SOUTHWESTERN RADIOLOGICAL HEALTH LABORATORY

INTRALABORATORY TECHNICAL REPORT NUMBER 4

December 2, 1963

THERMOMETRIC STUDIES OF SELECTED CALCIUM AND STRONTIUM CHELATES

Erich Bretthauer

SUMMARY

With the completion of the thermal titrator, Technical Report Number 3, experiments were performed with the objective of providing information on strontium and calcium chelation compounds which might ultimately lead to their separation.

If a chelation agent could be found which would complex calcium or strontium independently in the presence of the other then separation would be relatively easy. It is known that magnesium, due to its inner shell configuration, forms chelation compounds of unusually high entropy. This unusually high entropy value accounts for the endothermic formation characteristic of magnesium chelation compounds. Strontium and calcium, on the other hand, chelate exothermically. Therefore, if one could find a chelate whose formation constants for calcium, magnesium, and strontium were of such magnitude and difference that their strong order of reaction was calcium, magnesium, and strontium, a separation could be effected. Measurement and evaluation of heats of formation should yield the desired information.

Two chelates, nitrilotriacetic acid and ethylenediaminetetraacetic acid, were examined for the above properties. The results indicate a possible means of independent determination and/or separation of calcium and strontium.

With the completion of the thermal titrator, Intralaboratory Technical Report Number 3, experiments were performed with the objective of providing information on strontium and calcium chelation compounds which might ultimately lead to their separation.

If a chelation agent could be found which would complex calcium or strontium independently in the presence of the other, then separation would be relatively easy. It is known that magnesium forms chelation compounds of unusually high entropy. This is accounted for by the relaxation of front strain of the four five-membered rings of the chelate due to the comparatively large ionic size of magnesium (8Å) as compared to strontium (6Å) and calcium (5Å). This unusually high entropy value then explains the endothermic formation characteristic of magnesium chelation compounds. Strontium and calcium, by the same reasoning, chelate exothermically. Therefore, if one could find a chelate whose formation constants for calcium, magnesium, and strontium were of such magnitude and difference that their strong order of reaction was calcium, magnesium, and strontium, a separation could be effected. Measurement and evaluation of heats of formation should yield the desired information.

A search of the literature on all known chelating agents was conducted. Ethylenediaminetetraacetic acid (EDTA)[2] and nitrilotriacetic acid (NTA)[1] appeared to be the only chelons which had the desired formation constants (Table I).

TABLE I. FORMATION CONSTANTS OF EDTA AND NTA COMPLEXES
(20°C and ionic strength = 0.1)

Chelon	Cation	Log K
EDTA	Ca^{++}	10.59
	Mg^{++}	8.69
	Sr^{++}	7.91, 8.63
NTA	Ca^{++}	8.2, 3.4
	Mg^{++}	7.0, 3.2
	Sr^{++}	5.0

The first chelon studied was EDTA. EDTA forms a 1:1 complex with metal ions.

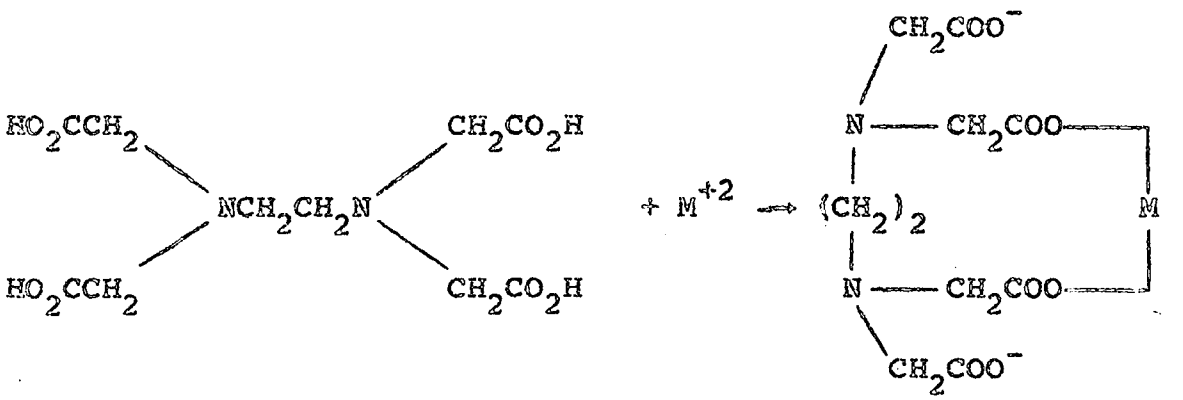


Figure 1 shows the thermometric titration of calcium and magnesium with the tetrasodium salt of EDTA at pH 10.

