Electric Ionization

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1 Introduction

R. W. Satz discusses[1] the fundamental motions of the physical universe from the point of view of the *Reciprocal System* of theory and derives their mathematical expressions. In a subsequent paper[2] he shows how the work function, the ionization energy, and the magnetic resonance frequencies of the atoms and the subatoms can be theoretically derived from the fundamental postulates of the *Reciprocal System*. These two works form the starting point of the present paper.

The theory of the electric ionization and magnetization developed in References 1 and 2 leaves certain unresolved difficulties:

1.1 The mass effect of an electric charge.

Satz evaluates the energy necessary for creating a positive electric charge as 8.68 eV (Equation 7 of Reference 2 and page 8 of Reference 1). Larson, calculating the individual masses of the subatoms, concludes that the electric charge produces a mass effect amounting to 0.00004494 amu.[3] This is equivalent to nearly 41850 eV. How such a mass effect of 41850 eV is produced from an electric charge that came into being from an energy of 8.68 eV is not clear. Similarly, it can be seen that the energy associated with the unit isotopic charge is 2.17 eV, since its rotational frequency is $R/2\pi$ (page 8, Reference 1). It is once again not clear how this can compare with the mass effect of an isotopic charge, namely, 931.3 MeV. Further, I have shown[4] that, following Larson's line of argument, a unit magnetic charge gives rise to a negative mass effect equivalent to -243.19 eV, which also contrasts with the energy required to create a magnetic charge, namely, 2.17 eV as derived by Satz.

1.2 Magnetic Rotation

Under Table I (page 23, Reference 2), Satz mentions in a footnote: "…where value 3 appears in magnetic rotation, this is the inverse of actual rotation," whereas in the work[5] from which these values were taken, Larson was more careful, noting that "…where the value 3 appears as the magnetic rotation of one of the higher group elements, this is the inverse of the actual rotation, 5." However, what both these authors fail to make clear is how rotation 5 is the inverse of rotation 3, since in the magnetic dimension the two "zero points" are separated by 4 units and not 8.

1.3 Photoionization

The photoionization theory developed by Satz[2] seems to give good results, but there are certain inadequate features. The first of these is the rather large discrepancy (16 to 19%) between the calculated and the observed values of the ionization energy of some of the elements. See, for example,

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[1] Satz, R. W., "Further Mathematics of the Reciprocal System," *Reciprocity* X(3), 1980.

[2] Idem, "Photoionization and Photomagnetization," *Reciprocity* XII(1), Winter 1981-82.

[3] Larson, Dewey B., *Nothing But Motion*, North Pacific Publishers, Portland, Or., 1979, p. 163.

[4] K.V.K. Nehru, "Internal Ionization and Secondary Mass," privately circulated paper.

[5] Larson, The Structure of the Physical Universe, North Pacific Publishers, Portland, Or., 1959, p. 119.

the cases of C, Zn, Cd, Hg, etc. (Table I, pages 22-23, Reference 2).

1.4

The appropriateness of taking the magnetic speed as 3 (see Table I, page 23, Reference 2) when the magnetic displacement is 3, in the cases of Ni, Cu, Zn, Zr, Nb and Mo or that of taking the electric speed as 5 and 6 when the electric displacement is (4) and (3) respectively in the cases of Ge and As is not explained. This lapse occurs in the cases of Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, etc.

1.5

While Table I[2] covers a good number of the elements for which the calculated values of the work function and the ionization energy are compared with the observed values, there is a considerable number of elements left out. Conspicuous among the latter are all of the inert gases.

1.6

Similarly, while it was mentioned that the electron, the positron, the proton, and H^1 can take an electric charge (page 23, Reference 2), no reason was given as to why the neutrino and the neutron do not do so.

1.7

In the case of H^1 the Principle of Equivalence was invoked (page 24, Reference 2) to show that the ionization energy is 13.595 eV. However, no attempt was made to derive this value, from the rotational speeds of H^1, even though this was done in the case of the ionization energies of the free positron and proton (Equation 7, Reference 2), as well as atoms (Equation 9-a, Reference 2).

