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ENERGY RELATIONSHIPS AND IONIZATION POTENTIALS OF ATOMS OF THE FIRST ROW OF THE PERIODIC TABLE IN ALL STAGES OF IONIZATION

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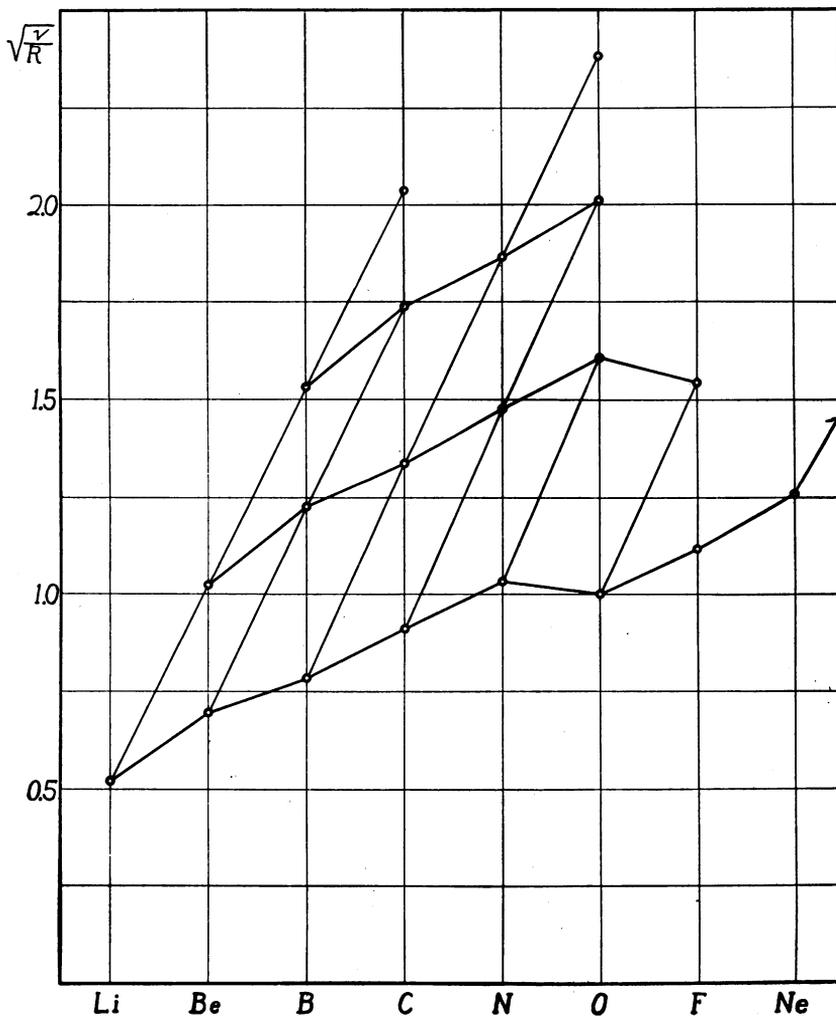
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With the aid of the four agencies listed below we have been able to complete the identification of all of the extreme ultra-violet lines ($\lambda = 2000$ A to $\lambda = 200$ A) of any strength emitted by the atoms of the first row of the periodic table in all stages of stripping. *The main features of the spectra of these atoms may then be considered as now determined.* The agencies used in these identifications are the following:

- (1) The Rydberg-Ritz formula handed down from the empirical age in spectroscopy preceding 1913 (Bohr).
- (2) The Bohr theory which since 1913 has been the most fundamental instrument of spectroscopic prediction.
- (3) The regular and irregular doublet laws discovered first in the field of X-rays and found by us to be not only applicable to optical spectra as well, but to be very powerful aids in making identifications of spectra.
- (4) The new Russell-Pauli-Heisenberg-Hund rules with the aid of

which *the structure* of the spectra, even of the most complex electron configurations, can be completely foretold.

The completion of these identifications now makes possible the most general representation of the extension of diagrams of the Moseley type into the region of low atomic numbers (see Fig. 1).



The Moseley law was in Moseley's hands a relation between atomic number and square root of emitted frequencies, and when we first succeeded in obtaining the extreme ultra-violet spectra of the light elements we followed Moseley's procedure in attempting to trace the relationship between atomic number and the square root of emitted frequencies of the

L series down to neon, and then with the aid of a line which now departed largely from linearity from neon down to hydrogen.¹

We have herein, however, adopted the more correct and the more significant procedure—one also recently followed by most other authors—of presenting as the Moseley diagram the relation between atomic number and the square root of the frequencies of the *energy levels* rather than of any series of emitted lines.

Figure 1 presents, then, in such a general form the extension of the Moseley diagram from neon down through lithium.

The first straight line to the left is the Moseley diagram for stripped atoms, i.e., for one-electron systems. The plotted points are the energies, spectroscopically determined, necessary to remove an electron from the $2p$ orbit of the stripped atoms from lithium through carbon. The corresponding energy for stripped nitrogen, oxygen and fluorine can, of course, be obtained with much precision by simply extending upward the straight line in question.

The second line from the left gives, similarly, the observed energies necessary to remove an electron from the $2p$ orbit of a two-electron system from beryllium to carbon, and it makes possible, by a similar extrapolation, the determination of the corresponding energies in two-electron nitrogen, oxygen and fluorine.

Similarly, the third line from the left gives the corresponding energies for a three-electron system; and so on for four-, five- and six-electron systems. For seven- and eight-electron systems the graph shows but one point for each, but even here the direction of the Moseley lines might be obtained with considerable accuracy by simply paralleling the other Moseley lines farther to the left in the diagram.

