

*Sterility.*—Many and diverse spas have been credited with the cure of sterility. Mineral waters can only act by causing the disappearance of material or functional defects. Chronic leucorrhœa and acidity of the vaginal secretions may be removed: by the application of vaginal douches the circulation and nutrition of the uterus may be improved; iron tonics and a bracing climate may improve the general health and tone.

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Chem

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## CHAPTER VII

### CHEMISTRY OF MINERAL WATERS

BY

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#### INTRODUCTION

The chemical examination of the mineral waters of Colorado was begun in June, 1911, and finished in the following winter. The samples were collected by Mr. Roy M. Butters. Bottles for this purpose were cleaned at the laboratory in Boulder, boxed in wooden crates and shipped to convenient points. In collecting the samples the bottle was first rinsed with the spring water, then completely filled, tightly corked and shipped to the laboratory. The temperature of the spring was taken with an ordinary thermometer. Where the flow was small and could be conveniently measured, this was done. In other cases the flow was estimated. The rates given must therefore be considered as approximate. The hydrogen sulphide content of the water was determined at the spring, as indicated under "Methods of Analysis." Mr. Butters also noted the location of the spring, the geologic formations appearing in the neighborhood, and the other points of interest regarding the spring.

In the analytical work the writer was assisted by Dr. Paul M. Dean, now instructor in chemistry, University of Colorado; by Mr. H. R. Mosley, now chemist for the Black Metal Reduction Company, Boulder, and later by Mr. Roy M. Butters, now a consulting geologist in Mexico. All calculations were made by the writer. During the summer of 1911 the work was much facilitated by the loan of several hundred dollars worth of platinum-ware by the Colorado School of Mines.

#### LOCATION OF SPRINGS

In the table below will be found the location of springs by county, nearest post office, name, and by natural surroundings. Wherever the spring sampled had been given a name which was used to any extent by people living in the neighborhood, this name will be found in the table below, printed in ordinary type. The names printed in italics were given the other springs in order to facilitate the making of field and laboratory notes. These names in many cases refer to either the location or ownership of the springs and may become permanent.

The numbers given the springs are those used to refer to the springs throughout this bulletin. It will be noted that not all of the two hundred fifty-four springs listed were analyzed. The table includes all the springs analyzed as well as those on which radioactivity measurements were made. The springs analyzed are indicated by the sign † after the number.

No.	County	Postoffice	Name	Location
183†	Gunnison	Powderhorn	Lower Hot Spring	About 300 yds. above Nichol's Spring, on lower side of road, 125 yds. from creek.
184†	Gunnison	Powderhorn	Schrecker's No. 1	On Schrecker's property 200 yds. S. of Powderhorn P. O., about 50 yds. from creek.
185†	Gunnison	Powderhorn	Schrecker's No. 2	On Schrecker's property, about 10 ft. from creek, across from Schrecker's house.
186†	Gunnison	Powderhorn	Nichol's Spring	By roadside 100 yds. E. of Powderhorn Postoffice.
187†	Pueblo	Pueblo	Sisters' Hospital	Well in grounds of Sisters' Hospital.
188†	Pueblo	Pueblo	Ferris Artesian Well	Well over 1,500 ft. deep.
189†	Pueblo	Pueblo	Pueblo Lithia Water	Well 1,200 ft. deep at Congress Hotel.
190†	Pueblo	Pueblo	Clark's Magnetic Mineral Water	Well 1,425 ft. deep at B and Spring Streets.
191†	Dolores	Rico	Railroad Spring	By railroad track ¼ mi. N. of Rico.
192†	Dolores	Rico	Rico Spring	In N. W. corner of city, on west side of Dolores River, 25 ft. from stream near large pine tree at end of bridge.
193†	Dolores	Rico	Dolores Spring	Spring 100 yds. S. of No. 192.
194†	Dolores	Rico	River Spring No. 1	In old river bed 50 ft. from No. 193.
195†	Dolores	Rico	River Spring No. 2	Spring 30 ft. S. E. of No. 194.
196†	Ouray	Ridgway	Orvis Spring	On Orvis Ranch, 2 mi. S. E. of Ridgway, spring at foot of hill about 300 yds. from river.
197†	Ouray	Ridgway	Ridgway Spring	Spring ½ mi. S. W. of Ridgway, at ranch house, on south side of small stream.
198†	Larimer	Rustic Lodge	Rustic Lodge Spring	Spring ¾ mi. W. of the Rustic Lodge, on Cache La Poudre River.
199†	Pueblo	Siloam Bubbling Sp.	Red Creek Springs No. 1	In bottom of gulch, near granite contact on south side of gulch. Red Creek Springs near head of Red Creek, 12 mi. S. of Siloam.
200†	Pueblo	Siloam Resort Sp.	Red Creek Springs No. 2	Across gulch from No. 199, near site of old resort.
201†	Pueblo	Siloam Clear Sp.	Red Creek Springs No. 3	In gulch 100 yds. below No. 199, at foot of a 12-ft. drop in gulch bed.
202†	Pueblo	Siloam Iron Sp.	Red Creek Springs No. 4	In gulch 75 ft. below No. 201.
203†	Pueblo	Siloam Mound Sp.	Red Creek Springs No. 5	On mound 50 yds. up hill from No. 202.
204†	Pueblo	Siloam	Artesian Well	Well used for irrigation, 1 mi. N., 1 mi. E. of Siloam Postoffice.
205†	San Juan	Silverton	Mineral Creek Spring	4 mi. up So. Mineral Creek.
206†	Rio Grande	South Fork	Million's Spring	5 mi. up So. Fork of Rio Grande River from South Fork Postoffice, in Million's pasture, in draw 100 yds. east of river.
207†	Boulder	Springdale	Tile Spring	Beside Jimtown road on Left Hand Creek, near site of old Springdale P. O., on north side of creek.
208†	Boulder	Springdale	Tunnel Spring	About 50 ft. up stream, on same side of creek as No. 207.
209†	Boulder	Springdale	Bath Spring	Above No. 208, about 50 ft. distant.
210†	Boulder	Springdale	Well Spring	Above No. 209, about 75 ft. distant.
211†	Routt	Steamboat Springs	Milk (Lithia, etc.) Spring	¼ mi. S. W. of Cabin Hotel on south side of river, 400 yds. S. of Moffat depot.
212†	Routt	Steamboat Springs	Bath House Spring	Just north of large bath house at east end of main street.
213†	Routt	Steamboat Springs	Heron Spring	Across street N. of Cabin Hotel. Called also the Iron Spring.
214†	Routt	Steamboat Springs	Bubbling (Sulphur) Spring	300 ft. W. of Cabin Hotel in round cement pool, 30 ft. from north bank of river.

215†	Routt	Steamboat Springs	Hot Springs	Hot spring group on creek 8 mi. N. of Steamboat.
216†	Routt	Steamboat Springs	Steamboat Spring	Near bridge.
217†	Routt	Steamboat Springs	Crawford Spring	
218†	Routt	Steamboat Springs	Soda Spring	In pavilion about 200 ft. N. W. of Cabin Hotel.
219†	Routt	Steamboat Springs	Magnesia Spring	
220†	Routt	Steamboat Springs	Moffat Spring	Under Moffat railroad.
221†	Routt	Steamboat Springs	Sulphur No. 2	Second spring above No. 216.
222†	Routt	Steamboat Springs	Rumbling Spring	In cut on Moffat railroad. Also called Bitter Spring.
223	Routt	Steamboat Springs	Navajo Spring	150 yds. E. and a little S. of the Milk Spring, No. 211.
224	Routt	Steamboat Springs	Little Steamboat	35 yds. S. W. of cave spring in hillside.
225	Pueblo	Swallows	Hobson's Well	Artesian well on Hobson Ranch, 540 ft. deep, near ranch house.
226	Pueblo	Swallows		
227†	Otero	Symons	Symon's No. 1	Spring in an arroya ¼ mi. S. W. of Symons, near group of old buildings.
228†	Otero	Symons	Symon's No. 2	Near old stone house by road, about 100 yards W. of No. 227.
229†	La Plata	Trimble	Bath Spring	Spring at bath house by road, ¼ mi. N. of Trimble, on west side of Animas River.
230†	La Plata	Trimble	Main Spring	Spring feeding swimming pool. Main spring of the group.
231	La Plata	Trimble	North Spring	Northernmost spring of the group, near hotel.
232†	Pitkin	Thomasville	Bridge Spring	Under Colo. Midland R. R. Bridge No. 168A, 50 ft. from creek, ¾ mi. W. of Thomasville.
233†	Pitkin	Thomasville	Meadow Spring	Spring in field 100 yds. from creek, ¼ mi. east of No. 232.
234†	Mineral	Wagon Wheel Gap	Boiling Spring	Resort about 1 mi. from railroad station. Large spring near hotel on same side of creek.
235†	Mineral	Wagon Wheel Gap	Hot Saline Spring	At foot of hill about 100 yds. from the Hot Sulphur Spring and on opposite side of creek.
236†	Mineral	Wagon Wheel Gap	Hot Soda Spring	At foot of hill across creek from Hot Sulphur Spring. Spring cemented up.
237	Mineral	Wagon Wheel Gap	Little Spring	Small spring beside No. 234.
238†	Gunnison	Waunita	Hotel No. 1	In lower group, ½ mi. below postoffice. Uppermost spring on south bank of Hot Springs Creek.
239	Gunnison	Waunita	Hotel No. 2	In lower group.
240	Gunnison	Waunita	Hotel No. 3	In lower group.
241	Gunnison	Waunita	Hotel No. 4	In lower group.
242	Gunnison	Waunita	Hotel No. 5	In lower group.
243	Gunnison	Waunita	Hotel No. 6	In lower group.
244	Gunnison	Waunita	Hotel No. 7	In lower group.
245†	Gunnison	Waunita	Hotel No. 8	In little gully well up on hill on south bank of creek, about two-thirds way down springy area in lower group of springs.
246†	Gunnison	Waunita	Hotel No. 9	In lower group, on north bank of creek, about 4 ft. from stream, near site of old hotel.
247	Gunnison	Waunita	Hotel No. 10	In lower group.
248	Gunnison	Waunita	Hotel No. 11	In lower group.
249	Gunnison	Waunita	Hotel No. 12	In upper group.
250	Gunnison	Waunita	Hotel No. 13	In upper group. Long oval pool near hotel.
251†	Gunnison	Waunita	Hotel No. 14	In upper group. Pavillion spring.
252†	Fremont	Wellsville	Wellsville Spring	From tunnel feeding swimming pool.
253	Jefferson	Wheatridge	Reservoir Spring	Yousse Radium Springs.
254	Jefferson	Wheatridge	Palmer Spring	Yousse Radium Springs.