1.8

Developing the equation for the ionization energy of an atom, Satz writes: "From mechanical considerations it is obvious that the energy necessary to create a positive-negative charge pair is twice that needed to create the negative charge on the electron" (page 24, Reference 2). Thus he takes it as 2 × 2.1 = 4.34 eV. But it can be asked, why should not this energy be taken as twice the energy needed to create the positive charge on the atom (2 × 8.68 eV), or the sum of the energies required to create the negative and the positive charges (2.17 + 8.68 eV), instead of 4.34 eV?

2 Equation for the Ionization Energy

We will now attempt a refinement of the electrical ionization theory developed by Satz[2] with a view to meet the difficulties mentioned in section 1 above.

We find ths test way to get an insight into the situation is to consider the ionization energies, E_I, of the atoms of the alkali metals, all of which have only one unit of rotational displacement in the electric dimension. From the *Handbook of Chemistry*,[6] We have the following data:

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[6] J. A. Dean, ed., *Lange's Handbook of Chemistry*, 1973, pp. 3-6 to 3-8.

Element	**Displacement**	**E_I in eV**
Li	2-1-1	5.392
Na	2-2-1	5.139
K	3-2-1	4.341
Rb	3-3-1	4.177
Cs	4-3-1	3.894

It can be noted from me observational data that as the displacement in the magnetic dimension increases, there is a systematic decrease in the ionization energy. On the other hand, the value calculated by Satz (his Table I, Reference 2) is the same, 4.34 eV, for all of these elements. From this it is apparent that there ought to be some missing factor that accounts for this discrepancy. This factor, whose existence has not been recognized hitherto, is what might be called the transverse effect of the rotations in the two dimensions other than the one considered in the Satz Equation 9-a (page 25, Ref. 2):

$$E_{I,\,atom}=4.34\times\left(\frac{c}{v_{mag}}\right)^{1/2}\text{eV}$$

$$E_{I,\,atom}=4.34\times\left(\frac{c}{v_{elec}}-1\right)^{1/2}\text{eV}$$

That is to say, if *u* and *v* are the two magnetic speeds and *w* the electric speed, and if the ionization energy happens to be given by

$$E_I=4.34\times\left(\frac{c}{u}\right)^{1/2}$$

the speeds *v* and *w* in the orthogonal dimensions do have a transverse effect on E_I. Or if E_I happens to be given by

$$E_I=4.34\times\left(\frac{c}{w}-1\right)^{1/2}$$

then the speeds *u* and *v* exert the transverse effect.

This transverse effect can be evaluated as follows. Firstly, we note from Satz's Equation 9-a[2] given above that the *collinear* effect of the atomic rotation on the electric ionization is arrived at by considering the inverse speed c/v_{mag} or c/v_{elec}. The transverse effect is the inverse of the collinear effect, and as such, is to be arrived at by considering the specific speeds, namely, v_{mag}/c and v_{elec}/c directly.

Secondly, since speeds in two different dimensions are simultaneously involved in the transverse effect, their net effect can be calculated by taking their geometric mean.[7] Incidentally, it may be noted that the reason for the geometric mean of the specific rotations to be the relevant quantity, as Larson takes, is that the *force effect* of a specific rotation *t* is given by ln(*t*) (i.e., the natural logarithm of *t*), and that the average force due to the two rotations t_1 and t_2 is

$$\frac{1}{2}\left(\ln(t_1)+\ln(t_2)\right)=\ln(t_1\times t_2)^{1/2}$$

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[7] Larson, Dewey B., "Solid Cohesion," *Reciprocity* XII(1), Winter 1981-82, p. 15.

That is, it is equivalent to the force effect of a rotation $(t_1 \times t_2)^{1/2}$.

Finally, the square-root of the expressions is to be taken in order to convert the time region quantity into the time-space region quantity. Thus the factor responsible for the transverse effect can be written down as

$$\left[\left(\frac{v_x}{c}\times\frac{v_y}{c}\right)^{1/2}\right]^{1/2}=\left(\frac{v_x \times v_y}{c^2}\right)^{1/4} \tag{1}$$

where v_x/c and v_y/c are the specific rotations in the other two dimensions.

