose). Gonyer, analyst, 1950.
10. (NH<sub>4</sub>)<sub>2</sub>(UO<sub>2</sub>)<sub>2</sub>(AsO<sub>4</sub>)<sub>2</sub> · 8H<sub>2</sub>O. Theoretical weight percentages.
11. Ammonium-uranospinite. Synthetic (Mrose). Gonyer, analyst, 1950.

dimensions obtained by the powder method (Table 1) and assuming Na<sub>2</sub>(UO<sub>2</sub>)<sub>2</sub>(AsO<sub>4</sub>)<sub>2</sub> · 8H<sub>2</sub>O as the formula for sodium-uranospinite and (NH<sub>4</sub>)<sub>2</sub>(UO<sub>2</sub>)<sub>2</sub>(AsO<sub>4</sub>)<sub>2</sub> · 8H<sub>2</sub>O as the formula for ammonium-uranospinite, the calculated specific gravities are 3.80 and 3.60, respectively.

#### Dehydration Data

X-ray powder photographs of synthetic air-dried hydrogen-, calcium-, sodium-, and ammonium-uranospinite were of the meta-autunite I type of structure, and each pattern probably represents material containing 8 molecules of water. The spacing data for these patterns are listed in Table 2.

No structural change was produced by heating hydrogen-uranospinite at 90°, but an unidentified phase was formed between 90° and 200°. Frondel's synthetic calcium-uranospinite lost 11.3% of zeolitic (?) water when heated to 110°, the indices of refraction increased to  $\omega$  1.637,  $\epsilon$  1.615 with 2V 0°, and the color changed from lemon yellow to martius yellow (Ridgway, 1912). When exposed to air at room temperature the material regained most of its water (8.3%) and the indices decreased. The water content of this phase thus varies zeolitically over a wide range. The same material when immersed in water at room temperature converted to the fully hydrated phase with  $\omega$  1.589,  $\epsilon$  1.562, 2V 0° and when exposed again to air reverted to the meta-I hydrate with  $\sim$ 8H<sub>2</sub>O. A sample heated to 1000° changed in color from lemon yellow to old

gold (Ridgway, 1912), and afforded an entirely new pattern unlike that of the meta-I or meta-II hydrates of torbernite that probably represents the anhydrous phase  $\text{CaU}_2\text{O}_7$ ; it was uniaxial negative with  $\omega$  1.778,  $\epsilon$  1.765.

Fluorescence varies with water content. All the synthetic uranospinites ( $\sim 8\text{H}_2\text{O}$ ) fluoresce bright lemon yellow in both short-wave and long-wave ultraviolet radiation; calcium-uranospinite when reduced in water content by heating to  $110^\circ$  fluoresces weak olive green; the same synthetic material heated to  $1000^\circ$ , clove brown. The intensity of the fluorescence in all instances is somewhat greater in long-wave than in short-wave radiation.

The status of natural uranospinite and troegerite is still problematic and further work on these minerals is desirable, provided sufficient material is available for chemical analyses.

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