

SPECIAL COLLECTION: BIOMATERIALS—MINERALOGY MEETS MEDICINE

## Substitution of sulfate in apatite

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### ABSTRACT

The substitution of sulfate in apatite is of potential importance in synthetic biomaterials used in bone repair and reconstruction. The counter ion (e.g., Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Sr<sup>2+</sup>) in the sulfate reagent may also be used as a source of medically beneficial ions. An understanding of the structural parameters controlling sulfate substitution is also important in expanding our knowledge beyond the substitution of carbonate in apatites.

The incorporation of sulfate in calcium and strontium hydroxylapatites, prepared in aqueous solution at pH 9, was verified by combustion analysis of sulfate, infrared and Raman spectroscopy, and by determination of unit-cell parameters. Sulfate could not be incorporated into barium hydroxylapatite because of the preferential formation of BaSO<sub>4</sub>.

The amount of sulfate substituted in the apatite was affected by the mole ratio of sulfate to phosphate in the reaction mixture and by the nature of the counter ion in the sulfate reagent. When sodium is the counter ion in the sulfate reagent, the molar amounts of both sodium and sulfate in the product apatite can be explained by assuming charge compensation by sodium ions and sulfate displacement of phosphate and calcium. With lithium as the counter ion, a greater molar amount of lithium than sulfate is incorporated into the apatite, an observation that requires an additional charge-compensation mechanism. With potassium and rubidium as counter ions, less of the counter ion is incorporated than sulfate, probably a result of less favorable accommodation of the larger cation in the apatite structure.

The maximum molar amount of sulfate incorporated in hydroxylapatite (prepared in the presence of Na<sup>+</sup>) is more than three times lower than the maximum molar amount of carbonate that can be incorporated, a difference that can be explained by the relative solubilities of the substituted apatites. The unit-cell parameters determined for both sulfated calcium and strontium hydroxylapatites synthesized with the sodium counter ion show a slight increase in the *a*-axis length and a nearly constant *c*-axis length with increasing sulfate content. The difference in the variation of unit-cell parameters with anion content can be rationalized by the difference in size of the anion.

The results indicate that sulfate can be incorporated into biomaterials such as apatite or in composites with calcium sulfate and that the design of new apatites and composites could include the use of medically desirable counter cations.

**Keywords:** Apatite, sulfate, incorporation of sulfate, unit cell, IR, strontium apatite, sulfated apatite, calcium sulfate-apatite composite, Biomaterials—mineralogy meets medicine