It is necessary to consider one more item before we can set up the final expression for the ionization energy of the atom. This concerns the energy required to create a positive-negative charge pair, mentioned in section 1.8 above. This is not twice the energy needed to create the negative charge as Satz supposes (nor, of course, twice the energy needed to create the positive charge). In Reference 1, Satz concludes that the natural frequency of electric charge is R/π Hertz (his Equation 23, Reference 1) and then shows that the frequency of unit negative charge is R/2π, since the negative charge is one unit of time displacement and its speed is 1/(1 + 1) = 1/2. Similarly, he shows that since the unit of positive electric charge is a unit of space displacement, its speed is (1 + 1)/1 = 2, its frequency is 2R/π (also see his Equations 4 & 7, Reference 2). Now, when a charge pair is created the relevant speed is the geometric mean (of the speeds of a positive and negative charge), that is, $(1/2 \times 2)^{1/2} = 1$. Hence the energy necessary to create the charge pair is twice *h* × 1 × R/π (where *h* is Planck's constant), or 8.68 eV. Therefore, the energy for the first ionization level is given by

$$\begin{aligned} &E_{I,atom}=8.68\times\left(\frac{c}{v_{mag}}\right)^{1/2}\times\left(\frac{v_x \times v_y}{c^2}\right)^{1/4} eV \\ &or \\ &E_{I,atom}=8.68\times\left(\frac{c}{v_{elec}}-1\right)^{1/2}\times\left(\frac{v_x \times v_y}{c^2}\right)^{1/4} eV \end{aligned} \tag{2}$$

3 Observational Validation

In Table II are listed the values of E_I calculated from Equation (2). In column 2 of the Table the displacements in the three dimensions are given for each element, and in the third column are given the rotations causing the collinear effect, namely, either c/v_{mag} or c/v_{elec}. In those cases where these speeds are derived from any of the alternative orientations the atomic rotation is able to assume, as will be presently discussed, they are marked by an appropriate sign. In the fourth column are listed the two specific rotations that produce the transverse effect. In column 5 are listed the calculated values and the observed values according to Reference 6.

The agreement with the observational values can be seen to improve very materially compared with that achieved by the Satz equation. (The correlation coefficient is 0.992.) There are several aspects to the computation:

3.1 The Neutral Particles.

As pointed out in section 1.6 above, the neutrino and the neutron do not take any electric charge. I have shown elsewhere[4] that the "½-½" type of effective displacement in both the magnetic dimensions of these particles is what makes the acquirement of an electric charge impossible.

3.2 Hydrogen.

One of the two intermediate type of particles, H^1, has the following speeds in its two rotating systems:

$$\left\{\begin{matrix} \frac{1}{3}-\frac{1}{2}-\frac{2}{1} \\ \frac{1}{2}-\frac{1}{2}-\frac{2}{1} \end{matrix}\right\}$$

Since the speeds in the two rotating systems in the primary magnetic dimensions are unequal, their geometric means, $\sqrt{(1/3\times1/2)}=1/\sqrt{(6)}$ is to be taken. This causes the collinear effect. The transverse effect comes from the two speeds 1/2 and 2 in the remaining two dimensions. Thus, from Equation (2) we have:

$$E_{I,H^1}=8.68\times\left(\sqrt{6}\right)^{1/2}\times\left(\frac{1}{2}\times2\right)^{1/4}=13.585\,\text{eV}$$

3.3 The Inert Gases.

A typical case is that of the inert gases, all of which have zero electric displacement. It must be recalled that the positive and negative zero-points (from either of which the atomic rotation can be alternatively reckoned) are separated by 8 (or 16) displacement units in the electric dimension.[8] Now for the purpose of taking on the electric charge the rotation in the electric dimension of the inert gases is able to assume the role of this alternative zero-point. We shall refer to this phenomenon by the term “zero-shifting.”