## METHODS OF ANALYSIS

The methods of analysis used were essentially those given in Bul. 91, U. S. Bureau of Chemistry, and are briefly outlined below.

## SILICA

A one-liter sample of the water, filtered if not clear, was evaporated on the water bath in a platinum dish. The dish was then covered with a watch glass, and hydrochloric acid added, a little at a time, until effervescence ceased and the solution was decidedly acid. This solution was brought to boiling to expel dissolved  $\text{CO}_2$ , after which the watch glass was rinsed over the dish in the usual way. The solution was next evaporated to dryness, on the water bath, the residue dehydrated for two hours at  $130^\circ$ , taken up in 1:1 hydrochloric acid, filtered and washed with hot water. The residue on the filter was placed in a weighed platinum crucible, ignited, cooled in a dessicator and weighed as silicon dioxide.

## IRON AND ALUMINUM

The filtrate from which the silica was removed was caught in a 250cc. graduated flask and the volume made up to 250cc. with distilled water after cooling. The solution was made of uniform concentration by pouring it out into a dry beaker and back into the flask several times. Two samples of 50cc. each were then withdrawn by means of pipettes placed in covered beakers, and duplicate analyses made as follows: Ammonium hydroxide was added to each until the solutions smelled strongly of ammonia. The solutions were then boiled until they smelled but faintly of ammonia. The precipitated hydroxides were filtered off, redissolved in warm dilute hydrochloric acid and reprecipitated as usual, after which they were ignited in a platinum crucible and weighed together as aluminum oxide and ferric oxide. If the combined oxides ran low and the duplicate analyses checked, the oxides were not separated. When the combined oxides ran high, the iron and aluminum were separated as indicated below.

## IRON

Several grams of acid potassium sulphate were added to each of the crucibles containing the combined oxides. The oxides were brought into solution by very slow and careful fusion. The melts were cooled, dissolved out with water, the solutions made acid with sulphuric acid, the iron reduced by pure sheet aluminum and titrated with standard potassium permanganate solution.

## ALUMINUM

In those cases where the iron and aluminum were separated, the aluminum was calculated from the combined oxides of iron and aluminum by difference.

## CALCIUM

The filtrates from the two samples used in determining iron and aluminum were made distinctly alkaline with ammonium hydroxide and then an excess of ammonium oxalate solution added. The solutions were kept hot for an hour and then allowed to settle for an hour or longer, after which the calcium oxalate was filtered off, washed with hot water, ignited and weighed as calcium oxide,  $\text{CaO}$ .

## MAGNESIUM

The filtrates from which the calcium had been removed as indicated above, were evaporated to dryness in platinum dishes, the excess of ammonium salts removed by heating, the residue taken up in a small amount of dilute hydrochloric acid and filtered. The filtrates were made strongly alkaline with ammonium hydroxide, an excess of sodium acid phosphate added, and the solutions allowed to stand overnight. The precipitated ammonium magnesium phosphate was then filtered off, washed with ammoniacal ammonium nitrate solution, dried and ignited very slowly with the usual precautions to insure complete combustion of the filter paper and complete transformation of the solid to magnesium pyrophosphate, in which form it was weighed.

## SULPHATES

Two 50cc. samples of the original filtrates from the silica were measured out into beakers, brought to boiling and a hot 10% solution of barium chloride added. The solutions were kept hot for an hour, then filtered and the barium sulphate washed with hot water. The barium sulphate was then ignited and weighed in the usual way.

## ALKALIES

The filtrates from the sulphate determination were evaporated to dryness in a platinum dish and the residue taken up in water. An excess of barium hydroxide solution was added, the magnesium hydroxide filtered off, washed free of mother liquor, and discarded. To the filtrates were added ammonium hydroxide, ammonium carbonate and ammonium oxalate and the mixture allowed to stand

overnight. The precipitate was removed, washed and discarded. The filtrate was evaporated to dryness, the ammonium salts removed by heating, and the residue taken up in water. The treatment with ammonium hydroxide, ammonium carbonate and ammonium oxalate, etc., was repeated twice to make sure that all barium, calcium, etc., were removed from the solution.

The ammonium salts were now removed by evaporating the solutions to dryness and heating. The residues were dissolved in water containing a little hydrochloric acid and filtered, the process being repeated until there remained pure white crystals of the alkali chlorides, which gave no white fumes and no blackening on heating. When considerable quantities of alkali chlorides were obtained, it was found necessary to dry the residue for several hours in the air bath in order to avoid loss by decrepitation when the residues were heated to remove the ammonium salts. The pure dry alkali metal chlorides were now weighed, and the preparation of the alkalies made as indicated below.

Lithium was first tested for by means of the spectroscope. If the lithium line was bright, the lithium was determined as sulphate by the Gooch method, as follows: The dry chlorides were moistened with a few drops of water and then 30cc. of amyl alcohol added. The liquid was brought to boiling, one drop of hydrochloric acid added, and the boiling continued until the volume of the liquid reached 15cc. The amyl alcohol solution was then run through a dry filter paper and caught in a weighed platinum dish. The undissolved salts were washed twice by decantation with a little amyl alcohol. The amyl alcohol was evaporated from the platinum dish, a few drops of sulphuric acid added, the dish heated gently until the residue was almost white, and the lithium sulphate weighed. From the weight of the sulphate, 0.0017 gram was subtracted to correct for the solubility of sodium and potassium chlorides in 15cc. of amyl alcohol.

The chlorides of potassium and sodium remaining in the platinum dish and on the filter were dried to remove amyl alcohol and then dissolved in water. The amount of hydrochloroplatinic acid necessary to combine with the alkalies was calculated, considering the whole of the alkali chlorides to be sodium chloride. A slight excess of hydrochloroplatinic acid in 56% solution was then added to the solution of the alkali chlorides and the solution evaporated in a porcelain dish over a simmering (not boiling) water bath until a pasty mass remained in the dish. About 20cc. of 80% ethyl alcohol were now added and the mass thoroughly worked up in the

alcohol. The mixture was filtered, then a small dry filter and the insoluble potassium chloroplatinate washed on the filter with 80% alcohol. The filter paper was dried, the potassium chloroplatinate dissolved out with a little warm water, the solution evaporated to dryness in a small weighed platinum dish and the weight of the potassium chloroplatinate determined. Knowing the weight of the lithium sulphate, the potassium chloroplatinate and the combined chlorides of lithium, potassium and sodium, it is evident that the weights of the three alkali metals could be calculated.

#### PHOSPHORIC ACID

The remaining 50cc. of the original filtrate from the silica were used to test for phosphates by the usual ammonium molybdate method. The amount of ammonium phosphomolybdate obtained was not large enough in any case to warrant a quantitative determination, and the phosphates reported as a trace in those cases in which any of the yellow phosphomolybdate appeared.

#### HYDROGEN SULPHIDE

This determination was made at the spring by the collector of the samples. The hydrogen sulphide was titrated with tenth normal iodine solution, using 500cc. of the mineral water when the sulphide was low and a smaller amount when the mineral water ran high in hydrogen sulphide.

The tenth normal iodine solution for this purpose was standardized in the laboratory and fresh amounts sent to the collector in the field from time to time.

#### CARBONATES AND BICARBONATES

Two 100cc. samples of the mineral water were pipetted out and a few drops of phenolphthalein added. Normal carbonates give a red color. The samples were titrated with twentieth normal hydrochloric acid until colorless. This occurs when the carbonates have been converted into bicarbonates, thus:  $2MCO_3 + 2HCl = MCl_2 + M(HCO_3)_2$ , from which the amount of carbonates may be calculated. Methyl orange was then added, and the samples again titrated to an end with the standard acid:  $M(HCO_3)_2 + 2HCl = MCl_2 + 2H_2O + 2CO_2$ .

In this second titration it is to be noted that both the bicarbonates originally present and those formed by the titration of the normal carbonates consume the standard acid. Therefore the volume of acid used in the first titration must be subtracted from the volume used in the second titration, since only one-half of the

carbonates were converted to chlorides in the first titration, the other half being converted from bicarbonates to chlorides during the second titration.

#### CHLORIDES

Two 100cc. samples of the mineral water were measured out by means of a pipette. To these samples a couple of drops of phenolphthalein were added. If a red color developed, showing carbonates, the solution was titrated to colorless by means of acid potassium sulphate solution. A little potassium chromate solution was then added as an indicator and the chlorides titrated with standard silver nitrate solution.

#### OXYGEN CONSUMING CAPACITY

Two 200cc. samples of the mineral water were measured out, and 2cc. of sulphuric acid added to each. They were then brought to boiling and standard potassium permanganate added until the color was red. The boiling was continued for ten minutes, adding more potassium permanganate solution if the color faded out, and the excess of permanganate then determined by titrating back to an end with standard ammonium oxalate solution.

#### PRECIPITATED IRON

On standing, especially in the light, an iron containing mineral water will lose most of the iron by reason of the precipitation of basic iron salts. In order to avoid the absurdity of reporting a trace of iron in a mineral water which, at the time of collection, may have contained a considerable quantity of iron, the precipitated iron was determined as follows: The whole sample was filtered and the filtrate set aside. The iron adhering to the inside of the container was dissolved in a little hydrochloric acid, reprecipitated with ammonium hydroxide and the hydroxide washed on to the filter. The whole of the iron salt was now dissolved from the filter in warm dilute sulphuric acid, the iron reduced by aluminum and titrated with standard permanganate solution. The total volume of the sample was measured and the precipitated iron calculated to parts per million.

#### EXCESS CARBON DIOXIDE

By this term is meant, in this report, the amount of carbon dioxide given off when the bicarbonates are converted to carbonates, as occurs during evaporation of the mineral water. The excess carbon dioxide was calculated from the known amounts of bicar-

bonates present according to the following equation:  $M(\text{HCO}_3)_2 = \text{MCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$ . The amount of free carbon dioxide dissolved in the water was not determined. Under "Remarks" in connection with the analyses it is indicated in many places that the water was saturated with the gas, shown by the fact that gas was bubbling through the water.

#### EVAPORATION SOLIDS

One hundred cubic centimeters of the water were evaporated to dryness in a weighed platinum dish on the water bath. The residue was dried for two hours in an air oven at about 120° and the weight of the residue determined.

In evaporating a mineral water, the bicarbonates are converted to normal carbonates, causing the residue to weigh less than the sum of the constituents shown in the analysis. This may be in part or wholly compensated by the fact that certain of the salts in the residue, notably the calcium sulphate, retain some water of crystallization at 120°. For these reasons the amount of residue to be obtained upon evaporating a given weight of a mineral water can be calculated only approximately from the amount of bases and acid radicles shown in the analysis.

#### SUMMARY

In the table below is shown the form in which the various constituents were determined and the form to which they were calculated for report.