The irregular line connecting the lowest points in the diagram represents at each point the energy necessary to detach a p electron from a *neutral* atom. *This line, representing a sequence of corresponding energy levels in neutral atoms rather than a sequence of emitted frequencies, has perhaps the best claim of any of the lines shown, to be regarded as the extension of the Moseley diagram from neon down to lithium.* From neon up to uranium this line of energy levels runs continuously with little change in slope and always in the approximate direction of the arrow shown starting obliquely upward from neon.

From a somewhat broader point of view the whole diagram is but the graphical representation of the extension of the Moseley graph to the atoms below neon.

In table 1 are presented the most important ionizing potentials, spectroscopically computed, of the atoms of the first row in a large number of stages of ionization. The potentials that have bracketed numbers beneath them are among those that are of particular significance for the

determination of stellar temperatures. Indeed, the bracketed numbers represent ionizing potentials which have heretofore been merely estimated, sometimes too with very considerable errors, as is seen from their values, from other means of obtaining stellar temperatures.²

| IONIZATION POTENTIALS | | | | |
|-----------------------|----------------------|-----------------------------|---------------------------|--------------------|
| Li | ³ 5.371 | | | |
| Be | ⁷ 9.50 | ⁴ 18.141 | | |
| B | ⁸ 8.34 | ⁷ 24.2 | ⁵ 37.786 | |
| C | ⁸ 11.3 | ⁸ 24.289 | ⁷ 45.5 (45) | ⁶ 64.23 |
| N | ⁹ 14.494 | ⁸ 29.56 (24) | ⁸ 47.2 (45) | |
| O | ¹⁰ 13.565 | ⁸ 34.999 (32) | ⁸ 54.8 (45) | ⁸ 77.0 |
| F | ⁸ 16.9 | ⁸ 32.3 | | |
| Ne | ¹¹ 21.482 | | | |

In considering ionization potentials it should not be overlooked that unless there has been careful definition the term ionizing potential has no definite meaning at all. Thus the normal oxygen atom has two electrons in *s* orbits and four in *p* orbits, and this configuration is, therefore, designated as the s^2p^4 configuration; but this configuration has triplet *P*, singlet *D* and singlet *S* terms, which correspond to five different orientations of the orbits and the spins of the four *p* electrons. When one of these *p* electrons is removed, the atom, now an ion, having left two *s* and three *p* electrons, may in its turn exist in any one of five different states, namely a quartet *S*, a doublet *P*, and a doublet *D*, so that the atom can be ionized in twenty-five different ways each of which requires a slightly different energy and hence represents a different ionization potential from all the others. "Ionization potential," therefore, has no definite significance, unless it is defined, for example, as the energy corresponding to the passage from the most stable state of the atom to the most stable state of the ion. It is this definition that has been used in the calculation of the foregoing table.

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¹ Millikan, *Proc. Nat. Acad. Sci.*, **7**, 289, 1921.

² Payne, *Stellar Atmospheres*, p. 15, 1925.

³ Fowler, *Series in Line Spectra*, p. 97 (1922).

⁴ Bowen and Millikan, *Physic. Rev.*, **28**, 256, 1926.

⁵ Bowen and Millikan, *Proc. Nat. Acad. Sci.*, **10**, 199, 1924.

⁶ Millikan and Bowen, *Nature*, **114**, 380, 1924.

⁷ Bowen and Millikan, *Physic. Rev.*, **26**, 310, 1925. (Values slightly revised.)

⁸ Bowen, *Physic. Rev.*, 29, 231, 1927.

⁹ Hopfield, *Ibid.*, 27, 801, 1926.

¹⁰ Hopfield, *Astrophys. J.*, 59, 114, 1924.

¹¹ Lyman and Saunders, *Proc. Nat. Acad. Sci.*, 12, 92, 1926.

POLARIZATION OF LIGHT REFLECTED FROM ROUGH SURFACES WITH SPECIAL REFERENCE TO LIGHT REFLECTED BY THE MOON

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The human race has always been interested in the moon and in its influence on living things; and has speculated much about its origin, its surface features and its course through the heavens. Notwithstanding this long-continued interest, however, we do not yet know what the materials are that we see exposed at its surface, nor do we know definitely how any one of its many surface features was formed.

This problem appealed to Dr. John C. Merriam, President of the Carnegie Institution of Washington, as one that might be attacked most effectively by a group of men from the fields of astrophysics and geology; he accordingly appointed a committee of members within the Institution interested in these sciences to study the surface features of the moon with special reference to the factors that were active in producing the observed surface forms.

In approaching this task as one of the geologist members of this group the writer has felt that the first step to be taken is to find out, if possible, what substances are exposed at the moon's surface before the more difficult problem of the origin of its surface features is considered seriously. Unfortunately, we cannot make an excursion to the moon and learn at first hand what its materials are. Our only approach to the moon at present is through the aid of the reflected sun's rays. These rays reach us a little over a second and a quarter after they leave the moon and can tell us much about its surface materials by reason of the effects these produce on the sun's rays on reflection. By comparing the reflected sun's rays with the direct sun's rays we can ascertain what changes are produced on reflection at the moon's surface; then by comparing these changes with the effects produced on reflection by terrestrial materials, we may be able to form some idea of the composition of the lunar surface materials.

The effects produced on reflection are of two kinds: (1) changes in the relative intensities of different wave-lengths, from the infra-red through