Both He and Ne, with their smaller atomic numbers (net total electric displacement), are able to take the double leap of 16 units (two 8-unit shift). This has been indicated in Table II by ¶¶. Kr, Xe and Rn, with higher atomic numbers, take on the 8-unit zero-shift (indicated in Table II by ¶). Ar, the element next to Ne in the inert gas series, is also able to take on the 16-unit zero-shift like both of its predecessors. But its net total displacement being much higher than that of He or Ne, the probability of the 16-unit shift competes equally with that of the 8-unit shift resorted to by Kr and the higher members.

We will find in a number of instances where alternative atomic rotational orientations are possible, as will be seen below, the question of the relative probabilities plays a significant role in determining the value of the ionization energy observed macroscopically. Pending detailed study of the relative probabilities we will assume that the 16-unit shift and the 8-unit shift have equal probabilities in the case of Ar. Thus the ionization energy of Ar comes out to be the arithmetic mean of the two values resulting from the 16-unit shift and the 8-unit shift, namely, 15.92 eV.

3.4 Electro-negative Elements.

From the principles of the *Reciprocal System* it is evident that positive ionization—that is, acquisition of a rotational vibratory space displacement—of the atom is not possible because of the space displacement in the electric dimension of these elements. The rotation in the electric dimension must assume an alternative orientation, thereby acting as an equivalent time displacement. This alternative

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[8] Idem, *Nothing But Motion*, p. 222.

orientation may be achieved by any of the following three expedients.

3.4.1 The first expedient is to revert to the all-positive equivalent displacement.

Thus, for example, Ni, with the usual displacement of 3-3-(8) can assume the equivalent displacement 3-2-10. This all-positive displacement is not normally realized due to its lower probability. This possibility, therefore, occurs only when the element belongs to the highest position in Division III (see pp. 223-4, Reference 3)—near the border between Divisions II and III. In fact, it is encountered in only one more case, that of Lu (4-4-(15)).

3.4.2

If the rotation in the electric dimension is involved only in the transverse effect, another possibility opens up. In view of the space-time symmetry around unity, a speed *n* can achieve the effect of inverting the space-time orientation of the rotation by its ability to act in the capacity of its reciprocal, namely, the speed 1/*n*. But this ability to act as its reciprocal is limited only to the transverse effect and cannot extend to the collinear effect, since the transverse effect is an inverse effect itself. Thus, in the case of Au (4-4-(7)), for example, the speed 8 in the electric dimension is able to act as speed 1/8 as far as the production of the transverse effect is concerned. This type is indicated in Table II by §. Other examples are Cu, Pd, Ag, Cd, and Hf. The probability of this type of alternative configuration becomes very low as we move away from the middle of a Group.

3.4.3

Under these circumstances, none of the elements of Division IV nor any of those in the lowest positions in Division in are able to take up this expedient The negative rotation in the electric dimension of these elements is, however, able to achieve the same result by taking recourse to the expedient of zero-shifting mentioned in section 3.3.

As an example, let us consider the element Se with the displacement 3-3-(2). An 8-unit zero-shift in orientation turns the space displacement (2) into the time displacement 6, which then is able to produce the collinear effect. It must also be noted that the inversion of the orientation effected by the zero-shifting enables the rotation to exert either the collinear effect or the transverse effect with equal facility. In the example of Se cited above, the two effects seem to have equal probabilities. The macroscopic result, once again, is that the ionization energy required is the arithmetic mean of the two values.

It will be seen that this alternative of zero-shifting is invariably the expedient adopted by all the elements of Division IV (and those of Division m nearer the border between Divisions III and IV), of Groups 2B, 3A, 3B and 4A. In the case of Group 4A elements Ta (4-4-(14)) through Pt (4-4-(8)) the 8-unit zero-shift is not feasible, since the existing space displacement in the electric dimension is greater than 8 units. These elements, therefore, take the 16-unit zero-shift. It is worth noting that in the case of the elements S (3-2-(2)), Se (3-3-(2)), Os (4-4-(10)), Ir (4-4-(9)) and Pt (4-4-(8))—in all of which the electric displacement is at the bottom of the first or second 8-unit stretch—the positive rotation effectuated by zero-shifting seems to act either in the collinear or in the transverse capacity with equal probability.