Form in Which Reported	Form in Which Determined
SiO <sub>2</sub> , silica .....	SiO <sub>2</sub>
Fe, iron .....	Fe, by titration with permanganate
Al, aluminum .....	Al <sub>2</sub> O <sub>3</sub> by difference
Fe <sub>2</sub> O <sub>3</sub> } iron and alumi- Al <sub>2</sub> O <sub>3</sub> } num oxides	{ Fe <sub>2</sub> O <sub>3</sub> + Al <sub>2</sub> O <sub>3</sub>
Ca, calcium .....	CaO
Mg, magnesium .....	Mg <sub>2</sub> P <sub>2</sub> O <sub>7</sub>
SO <sub>4</sub> , sulphate .....	BaSO <sub>4</sub>
K, potassium .....	KCl and K <sub>2</sub> PtCl <sub>6</sub>
Na, sodium .....	NaCl and difference
Li, lithium .....	Spectroscope and Li <sub>2</sub> SO <sub>4</sub>
H <sub>2</sub> S, hydrogen sulphide .....	H <sub>2</sub> S, titration with iodine
CO <sub>3</sub> carbonates .....	CO <sub>3</sub> , titration with acid sulphate
HCO <sub>3</sub> , bicarbonates .....	HCO <sub>3</sub> , titration with acid sulphate
Cl, chloride .....	AgCl by titration with silver nitrate

Oxygen capacity ..... Titration with permanganate  
 Precipitated iron ..... Titration with permanganate

#### FORM OF REPORT

Following the scheme used in the older U. S. government bulletins, both the radicles and the hypothetical combinations are given in parallel columns in the present report. The amounts of the various constituents are reported in milligrams per liter. For a water not highly mineralized this is essentially equivalent to parts per million. In fact, in most published reports indicating parts per million the analyses were actually made on the basis of milligrams per liter. The following table shows the relations between the various units commonly used:

Milligrams per liter  $\times 0.0583$  = grains per U. S. gallon.  
 Milligrams per liter  $\times 0.07$  = grains per imperial gallon.  
 Milligrams per liter  $\times 0.0000833$  = avoirdupois pounds per U. S. gallon.

Milligrams per liter  $\div$  sp. gravity of mineral water = parts per million.

In calculating the "hypothetical combinations" the bases are taken in the order: lithium, potassium, sodium, magnesium, calcium, iron, aluminum, and are combined with the acid radicles in the order: chloride, sulphate, carbonate, bicarbonate, silicate.

Since the column of hypothetical combinations is calculated from the column of bases and acid radicles, it is well to show this fact by making the sums of the two columns equal. Obviously, the unavoidable errors of experiment will result in there being a small amount of base or acid radicle in excess of the theoretical amounts necessary in the hypothetical combinations. The scheme of calculating a part of the silica to silicates gives some leeway in adjusting the two columns to a balance, and where this does not permit the desired adjustment, the small excess of base or acid radicle has been neglected and the theoretical value used. The adjustment can usually be made in the bicarbonate, so that the agreement between theoretically required and experimentally determined amounts of bicarbonates furnishes a check upon the accuracy of the analysis. This adjustment to make the columns check is open to the criticism that it substitutes for an experimentally determined value a slightly different theoretical value. Undoubtedly this offers a temptation to patch up poor work, but it must be said on this point that the value of an analysis always depends upon the honesty as well as the skill of the chemist who makes it.

It is with considerable reluctance that the "hypothetical combinations" column is included in the reports. There are many arguments against this form of report, and some of these arguments are mentioned below, in the hope that they will help in giving those interested in water analyses a clear idea of the facts in the case. In spite of these arguments, it has seemed best to include this form of report parallel with that which indicates bases and acid radicles, for the reason that water analyses have long been reported in terms of these hypothetical combinations and those who make use of water analyses have long been familiar with reports in this form. To abandon the custom would lessen the usefulness of the analyses to those familiar only with the older form, and until a wider knowledge of chemistry obtains among laymen, and especially until our physicians have learned to interpret analyses reported in the newer form, it does not appear that the time is ripe to discard the scheme of "hypothetical combinations."

The custom of reporting water analyses in terms of "hypothetical combinations," is, however, a most unfortunate one. It implies that the chemist knows from his analysis which bases and acids are associated in a mineral water. Such is not the case. It is probable that the basic elements and acid radicles are associated to only a very small extent in so dilute a solution as a mineral water. In terms of the electrolytic dissociation theory in its simplest form, whenever a salt is put into aqueous solution the salt partly dissociates and there results an equilibrium between the undissociated part of the salt and the detached parts, or ions, as they are called. This state of affairs is usually represented in the following way:

$$\text{NaCl} \rightleftharpoons \overset{+}{\text{Na}} + \overset{-}{\text{Cl}}$$
 the double arrows indicating the reversible nature of the process and the + and - signs the kind of electrical charges on the ions.

As the solution is diluted, more and more of the salt dissociates into ions and at great dilution the salt is almost completely dissociated. This theory is strongly supported by a mass of experimental evidence and is accepted by most chemists. If the theory be true, the discussion of how the acid radicles and bases are combined in a mineral water is futile, and we should seek to express the therapeutic or other properties of a mineral water in relation to the ions which it contains, rather than hypothetical salts. Entirely aside from the fact that the practice of indicating the pres-

ence of certain salts in a mineral water runs counter to our best substantiated theory of solutions, the method of calculating hypothetical combinations is largely an arbitrary one. It is well known that if two salts, such as sodium chloride and potassium nitrate, are put together in solution, and the solution evaporated to dryness, not two, but four salts will be found in the residue, namely sodium chloride, potassium nitrate, potassium chloride and sodium nitrate. Similarly three such salts put together in solution will yield a residue containing nine salts, and in general  $n$  such salts, having different bases and acid radicles, will form  $n^2$  compounds between acid radicles and bases. In other words, every base will be found linked to every acid radicle, the amounts of the various salts formed depending upon a number of factors, the principal of which is the solubility of the individual salts in the presence of all the other salts.

It will be seen that residue from a mineral water containing say eight bases and five acid radicles will be much more complex than the hypothetical combinations would indicate. To be sure, some of the salts in the residue will be present in relatively large amounts and others in negligibly small amounts, but at best the residue will be a complex mixture of salts and will certainly not correspond, even approximately, to the hypothetical combinations.

One of the most frequently advanced arguments for reporting water analyses in hypothetical combinations is that these combinations aid the physician, and even the layman, in estimating the therapeutic value of the water. Here again the hypothetical combinations are likely to mislead. Most people are familiar with the medical value of magnesium sulphate, and would readily guess the effect of freely imbibing a water the analysis of which showed magnesium sulphate to be present. Suppose that we take a quart of pure water and add to it an ounce of crystallized magnesium sulphate. This solution would have decided medicinal properties. Suppose now that we add to said solution an ounce of sodium bicarbonate. The most characteristic property of the water will not have been affected in the least, but if this solution of the two salts be analyzed, and reported as hypothetical combinations, the analysis will not show the presence of magnesium sulphate at all, but of magnesium bicarbonate, a salt not familiar to the layman at least.

To sum up the objections to the practice of reporting analyses as hypothetical combinations: It is probable that the bases and

acid radicles are mostly free and not combined in the mineral water; on evaporating the water the residue obtained does not correspond to the hypothetical combinations; the calculation of the analytical results obtained to hypothetical combinations, which are largely fictitious, may frequently mask the real nature of the water so far as the average man, and often the physician, is able to interpret the analysis.

It is to be earnestly hoped that the engineer, the physician, the geologist, and all others who have occasion to interpret water analyses, will learn to dispense with the hypothetical combinations and to use the unmitigated results of the laboratory. The later U. S. government bulletins on water analysis report only the bases and acid radicles, and it is likely that this form of report, or one closely allied to it, will be generally adopted in the near future.

Chase Palmer, in his "Geochemical Interpretation of Water Analyses,"\* pleads for the use of "reaction capacities" obtained by dividing the weight of each radicle present by its respective combining weight. In chemical terminology, the elements and radicles are reported in gram equivalents instead of parts per million. This method of reporting analyses has a distinct advantage in that not only the quantity but the valence of each radicle and element is included in the values reported. This scheme has much to recommend it and may offer a satisfactory substitute for the hypothetical, or rather fictitious, combinations insisted upon by the physician and engineer especially.

#### ACCURACY OF EXPERIMENTAL WORK

Extreme analytical accuracy was not possible under the conditions imposed in this work. A moderate accuracy, with a sufficient number of checks on the work to preclude gross errors from creeping in, was maintained throughout. The determinations of sodium, potassium, calcium, magnesium, iron, aluminum, chloride, carbonate, bicarbonate, hydrogen sulphide and sulphate were made in duplicate. The average value was taken in each case if the duplicates checked closely; otherwise the determination was repeated. Silica, oxygen capacity, lithium, precipitated iron and evaporation solids were determined in single samples, and occasionally it was necessary to combine samples in determining sodium and potassium in order to avoid large percentage errors, because of the small amounts of these elements present.

Several chemists were engaged in the work at various times, a circumstance which usually decreases accuracy of results; but extreme familiarity with the various analytical steps involved was soon reached by all of them, and a skill was attained in the operations which the average chemist, who makes an occasional water analysis, does not possess.

By working with larger samples of water, the accuracy of certain determinations could have been increased and various constituents of the water, present in minute percentages, could have been determined. In this class fall manganese, phosphate, strontium, barium, arsenic, copper, etc. Determination of these elements would have increased greatly the dimensions of an analytical task already very large and the additional information secured would scarcely have justified the increased cost of the work.

Unfortunately the samples could not always be analyzed as soon as they reached the laboratory. It was rather necessary to complete the collecting during the summer months, both because of difficulty of travel at other times and because of the danger of breaking shipping bottles by freezing of samples during cold weather.

#### SAMPLE OF FORM FOR ANALYSES

No. 85.

Rate of flow: 12 to 15 gallons per minute from the tunnel

Temperature: 105 degrees Fahrenheit.