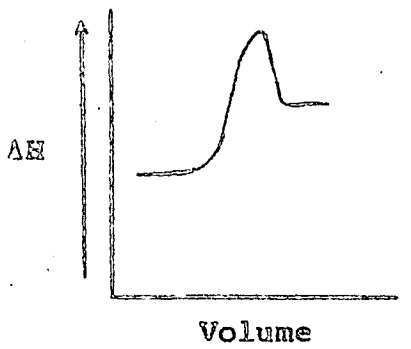


Fig. 1

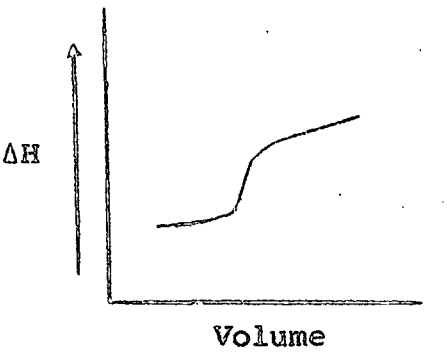


Fig. 2

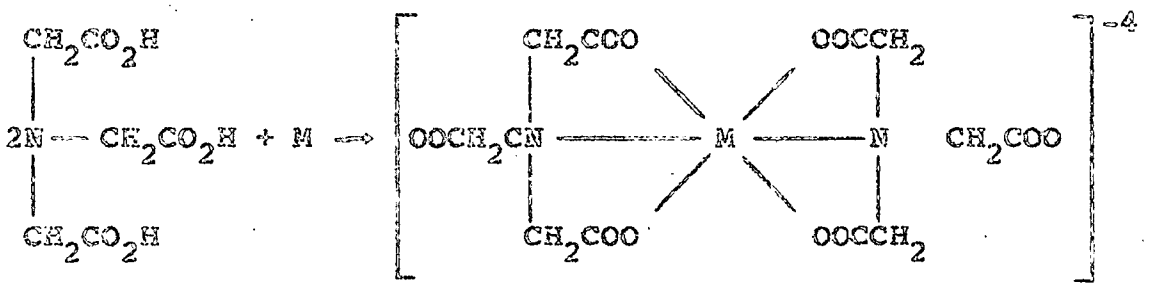
The stability constant of the calcium EDTA chelate is two orders of magnitude larger than that of the magnesium chelate. Consequently, in the course of the titration, calcium was initially chelated preferentially, while the chelation of magnesium was completed upon addition of EDTA beyond the calcium equivalence point. The end point is quite discernable as the chelation of calcium is exothermic and chelation of magnesium is endothermic (Table II).

TABLE II. THERMODYNAMIC DATA AT 25° FOR THE REACTION

Cation	ΔH°
Ca^{++}	-5.8
Mg^{++}	+3.1
Sr^{++}	-4.2

Since the log of the formation constants differed by 0.5, the simultaneous titration of Ca^{++}, Mg^{++}, and Sr^{++} was tried. As the chelation of Sr^{++} with EDTA is exothermic (Table II), we might expect an ascending portion of the curve corresponding to the chelation of strontium after the magnesium ion is complexed. The expected thermogram was not obtained (Fig. 2). The formation constant of the strontium EDTA chelate was checked in additional references and found to be 8.63[3] and not 7.91[2] as originally reported. Therefore, we could not expect to obtain the projected thermogram as the magnesium and strontium ions react nearly simultaneously.

Nitrilotriacetic acid forms a 2:1 complex with the metal (M) as shown below



Nitrilotriacetic acid was tested as a titrant for calcium, magnesium, and strontium. Thermograms for these titrations are shown below. All NTA titrations were carried out in an ammonium acetate pH 10 buffered system. The titrant was also buffered as the third proton attached to the nitrogen atoms is not given up until about pH 10 is reached. The ionization of this third proton is highly exothermic.

