GEOLOGICAL APPLICATIONS OF THE IONIC POTENTIAL

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INTRODUCTION

Quite frequently we are reminded that the 96 known chemical elements are too complex to be classified by reference to any single characteristic. The periodic classification gives us only qualitative ideas, and many attempts have been made to place the elements on a more quantitative scale.

The role of ionic radii in the properties of chemical compounds has been emphasized by many authors including Pauling, Goldschmidt, and Bragg. Another factor influencing the properties of chemical compounds is the oxidation number or charge which an ion carries. In order to obtain a more comprehensive view of an ion and its properties, we must take into consideration both of these factors.

DEFINITION

Increasing ionic charge and ionic radius act in opposite directions. That is, the lattice energy of a crystal is directly proportional to the charges and inversely proportional to the radii of the ions contained therein. From these considerations, Cartledge (1, 2) defined the ionic potential ($\varnothing$) as the charge on an ion divided by its radius. Table 1 gives a list of some common ions, their charges, radii, ionic potentials, and the square roots of their ionic potentials.

TABLE 1. IONIC POTENTIALS

Ion	Charge	Radius*	$\varnothing$	$\sqrt{\varnothing}$
Cs^+	1	1.65	0.61	0.78
Rb^+	1	1.49	0.67	0.82
K^+	1	1.33	0.75	0.87
Na^+	1	0.98	1.02	1.00
Ba^{++}	2	1.43	1.40	1.18
Pb^{++}	2	1.32	1.52	1.21
Sr^{++}	2	1.27	1.58	1.26
Li^+	1	0.78	1.67	1.30
Ca^{++}	2	1.06	1.89	1.38
Zn^{++}	2	0.83	2.40	1.55
Fe^{++}	2	0.83	2.40	1.55
Mg^{++}	2	0.78	2.56	1.60
Th^{+4}	4	1.10	3.63	1.91
Ce^{+4}	4	1.02	3.92	1.98
Fe^{+++}	3	0.67	4.48	2.12
Zr^{+4}	4	0.87	4.60	2.15
Pb^{+4}	4	0.84	4.76	2.18
Al^{+++}	3	0.57	5.26	2 30
Be^{++}	2	0.34	5.90	2.43
Ti^{+4}	4	0.68	5.90	2.43
Mo^{*6}	6	0.62	9.7	3.11
Si^{+4}	4	0 39	10.2	3.18
P^{+5}	5	0.34	14.7	3.82
B^{+++}	3	0.20	15.0	3.87
S^{+6}	6	0.29	20.0	4.46
C^{+4}	4	0.20	20.0	4.46
N^{+5}	5	0.11	45.5	6.70

*The radii have been taken from V. M. Goldschmidt, Br. *60,* 1263 (1927).

These values of the ionic potential may be related to many geological concepts, of which seven will be considered.

APPLICATIONS

1. If the square root of the ionic potential ($\surd\varnothing$) of a cation is less than 2.2, the oxide formed will be basic; if $\surd\varnothing$ is between 2.2 and 3.1, the oxide will be amphoteric; and if $\surd\varnothing$ is greater than 3.1, the oxide will be acidic. These data are summarized in Table 2 along with some examples.

TABLE 2.—ACIDIC-BASIC CHARACTER OF OXIDES

$\sqrt{\emptyset}$	Nature of oxide	Examples
<2.2	basic	Na_2O, K_2O, CaO, MgO
2.2-3.1	amphoteric	Al_2O_3, BeO
>3.1	acidic	SiO_2, CO_2

2. When the $\sqrt{\emptyset}$ of the cation of a chloride is greater than 2.2., the chloride is volatile at a little above room temperature and one atmosphere pressure. This means that the chlorides of silicon, germanium, titanium, plumbic lead, etc. could be lost in volcanic eruptions.

3. The hardness of binary crystals increases as the ionic potentials of their constitutents increase. This phenomenon is illustrated in Table 3.

4. If the $\sqrt{\emptyset}$ of the cation of a carbonate or nitrate is greater than 2, the compound will not be stable; if $\sqrt{\emptyset}$ is between 2 and 2.5, basic carbonates are formed which are soluble in carbonate solution. Thus, zirconium, aluminum, beryllium and others may be dissolved in carbonate solutions as basic carbonates.

5. Goldschmidt (3, 4) has divided the cations into three groups according to their ionic potentials. Group I consists of cations whose ionic potentials are less than 3; they remain in true ionic solution in the processes of weathering and transportation. An example of this is the presence of sodium, potassium, magnesium, calcium, and strontium in sea water. Group II is made up of cations which have ionic potentials between 3 and 6. These ions are precipitated by hydrolysis, examples being the presence of aluminum and beryllium in clays. Cations with ionic potentials greater than 6 comprise Group III. They form complex anions containing oxygen, some of them again being soluble. Examples of these are the silicates, phosphates, carbonates, borates, and nitrates.

6. Elements whose ionic potentials are less than 2 are found to be easily collected and exchanged by natural zeolites.

7. Elements with high ionic potentials enrich in silicates. Goldschmidt (4, 6) says that the limit is about 2.6 at ordinary temperature, but that the limit changes with the temperature.

TABLE 3.—HARDNESS OF BINARY CRYSTALS

Compound	NaF	MgO	ScN	TiC
Hardness (Moh's)	3.2	6.5	7-8	8-9
$\sqrt{\emptyset}$ cation	1.00	1.60	1.90	2.43
$\sqrt{\emptyset}$ anion*	0.86	1.19	1.32	1.38

*Values for the anions are calculated by neglecting the negative sign to facilitate the taking of the square root.

CONCLUSIONS

The concept of the ionic potential is very useful to the instructor as a teaching aid, and also to the research worker as a simple means of remembering various relations. The user is warned, though, because the idea is not infallible; but it is nevertheless applicable to many problems. Other references are provided for further reading.

REFERENCES

1. CARTLEDGE, J. Am. Chem. Soc. *50*, 2855 (1928).
2. CARTLEDGE, J. Am. Chem. Soc. *52*, 3076 (1930).
3. GOLDSCHMIDT, J. Chem. Soc. *1937*, 655.
4. GOLDSCHMIDT, Skr. Norske Vid.-Akad. Oslo, Mat. Natwiv. Kl. No. 4, (1937).
5. SUN, J., Chinese Chem. Soc. *5*, 148 (1937).
6. RANKAMA, Suomen Geol. Toimikunta, Bull. Comm. geol. Finlande, *126*, 24 (1941).