#### Analysis.

Formula and Name	Milligrams per Liter	Hypothetical Combinations	Milligrams per Liter
SiO <sub>2</sub> , silica	68.0	KCl, potassium chloride	Trace
SO <sub>4</sub> , sulphate	396.3	NaCl, sodium chloride	117.82
HCO <sub>3</sub> , bicarbonate	1513.8	Na <sub>2</sub> SO <sub>4</sub> , sodium sulphate	586.1
CO <sub>3</sub> , carbonate	None	Ca(HCO <sub>3</sub> ) <sub>2</sub> , calcium bicarbonate	561.4
PO <sub>4</sub> , phosphate	None	Fe <sub>2</sub> O <sub>3</sub> } iron and aluminum	
Cl, chloride	71.47	Al <sub>2</sub> O <sub>3</sub> } oxides	2.0
Fe <sub>2</sub> O <sub>3</sub> } iron and aluminum		CaSiO <sub>3</sub> , calcium silicate	19.05
Al <sub>2</sub> O <sub>3</sub> } oxides	2.0	SiO <sub>2</sub> , silica	58.13
Mn, manganese	None	Mg(HCO <sub>3</sub> ) <sub>2</sub> , magnesium bicarbonate	237.26
Ca, calcium	145.4	NaHCO <sub>3</sub> , sodium bicarbonate	1230.1
Mg, magnesium	39.43		
K, potassium	Trace		
Na, sodium	573.3		
Li, lithium	None		
Oxygen for SiO <sub>2</sub>	2.62		
	2812.32		
H <sub>2</sub> S, hydrogen sulphide	None	Evaporation solids	2045.
Oxygen capacity	0.55	Iron precipitated	2.38
Excess carbon dioxide	545.8		
Remarks:			

## GENERAL DISCUSSION OF MINERAL WATERS

### I. CLASSIFICATION

Most of the mineral waters of Colorado are to be classed as alkaline-saline, there being a few which would be classed as alkaline and a few as saline under the Peale scheme of classification.<sup>1</sup>

Amongst those which are typically alkaline may be mentioned Nos. 167 and 168 on Plateau Creek, and Nos. 171, 172 and 173, east of Phippsburg. Nos. 147 and 150, and springs Nos. 97, 98 and 99, of the Juniper group, have but little saline constituents.

Those which are typically saline are Nos. 37, 157 and 166. No. 67 and several of the springs of the Glenwood group are very high in saline constituents and low in alkaline. The alkaline-saline class includes, as said, most of the springs, but the constituents of the springs in this group range between very wide limits, giving a great variety of waters, as is shown by the analyses.

### II. TEMPERATURE OF THE MINERAL SPRINGS

In the table below, the springs are grouped under temperature intervals of ten degrees and in Fig. I the data of the table are shown graphically. Of course, the number of samples taken in each group of springs will affect the distribution curve, but in two hundred analyses this factor will not be of great weight, and the curve represents fairly well the grouping of the springs with regard to temperature.

<sup>1</sup>Mineral Waters of the United States, Fourteenth Annual Report, Part II. U. S. Geol. Survey, 1892-3.



TEMPERATURE OF SPRINGS, FAHRENHEIT	Number of Springs
180°-190°	142
170°-180°	.....
160°-170°	246 251
150°-160°	157 175 176 245
140°-150°	162 177 215 238
130°-140°	10 71 136 144 145 174 160 234
120°-130°	7 18 54 55 58 60 61 63 143 186 230 235 236
110°-120°	5 8 56 57 79 80 82 82 179
100°-110°	2 21 62 81 83 85 97 98 100 104 124 136 212
90°-100°	20 78 152 153 182 229 252
80°-90°	29 36 38 45 46 50 60 183 191
70°-80°	4 30 51 52 53 141 189 190 199 204 211 213 214 216 216 222
60°-70°	8 22 23 27 27 66 69 73 74 75 87 102 108 116 117 119 122 127 129 130 135 166 167 168 173 180 181 200 201 202 203
50°-60°	134 147 148 150 161 163 164 169 170 171 172 186 192 194 205 207 210 218 227 228
40°-50°	1 6 11 12 13 24 28 33 35 37 39 41 43 44 65 84 86 86 96 99 101 103 105 106 107 109 111 112 115 118 120 121 123 124 126 128 131

Temperature, Fahrenheit.

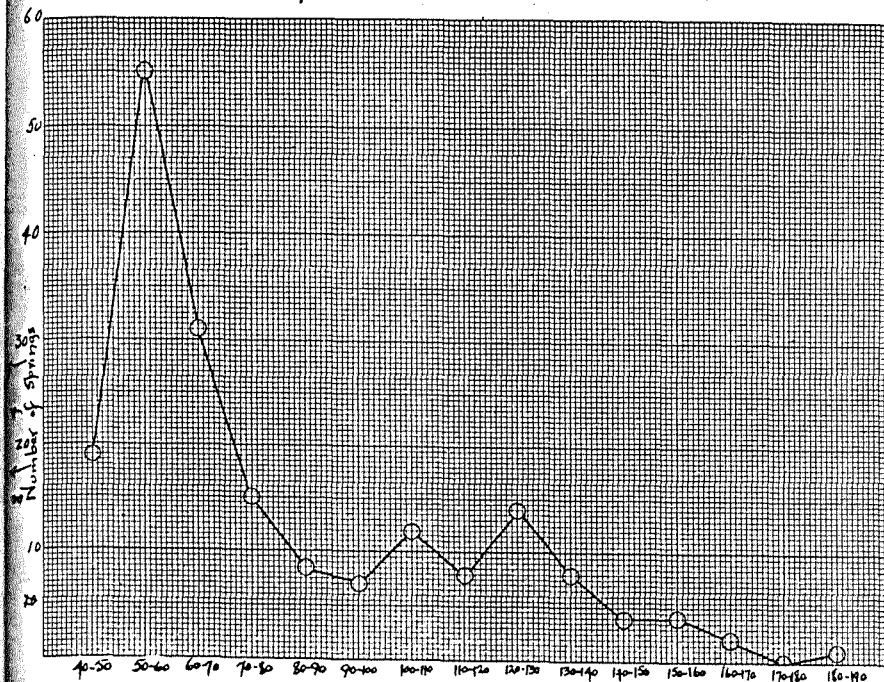


Fig. I

III. MINERALIZATION OF THE SPRINGS

In the following table the springs are grouped on the basis of the amount of mineral matter in the water, as indicated under "Evaporation Solids" in the analyses. It will be noted that of the 202 springs listed 86.44% have a mineral content of less than 4000 milligrams per liter. The spring at the old salt works in South Park stands highest with 31,166 milligrams per liter, next come the Glenwood Springs group, ranging from 13,772 to 23,246 milligrams per liter, two springs on the Gunnison River near Austin, two springs on the Grand River below Dotsero, and Hodge's Spring.

A number of the springs listed in the first column of the table are so low in minerals as not to be properly classed as mineral springs. In a few cases, however, the nature of the mineral matter present is such as to make the water valuable in spite of its low mineral content.

MINERALIZATION OF SPRINGS, IN PARTS PER MILLION	
0-500	18 29 30 32 33 34 38 40 52 53 72 102 104 106 107 108 109 110 119 142 143 144 145 146 147 148 152 153 173 178 182 205 206 252 33
500-1000	31 41 56 57 96 115 116 136 140 148 160 164 167 170 171 172 174 175 176 177 178 189 193 194 195 197 199 202 203 212 216 238 245 246 251 33
1000-1500	20 21 27 42 44 78 79 80 81 82 83 84 87 97 98 99 103 105 112 113 134 149 156 166 180 181 182 183 185 189 188 190 227 228 230 235 34
1500-2000	6 11 13 28 36 37 70 86 88 117 118 120 124 128 131 135 141 144 157 167 184 186 198 232 234 236 19
2000-2500	2 9 12 39 71 85 113 121 122 124 128 131 135 141 196 201 204 218 232 233 18
2500-3000	5 7 8 10 68 127 129 130 161 162 165 169 191 203 210 213 14
3000-3500	23 73 100 111 123 126 130 160 162 164 199 200 207 13
3500-4000	1 22 50 51 65 74 75 208 209 223 10
4000-4500	37 1 1
4500-5000	66 101 2
5000-5500	214 219 2
5500-6000	216 217 220 222 4
6000-10000	24 24 35 211 231 166 5
10000-20000	3 4 45 46 54 58 59 60 62 65 66 10
20000-30000	55 61 62 3
Over 30000	67

## IV. SILICA CONTENT

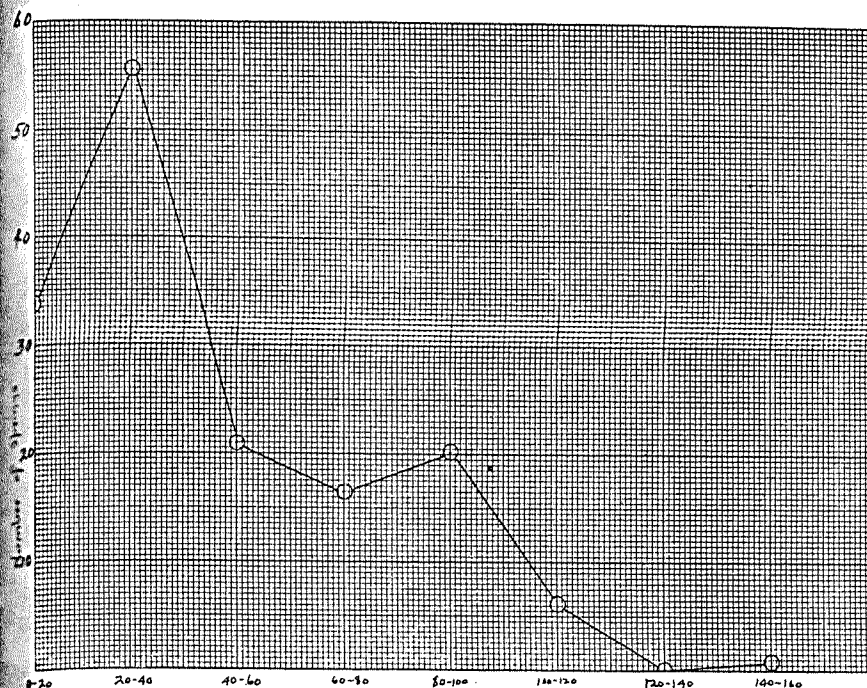
Each of the 202 waters analyzed contained silica, the amount varying from seven or eight milligrams per liter to more than a hundred. No. 160 has the highest silica content, 160.2 milligrams per liter. Others high in silica are Nos. 171, 199, 200, 203 and 251. In the following table the springs are grouped in the various columns according to their silica content, and in Fig. III these data are shown graphically.