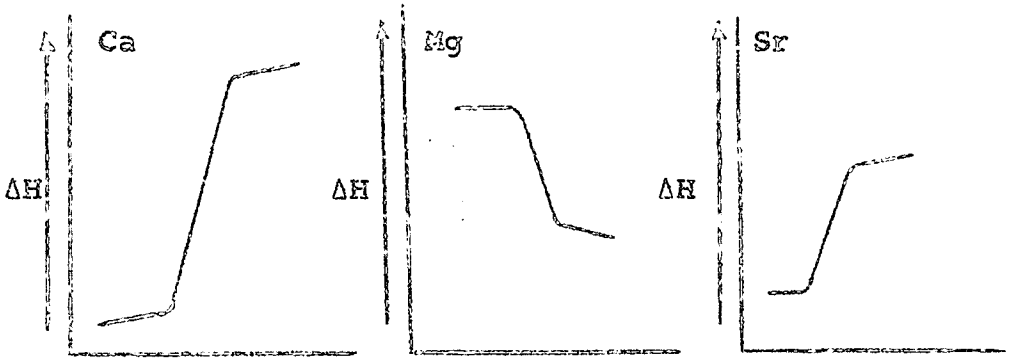


Fig. 3 Fig. 4 Fig. 5

These thermograms indicate that the heat of NTA chelation for calcium and strontium to be exothermic to the extent of 7.0 (Fig. 3) and 2.9 (Fig. 4) K-cal/mole. respectively, while magnesium chelation proceeds endothermic to the extent of 2.8 K-cal/mole. (Fig. 5).

Due to the large differences in formation constants of these chelate complexes (Table III) plus the fact that NTA-magnesium chelation is endothermic; simultaneous titrations using different combinations of these ions were tested. The resultant thermograms shown in Fig. 6 and 7 indicate the order of chelation is calcium, magnesium, and strontium and, therefore, that the heat of reaction is associated with the first molecule

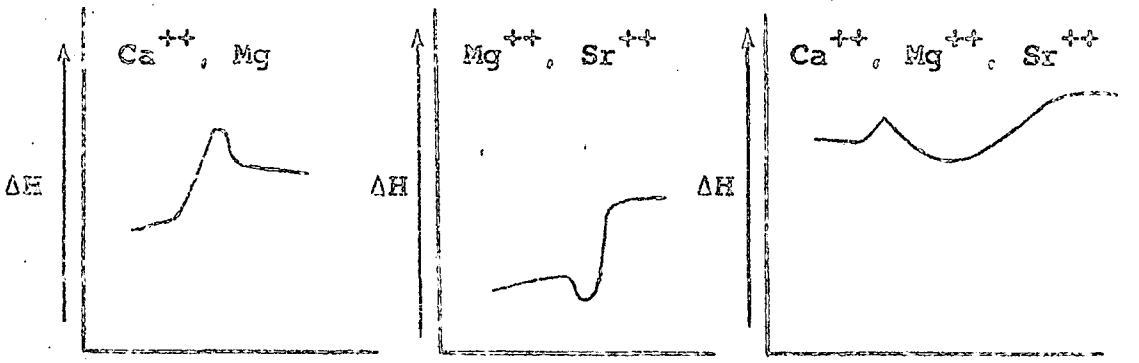


Fig. 6 Fig. 7 Fig. 8

of ligand. Figure 8 shows the simultaneous titration of calcium, magnesium, and strontium and indicates that if the titration were stopped just after calcium chelation, i.e. during magnesium chelation, that the calcium would be

chelated and be in the form of a negative ion while the strontium would still be in the positive ionic state. A suitable indicator could be used for this purpose, i.e. one in which a color change is observed with magnesium reaction. In that state, several different methods, i.e. solvent extraction, ion exchange, precipitation, etc. could be used for calcium-strontium separation. This should provide a good separation as there is no overlap of the pertinent reactions. This multiple titration could also be studied as a means of calcium and/or strontium determination.

This writer believes that the NTA titration of calcium, magnesium, and strontium ions is significant from two viewpoints. First, as stated above, NTA is the only known chelon which could selectively titrate these three metals and second, there is no published data on the heats of formation of these NTA complexes.

BIBLIOGRAPHY

1. Aikens, David and Reilley, Charles, "Formation Constants of Metal Complexes" in Handbook of Analytical Chemistry. L. Meites, Editor-in-Chief, McGraw-Hill, New York, New York, in print (1963).

2. Charles, Robert, "Heats and Entropies of Reaction of Metal Ions with Ethylenediaminetetraacetic Acid" J. Am. Chem Soc. 76, 15854 (1954).

3. Welcher, Frank, "Analytical Uses of Ethylenediamine Tetraacetic Acid" D. Van Nostrand Co., New York, New York, (1957).

ACKNOWLEDGEMENT

This writer is indebted to Messrs. Bernard Fumagalli, Frank Williams and James Dillon for their technical assistance during the course of this experiment.