Table II

SILICA CONTENT IN PARTS PER MILLION

0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160
6	1	2	5	7	171		160
25	3	12	10	8	199		
28	4	13	35	9	200		
31	11	20	39	10	203		
33	21	57	65	24	251		
40	22	58	66	38			
41	23	59	85	62	5		
46	29	61	86	67			
52	30	71	96	140			
53	32	75	104	165			
69	34	87	118	172			
70	36	102	130	175			
73	37	111	131	176			
84	43	113	142	181			
105	44	117	144	191			
106	45	126	145	207			
107	50	127	162	208			
108	51	128	177	209			
109	54	129	180	210			
110	55	136	182	211			
115	56	143	183	215			
119	60	157	235	229			
134	63	174		234			
135	68	196	22	236			
146	72	198		238			
147	74	201		245			
167	78	206		246			
173	79	212					
178	80						
184	81	28		27			
185	82						
186	83						
187	97						
188	98						
189	99						
190	100						
192	101						
193	103						
194	112						
195	116						
213	120						
227	121						
228	122						
232	123						
233	124						
	141						
	148						
	149						
	150						
	152						
	153						
	154						
	156						
	161						
	163						
	164						
	166						
	168						
	169						
	170						
	197						
	202						
	204						
	205						
	214						
	216						
	217						
	218						
	219						
	220						
	221						
	222						
	230						
	252						
	74						

Table III



Silica Content in parts per million  
Fig. III

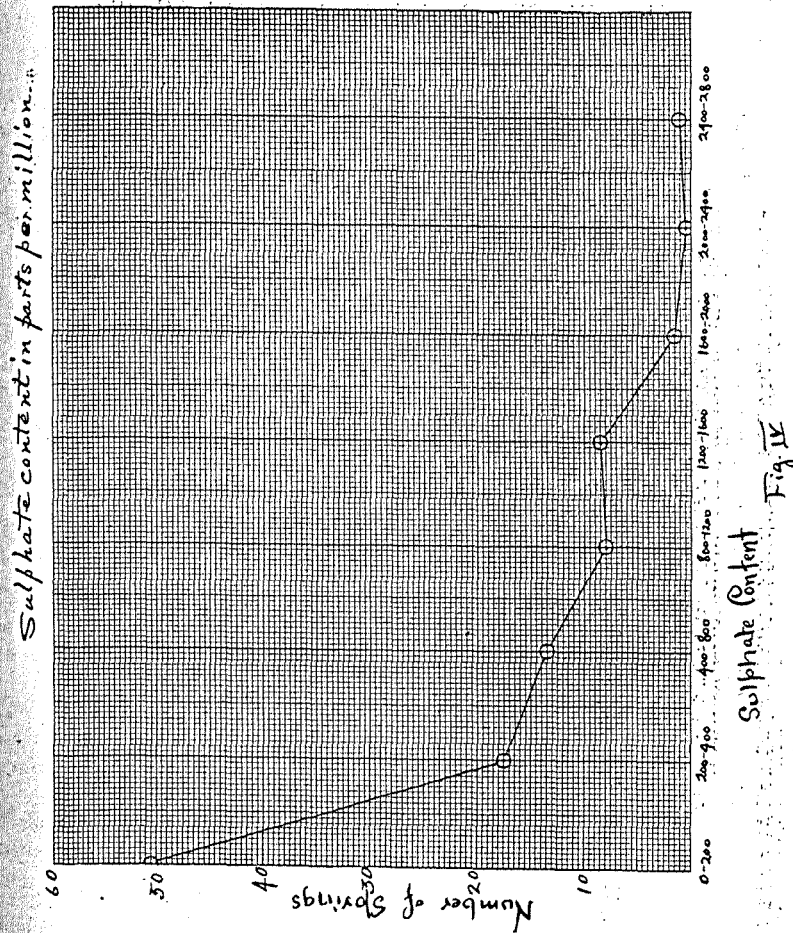
V. SULPHATE CONTENT

In the following table the springs are grouped according to sulphate content. It will be noted that sulphate is present in all the waters, the amount varying from a few milligrams per liter up to 2700 milligrams per liter. It is to be noted that 50% of all the mineral waters analyzed have less than 200 milligrams per liter of sulphate, and that only a few have more than 1600 milligrams per liter. Calcium sulphate is found crystallizing out about a number of the mineral springs. The sulphate content of a water is of importance therapeutically because of the purgative effect of sulphates.

SULPHATE CONTENT IN PARTS PER MILLION

0-200		200-400	400-800	800-1200	1200-1600	1600-2000	2000-2400	2400-2800
18	124	13	12	5	2	1	61	62
21	131	27	20	10	7	3	1	67
22	136	28	37	11	6	4		2
23	140	35	45	54	8	3		
24	142	36	46	55	9			
25	143	43	50	58	160			
30	144	44	51	59	162			
31	145	68	60	63	164			
32	146	71	75	74	169			
33	147	73	96	135	196			
34	148	84	134	157	207			
38	150	85	151	161	108			
39	152	86	156	163	209			
40	153	87	166	165	210			
41	167	103	187	191	229			
52	168	117	188	227	232			
53	170	118	190	227	233			
56	171	123	211	16				
57	172	126	214		17			
65	173	127	216					
66	175	128	217					
69	176	129	219					
70	178	130	220					
72	180	141	221					
78	181	149	222					
79	182	174	228					
80	183	177	230					
81	185	184						
82	192	186						
83	193	189	27					
97	194	197						
98	195	204						
99	198	213						
100	199	218						
101	200	234						
102	201							
104	202	35						
105	203							
106	205							
107	206							
108	212							
109	215							
110	235							
111	236							
112	238							
113	245							
115	246							
116	251							
119	252							
120								
121	101							
122								

Table IV



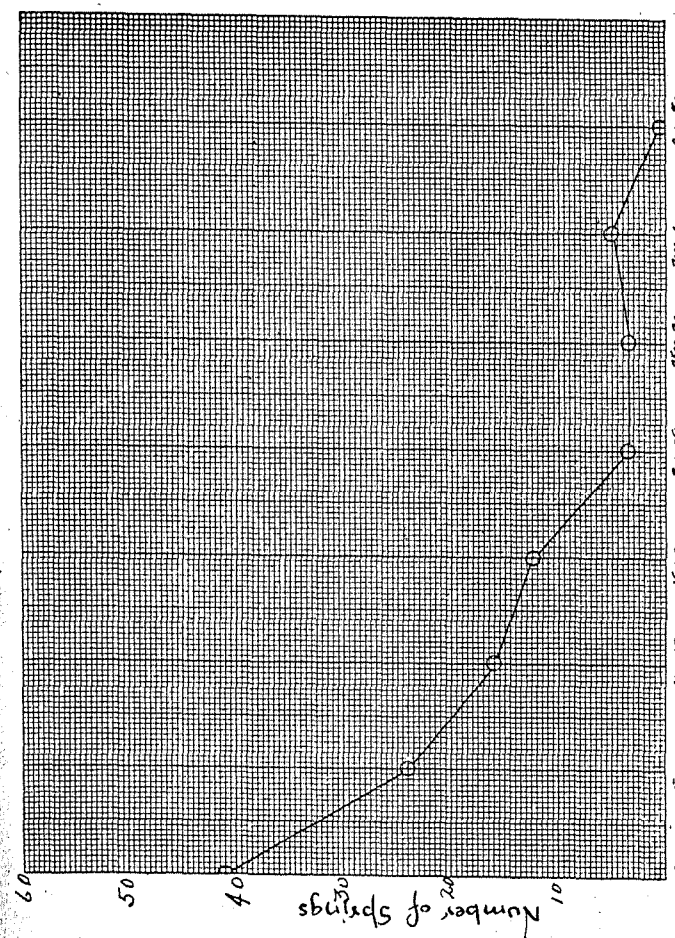
## VI. BICARBONATE CONTENT

In the following table the waters are grouped on the basis of bicarbonate content. All the mineral waters analyzed contain bicarbonate, the amount varying between wide limits, as will be noted in the table.

## BICARBONATE CONTENT IN PARTS PER MILLION

0-500		500-1000		1000-1500	1500-2000	2000-2500	2500-3000	3000-4000	4000-5000
2	152	1	198	12	22	101	66	3	
6	153	5	202	13	23	121	126	24	4
9	154	7	210	28	39	122	127	35	
11	156	8	235	36	69	123	128	65	1
13	157	10		50	73	129	130	211	
29	166	20	48	51	75	199	219	214	
30	169	21		74	85	200	222	216	
31	173	27		86	118			217	
32	174	41		98	120	7	7	220	
33	175	42		99	124			221	
34	176	44		100	141				
37	177	54		111	171				
38	178	59		113	172			10	
40	187	60		117	203				
45	188	61		131	218				
46	189	62		149					
52	190	63		165	15				
53	192	78		180					
55	196	79		181					
56	197	80		182					
57	205	81		183					
58	206	82		184					
67	212	83		186					
68	213	84		191					
70	215	87		201					
71	227	97		204					
72	228	103		207					
96	230	105		208					
102	232	112		209					
104	233	115		229					
106	238	148		234					
107	245	150		236					
108	246	160							
109	251	161		32					
110	252	162							
116		163							
119	82	164							
134		167							
135		168							
136		170							
140		185							
142		193							
143		194							
144		195							
145									
146									
147									

Table V

Bicarbonate Content in parts per million  
FIG. V.

## VII. CARBONATE CONTENT

Only a few of the mineral waters analyzed contained normal carbonates. No. 18 contains 8.21 milligrams per liter; No. 212 contains 11.73 milligrams per liter; and No. 215 contains 4.69 milligrams per liter. It is to be noted that these three are hot springs, the temperatures being 120, 104 and 148 deg. F. It is also to be noted that the presence of normal carbonates is associated with a low calcium content. The three springs named above show calcium contents of 4.65, 20.76 and 7.58 milligrams per liter.

Several other springs contain traces of normal carbonates. These are Nos. 38, 70, 73, 115, 116, 145, 146, 170, 206 and 251. Of these springs only one has a calcium content of more than 30 milligrams per liter.

VIII. CHLORIDE CONTENT

Chloride is present in every mineral water analyzed, the amounts varying between wide limits. Table VI shows the grouping of the springs on the basis of chloride content, and these data are represented graphically in Fig. VI.

CHLORIDE CONTENT IN PARTS PER MILLION

Spring No.	Chloride Content (ppm)	Group
1	144	0-200
2	145	0-200
6	146	0-200
11	147	0-200
18	148	0-200
20	149	0-200
21	150	0-200
27	152	0-200
28	153	0-200
29	154	0-200
30	156	0-200
31	157	0-200
32	162	0-200
33	163	0-200
34	164	0-200
35	167	0-200
36	168	0-200
38	169	0-200
40	170	0-200
41	171	0-200
43	172	0-200
44	173	0-200
52	174	0-200
53	175	0-200
56	176	0-200
69	177	0-200
72	178	0-200
78	180	0-200
79	181	0-200
80	182	0-200
81	183	0-200
82	184	0-200
83	185	0-200
84	186	0-200
85	187	0-200
86	188	0-200
87	189	0-200
96	190	0-200
97	191	0-200
98	192	0-200
99	193	0-200
102	194	0-200
103	195	0-200
104	196	0-200
105	197	0-200
106	202	0-200
107	205	0-200
108	208	0-200
109	207	0-200
110	208	0-200
115	209	0-200
116	210	0-200
118	215	0-200
119	227	0-200
120	228	0-200
121	230	0-200
122	232	0-200
124	233	0-200
131	238	0-200
134	245	0-200
135	246	0-200
136	251	0-200
140	252	0-200
141		0-200
142	129	0-200
143		0-200
5	70	200-400
7	73	200-400
8	74	200-400
9	75	200-400
10	113	200-400
12	119	200-400
13	200	200-400
39	203	200-400
57	213	200-400
112	218	200-400
117		200-400
123	10	200-400
125		200-400
127		200-400
128		200-400
129		200-400
130		200-400
160		200-400
161		200-400
165		200-400
172		200-400
201		200-400
204		200-400
212		200-400
229		200-400
234		200-400
235		200-400
236		200-400
28		200-400
23	23	400-800
24	24	400-800
50	51	400-800
66	68	400-800
71		400-800
100		400-800
111		400-800
211		400-800
214		400-800
216		400-800
217		400-800
219		400-800
220		400-800
221		400-800
222		400-800
18		400-800
22	22	800-1600
23	23	800-1600
24	24	800-1600
51	51	800-1600
66	66	800-1600
68	68	800-1600
71	71	800-1600
100	100	800-1600
111	111	800-1600
211	211	800-1600
214	214	800-1600
216	216	800-1600
217	217	800-1600
219	219	800-1600
220	220	800-1600
221	221	800-1600
222	222	800-1600
18	18	800-1600
37	37	1600-3200
101	101	1600-3200
3	3	1600-3200
45	45	3200-6400
46	46	3200-6400
48	48	3200-6400
55	55	3200-6400
56	56	3200-6400
57	57	3200-6400
58	58	3200-6400
59	59	3200-6400
60	60	3200-6400
61	61	3200-6400
62	62	3200-6400
63	63	3200-6400
8	8	3200-6400
55	55	6400-12800
56	56	6400-12800
57	57	6400-12800
58	58	6400-12800
59	59	6400-12800
60	60	6400-12800
61	61	6400-12800
62	62	6400-12800
63	63	6400-12800
8	8	6400-12800
1	1	Above 12800

Chloride content in parts per million

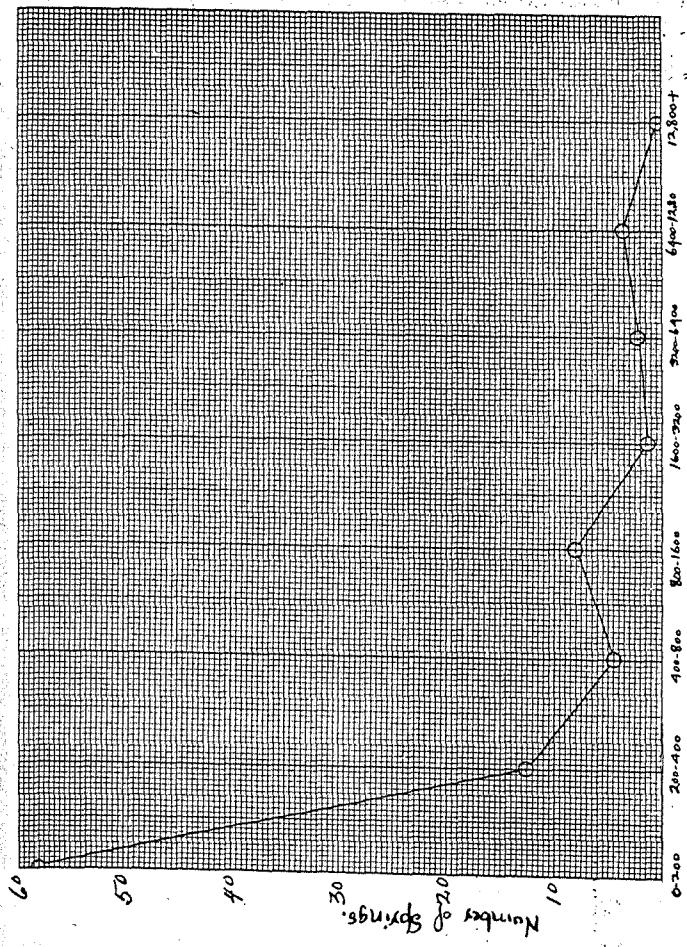


Fig. VI. Chloride Content

Table VI

IX. IRON AND ALUMINUM OXIDES

In the table below, the springs are grouped on the basis of their iron and aluminum content. For this purpose the "iron precipitated" has been calculated to the oxide and added to the "iron and aluminum oxides."

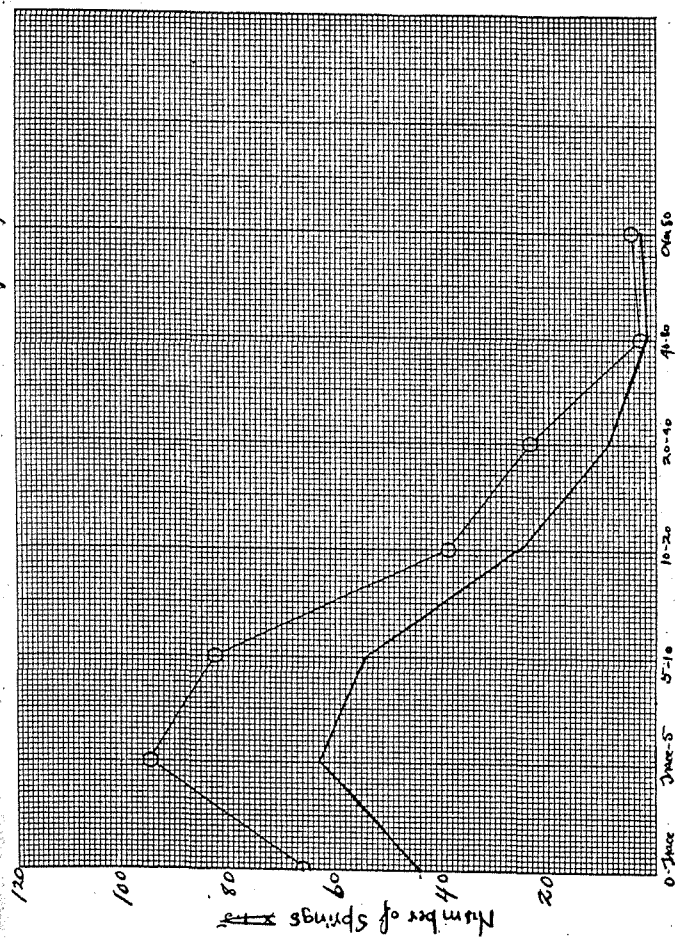
It is to be noted that there are not many springs in Colorado properly to be classed as iron springs, although nearly every spring contains a little iron.

IRON AND ALUMINUM OXIDES IN PARTS PER MILLION

0-Trace	Trace-5	5-10	10-20	20-40	40-80	Over 80
3	1	10	9	7	41	33
4	2	29	24	8	157	86
5	12	31	28	35		96
6	13	45	37	39	2	205
11	20	65	46	67		
18	23	68	51	75		4
21	27	73	60	191		
22	32	74	66	227		
30	38	78	104			
34	40	79	111	9		
36	43	80	112			
50	44	85	113			
54	52	87	118			
55	53	103	123			
57	56	106	135			
58	62	117	150			
59	63	121	162			
61	69	126	166			
70	71	127	173			
72	81	128	184			
99	82	129	186			
100	83	131	192			
101	84	134	198			
102	97	146	211			
110	98	147	216			
119	105	148	235			
120	107	152				
142	108	153	26			
143	109	160				
144	115	161				
145	116	171				
154	122	172				
163	124	180				
164	130	181				
165	136	182				
167	140	183				
168	141	185				
169	149	187				
170	156	189				
193	174	190				
197	175	194				
200	176	209				
201	177	210				
234	178	213				
	188	218				
44	195	219				
	196	220				
	199	228				
	202	229				
	203	230				
	204	232				
	206	233				
	207	236				
	208	251				
	212	252				
	214					
	215	55				
	217					
	221					
	222					
	237					
	245					
	246					

Table VII

Iron and Aluminum Oxides in parts per million.



Iron and Aluminum Oxides  
Fig. VII.

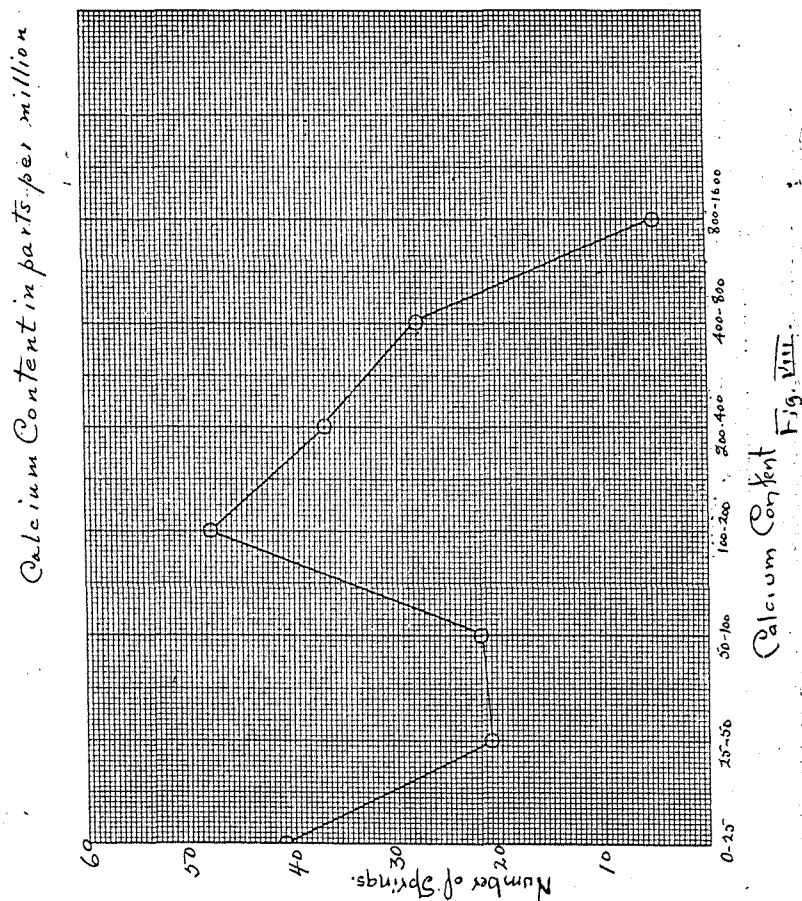
X. CALCIUM CONTENT

Calcium is present in all the mineral waters analyzed, the amount varying from a few milligrams per liter to more than 1300 milligrams per liter. The water from a number of springs is so high in both calcium and sulphate as to be saturated with calcium sulphate, which salt separates in clear, needle shaped crystals when the water stands exposed to air for a short time. In Table VIII and Fig. VIII the springs are grouped with regard to calcium content.

**CALCIUM CONTENT IN PARTS PER MILLION**

0-25	25-50	50-100	100-200	200-400	400-800	800-1600	Over 1200
18	4	3	11	7	1	61	166
33	32	29	12	8	2	62	
38	34	30	13	9	5	67	1
40	53	44	20	10	6	130	
52	56	71	21	45	35	166	
57	70	73	22	46	37		
69	72	87	23	58	50	5	
78	82	101	24	60	51		
79	84	112	27	66	54		
80	100	119	28	96	55		
81	105	140	31	117	59		
83	106	141	36	120	63		
97	107	147	39	124	65		
98	108	152	41	135	121		
99	109	187	43	149	122		
102	136	197	68	154	123		
104	148	202	74	156	126		
110	153	219	75	157	127		
115	178	234	85	160	128		
116	188	235	86	161	129		
142	205	236	103	162	131		
143		252	111	163	191		
144	21		113	164	207		
145		22	118	169	208		
146			134	171	209		
167			150	172	229		
168			165	184	232		
170			180	190	233		
173			181	193			
174			482	194	28		
175			183	195			
176			185	196			
177			186	199			
189			192	200			
206			198	210			
212			201	227			
215			203	230			
238			204				
245			211				
246			213				
251			214				
			216				
			217				
			218				
			220				
			221				
			222				
			228				
			48				

Table VIII





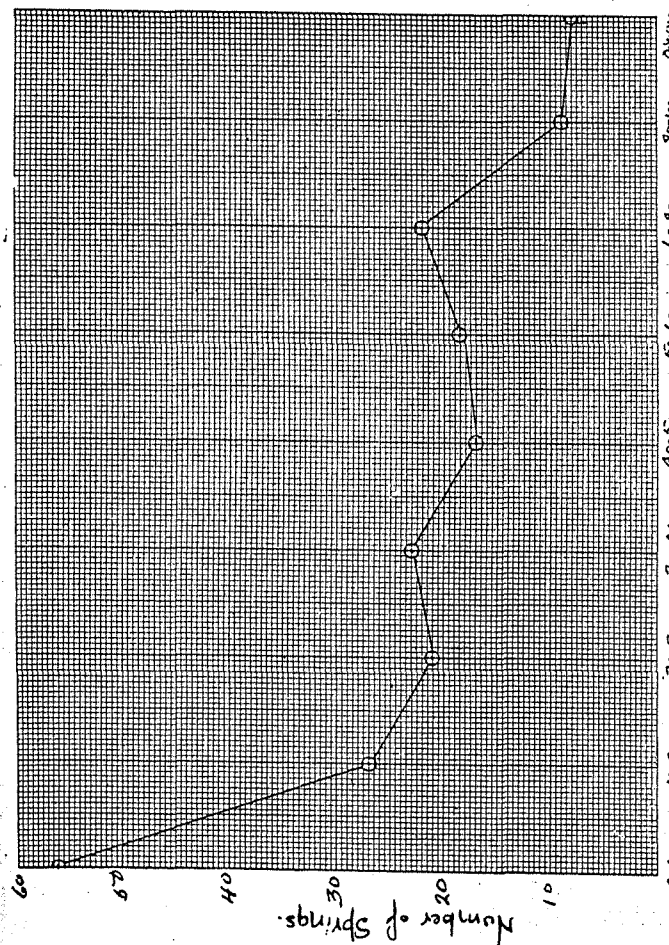
XI. MAGNESIUM CONTENT

Magnesium is present in nearly all the mineral waters analyzed. The amount ranges from only a trace to 112 milligrams per liter. In Table IX and Fig IX the springs are grouped according to magnesium content.

MAGNESIUM CONTENT IN PARTS PER MILLION

0-10	10-20	20-30	30-40	40-50	50-60	60-80	80-100	Over 100
2	32	13	28	9	3	1	35	24
18	41	29	50	10	4	20	54	62
33	43	30	51	11	5	27	55	65
34	44	53	56	12	6	45	58	66
37	70	71	60	22	7	46	59	74
38	72	87	68	31	8	61	67	123
40	84	101	69	73	21	63	75	169
52	100	119	85	117	23	111	149	171
57	103	150	112	163	36	121	172	
78	105	160	118	181	39	122		
79	131	184	129	182	113	126	9	
80	136	188	141	186	120	127		
81	140	195	161	197	124	128		
82	147	196	164	204	134	130		
83	152	198	190	208	180	135		
86	153	202	201	209	183	191		
96	157	216	207	229	213	199		
97	162	219	210		218	200		
98	165	222	211	17	232	203		
99	185	230	214			227		
102	187	252	217		19	228		
104	189		220			233		
106	192	21	221					
107	193							
108	234		23					
109	235							
110	236							
115								
116	27							
142								
143								
144								
145								
146								
148								
154								
156								
166								
167								
168								
170								
173								
174								
175								
176								
177								
178								
194								
205								
206								
212								
215								
238								
245								
246								
251								

Table IX



Magnesium Content in parts per million  
Fig IX.

XII. ALKALI METALS

In the next table the springs are grouped on the basis of the combined sodium, potassium and lithium content. For the purpose of this discussion this is better than a grouping based on either sodium or potassium because of the errors which are liable to be made in separating these metals.

ALKALI METALS IN PARTS PER MILLION

0-200	200-400	400-800	800-1600	1600-3200	3200-6400	6400-12800
2	215	5	1	22		
6	227	20	7	23	24	54
18	228	27	8	23	65	55
21	230	36	8	35	101	59
29	232	41	9	66	211	61
30	233	43	10	69	214	62
31	238	57	11	73	216	63
32	245	87	12	74	217	67
33	246	97	13	75	219	
34	251	103	28	100	220	7
38	252	112	37	111	221	
40		115	39	160	222	
52	71	116	44	162		
53		120	50	165	11	
56		121	51	166		
72		122	68	199		
96		148	70	200		
102		167	71	203		
104		168	78			
106		169	79	17		
107		170	80			
108		175	81			
109		177	82			
110		180	83			
119		181	84			
130		182	85			
131		182	86			
134		183	88			
135		185	98			
136		187	99			
140		188	105			
142		188	113			
143		189	117			
144		212	118			
145		123	123			
146	32	124	124			
147		126	126			
149		127	127			
150		128	128			
152		129	129			
153		141	141			
154		161	161			
156		163	163			
157		164	164			
171		184	184			
172		186	186			
173		196	196			
174		198	198			
176		201	201			
178		204	204			
190		207	207			
191		208	208			
192		209	209			
193		210	210			
194		213	213			
195		218	218			
197		229	229			
202		234	234			
205		235	235			
206		236	236			
		58				

TABLE X

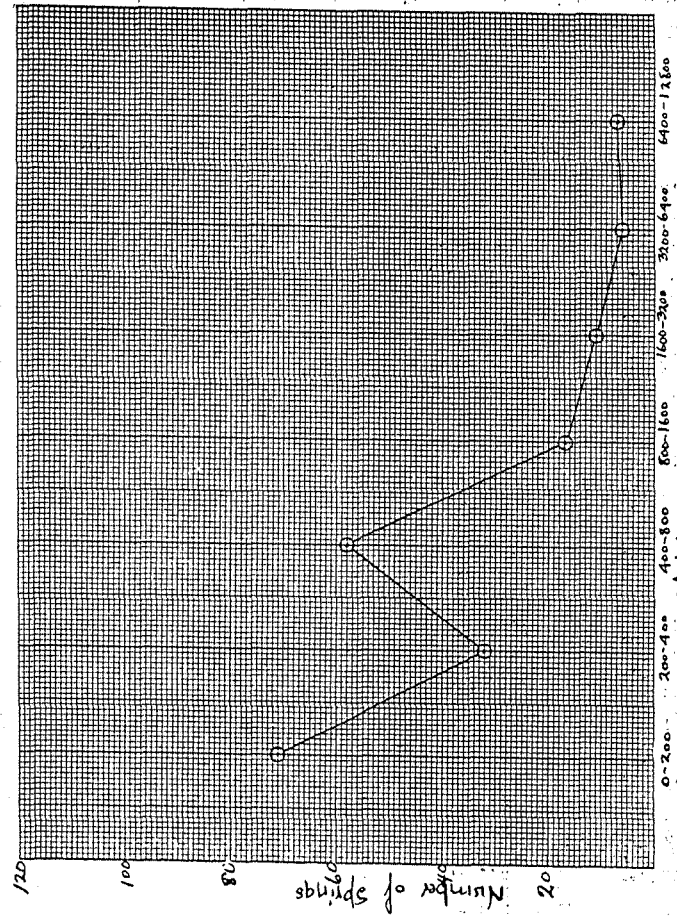


Fig. X

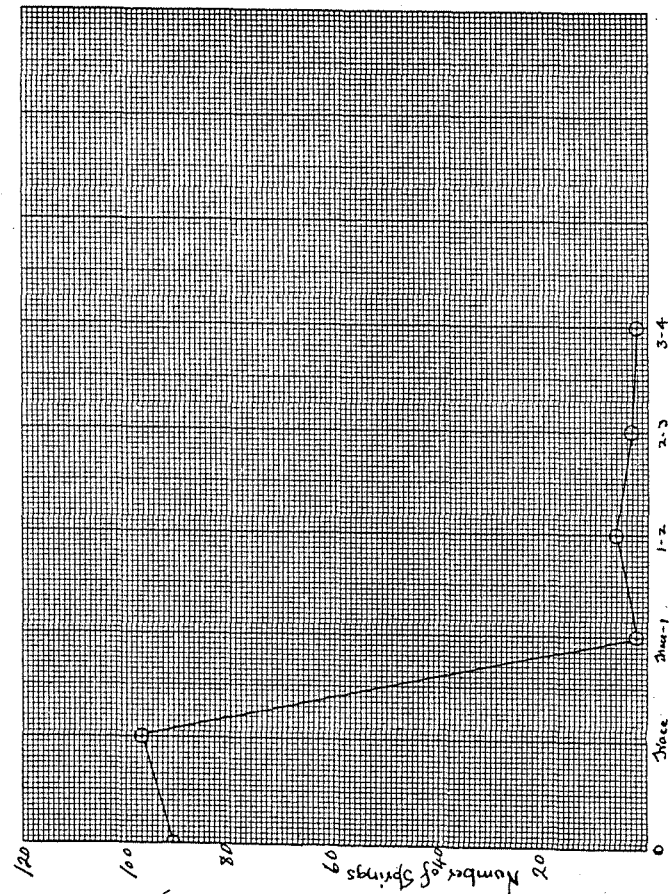
## XIII. LITHIUM CONTENT

By means of the spectroscope the presence of lithium was noted in 111 of the waters analyzed. In only twelve waters, however, did the lithium spectrum appear bright enough to warrant the separation of the lithium. Since the amount separated amounted, in some cases, to less than one milligram per liter, it is safely assumed that where a trace of lithium is reported the amount present is not more than one milligram per liter.

LITHIUM CONTENT IN PARTS PER MILLION

None	Trace	Trace-1	1-2	2-3	3-4	Not det.
2	148	1	123			
6	149	3	124			
8	150	4	126			
11	152	5	127			
24	153	7	128			
29	154	9	129			
30	166	10	130			
31	167	12	131			
32	168	13	136			
33	169	18	141			
34	170	20	142			
38	173	21	144			
40	174	22	145			
45	175	23	156			
46	176	27	161			
52	177	28	171			
53	178	35	172			
54	181	36	180			
55	192	37	182			
56	193	39	183			
57	194	41	184			
58	195	43	185			
59	197	44	186			
60	205	65	187			
61	206	66	188			
62	207	69	189			
63	208	70	190			
67	209	71	191			
68	210	72	196			
83	212	73	198			
85	213	74	199			
86	214	75	200			
87	215	78	201			
96	218	79	202			
98	227	80	203			
99	232	81	204			
102	233	82	211			
104	238	84	216			
110	245	97	217			
115	246	100	219			
116	252	101	220			
119	91	105	221			
120		107	222			
121		108	228			
134		109	230			
135		112	236			
140		113	251			
143		117				
146		118				
147		122				

TABLE XI



Lithium Content in parts per million

Lithium Content. Fig. XI.

XIV. HYDROGEN SULPHIDE CONTENT

In Table XII and Fig. XII the springs are grouped on the basis of the hydrogen sulphide content. It is to be noted that sixty-four springs in Colorado contain more than a trace of hydrogen sulphide and that a number of them are highly sulphureted.

HYDROGEN SULPHIDE

	None	Trace	Trace-1	1-5	5-10	10-20	20-40	40-80
1	134	20	99	31	10	3	107	73
2	135	38	123	32	58	79	108	74
4	136	39	190	54	78	81	115	75
5	140	101	235	55	80	82	116	84
6	141	147	238	56	98	83	170	105
7	142	167	245	57	129	164	219	
8	143	211	246	59	160	214	221	5
9	144	212		60	161	216	222	
11	145		7	61	163	217		
12	146	8		62		220	8	
13	150			63	9			
18	152			69		10		
21	153			86				
22	154			97				
23	156			100				
24	157			148				
25	166			149				
28	168			162				
29	169			165				
30	171			206				
33	172			232				
34	173			233				
35	174			234				
36	175			236				
37	176			251				
40	177							
41	178			25				
43	180							
44	181							
45	182							
46	183							
50	184							
51	185							
52	186							
53	187							
65	188							
66	189							
67	191							
68	192							
70	193							
71	194							
72	195							
85	196							
87	197							
86	198							
102	199							
103	200							
104	201							
106	202							
109	203							
110	204							
111	205							
112	207							
113	208							
117	209							
118	210							
119	213							
120	215							
121	218							
122	227							
124	228							
126	229							
127	230							
128	252							
130								
131	130							

TABLE XII

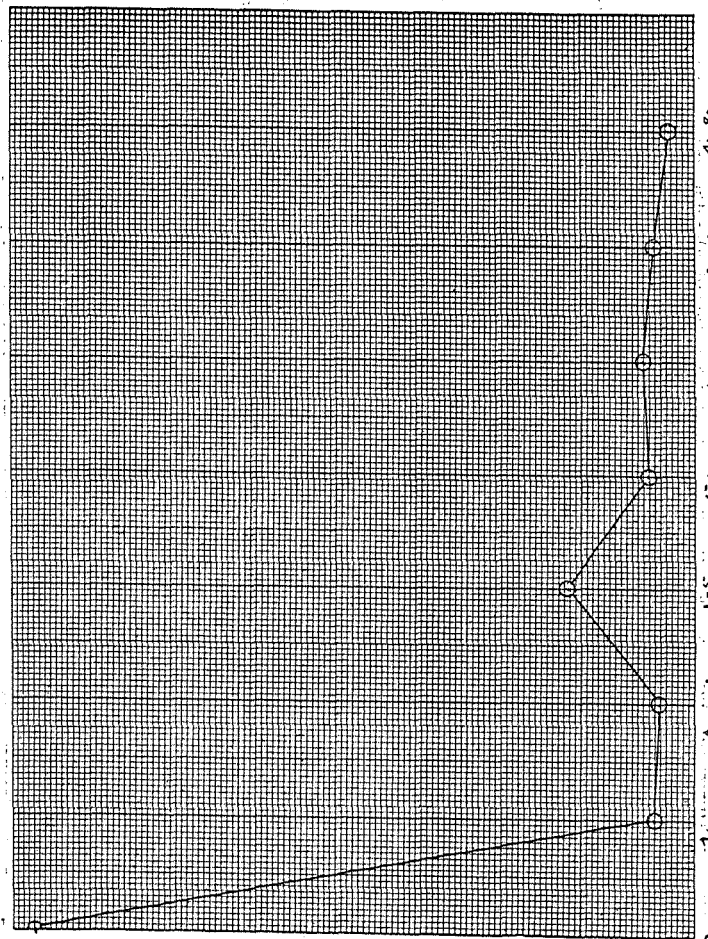


Fig. XII

Number of Springs (x 0.9)

Hydrogen Sulphide

SUMMARY OF GROUPINGS BY NOTABLE FEATURES

Very Large Flow	High Temperature	High Mineralization	High in Silica	High in Sulphate
No. 162, Big Pagosa Spring No. 102, McIntyre Spring No. 45, Big Dotsero Spring No. 29, Ranger's Spring on Cement Creek No. 55 } In Glenwood No. 59 } Group No. 212 } In No. 214 } Steamboat No. 222 } Group No. 53, Rhodes' Spring No. 234, Boiling Spring at Wagon Wheel Gap No. 152 } At No. 153 } Orient No. 252, Wellsville No. 146 Hayes Spring	No. 142, Hortense Hot Springs No. 246 } Waunita No. 245 } Group No. 251 } No. 238 } No. 157 at Ouray No. 175 } No. 176 } Poncha No. 177 } Group No. 162 of Pagosa Group No. 215 of Steamboat Springs	No. 67 at old Colorado Salt Works, So. Park. No. 55 } No. 54 } No. 58 } No. 59 } No. 60 } Glenwood No. 61 } Group No. 62 } No. 63 } No. 3 } Near No. 4 } Austin No. 45 } Near No. 46 } Dotsero No. 65, Hodges Spring	No. 160 of the Pagosa Group No. 171 Scott's Spring No. 199 } Red No. 200 } Creek No. 203 } Springs No. 251 of the Waunita Group	No. 62 } of the Glen-wood Group No. 61 } No. 67 at old Colorado Salt Works, So. Park. No. 1, Golden Lithia Water. No. 3 } Near No. 4 } Austin

High in Bicarbonate	High in Chloride	High in Iron and Aluminum	High in Calcium	High in Magnesium
No. 4 } Near No. 3 } Austin No. 24 on Grape Creek No. 35, east of Crisman No. 65, Hodges' Spring No. 211 } No. 214 } In No. 216 } Steamboat No. 217 } Springs No. 220 } Group No. 221 }	No. 67 at old Colorado Salt Works, So. Park. No. 54 } No. 55 } No. 58 } No. 59 } In No. 60 } Glenwood No. 61 } Group No. 62 } No. 63 } No. 4, near Austin No. 45 } Near No. 46 } Dotsero No. 65, Hodges' Spring No. 166, Strontia Springs	No. 33, Iron Spring near Crested Butte. No. 205, Mineral Creek Spring near Silverton. No. 96, Ironton Park Spring. No. 41, on Soda Creek, near Dillon. No. 157, Pavilion Spring at Ouray.	No. 166, Strontia Spgs. No. 67, old Salt Works No. 130 in the Manitou Group No. 61 } In Glenwood No. 62 } Group	No. 24 on Grape Creek No. 62 of the Glen-wood Group. No. 65, Hodges' Spring No. 66 near Guffey No. 74 of the Doughty Group. No. 123 of the Manitou Group No. 169 on Plateau Creek No. 171, Scott's Spring

High in Alkali Metals	High in Lithium	High in Sulphur	Miscellaneous
No. 54 } No. 55 } No. 59 } All these in No. 61 } the Glenwood No. 62 } Group No. 63 } No. 67 at the old Colorado Salt Works in So. Park.	No. 50 in Pinkerton Group No. 160 } No. 162 } These four No. 163 } in the Pa- No. 164 } gosa Group No. 165 at Placerville No. 157 at Ouray No. 111 near Leadville No. 229 near Trimble No. 234 } Wagon Wheel No. 235 } Gap.	No. 73—61.0 mg. per L. No. 74—51.1 mg. per L. No. 75—59.3 mg. per L. The above three are all from the Doughty Group. No. 84—61.09 mg. per L. Near Hygiene. No. 105—77.95 mg. per L. Mack Spring.	

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*Note*

I wished to comply with the request of Professor Curtis that he be permitted to read the proof of his part of the report, but I regret that the urgency for immediate action in the printing of the report made this impossible.

R. D. GEORGE.

## CHAPTER VIII

## RADIOACTIVITY

BY O. C. LESTER

## INTRODUCTION

At the present time there is a widespread popular interest in radium and in radioactivity. Its growth in recent years has been especially marked in Colorado, where there are large deposits of radioactive ores and numerous hot and cold radioactive mineral springs. The active production of radium through the operations of the United States Bureau of Mines and of private companies, its peculiar properties and fabulous price, and the increasing use of mineral springs for therapeutic purposes have all conspired to create an interest in radioactivity which is more than curiosity. This has been indicated by numerous requests for information both from persons having a general interest in the subject and from others with a definite interest in some ore or mineral water. These inquiries have shown that there is a considerable amount of misinformation concerning radioactivity passing as reliable, and that there is a desire for accurate knowledge. Although authoritative information is available in many books and journals, these are usually inaccessible and even unknown except to those with special training. Furthermore, the best of them are too technical for popular reading. Hence it has seemed worth while to preface the technical part of this investigation with a brief non-technical discussion of radioactivity in general with special reference to those phases of it which are usually found in connection with natural waters and gases.

Methods of testing and of measuring radioactivity have also become of general interest. The electroscope is no longer a laboratory instrument, but is found in mine and mill, and even in the prospector's camp. It is for such reasons that both methods and results have been discussed in this report with more detail than would be justifiable otherwise. Those desiring further information are referred to the list of treatises and articles in the