This leaves the Division IV elements of Group 2A, which have some peculiarity arising out of their low net total displacement These elements, N, O and F do resort to the zero-shifting, like the rest of their electro-negative family, but, by virtue of their low net total displacements they are able to take on the 16-unit double shift, like the two inert gas elements, He and Ne, that bracket their group. In fact, the probabilities of the 16-unit and 8-unit shifts are about the same for each of these elements.

4 The Special Cases.

There remain two special cases in which the large discrepancy between the calculated and the observational values of the ionization energy seems to warrant further study .

(i) The first of these pertains to those elements with displacement 3 in their electric dimension, irrespective of whether this displacement is the direct positive value of 3, or the equivalent positive displacement 3 obtained by an 8-unit zero-shifting of the negative displacement of 5. They are Al (2-2-3), Sc (3-2-3), Ga (3-3-(5)), Y (3-3-3), In (4-3-(5)) and La (4-3-3). The exceptions are B (2-1-3) at the low atomic number end, and Tl (4-4-(5)) and Ac (4-4-3) at the high atomic number end. The calculated value, in these cases, exceeds the observational value by about 15 to 35%, as shown in Table I below.

Table I: Cases of Large Discrepancy

Element	**Calculated**	**Observed**	**Discrepancy (%)**
Al	8.08	5.986	35.0
Sc	7.52	6.54	14.9
Ga	7.52	5.999	30.7
Y	7.52	6.38	17.8
In	7.11	5.786	22.9
La	7.11	5.577	27.5

(ii) The second special case pertains to the electropositive elements of Group 4A, namely, the Lanthanides from Ce (4-3-4) through Tb (4-3-11). The average calculated value of the ionization energy for these elements is 7.87 eV, while the average observational value is 5.62 eV.

Table II: Ionization Energy of the Elements

				Specific Speed	**E_I in eV**	
Element	**Displacement**	**c/v_m**	**c/v_e**	**Trans. Eff.**	**Calculated**	**Observed**
H	M l-l-(l)					
	M ½-½-(1)	√6		1/2 * 2	13.585	13.598
He	2-1-0		17¶¶	1/2.5 * 1/1.5	24.95	24.587
Li	2-1-1		2	1/3 * 1/2	5.55	5.392
Be	2-1-2	3		1/2 * 1/3	9.61	9.322
B	2-1-3	3		1/2 * 1/4	8.94	8.298
C	2-1-4		5	1/3 * 1/2	11.09	11.260
N	2-2-(3)		14¶¶	1/3 * 1/3	18.07	
			6¶¶	1/3 * 1/3	11.21	
			Av.		14.64	14.534
O	2-2-(2)		15¶¶	1/3 * 1/3	18.75	
			7¶	1/3 * 1/3	12.28	
			Av.		15.51	13.618
F	2-2-(l)		16¶¶	1/3 * 1/2.5	20.31	
			8¶	1/2.5 * 1/2.5	14.52	
			Av.		17.42	17.422
Ne	2-2-0		17¶¶	1/2.5 * 1/2.5	21.96	21.564
Na	2-2-1		2	1/3 * 1/2.5	5.25	5.139
Mg	2-2-2		3	1/2.5 * 1/2.5	7.76	7.646
A1	2-2-3	3		1/3 * 1/4	8.08	5.986
Si	2-2-4	3		1/2.5 * 1/4.5	8.21	8.151
P	3-2-(3)		6¶	1/4 * 1/3	10.43	10.486
S	3-2-(2)		7¶	1/2.5 * 1/4	11.96	
		4		1/2.5 * 1/7¶	8.49	
			Av.		10.22	10.360
Cl	3-2-(l)	8¶		1/2.5 * 1/4	12.91	12.967
Ar	3-2-0		17¶¶	1/4 * 1/3	18.65	
					13.19	
					15.92	15.759
K	3-2-1		2	1/4 * 1/3	4.66	4.341
Ca	3-2-2		3	1/4 * 1/3	6.60	6.113
Sc	3-2-3	3		1/4 * 1/4	7.52	6.54
Ti	3-2-4	3		1/4 * 1/5	7.11	6.82
V	3-2-5	3		1/4 * 1/6	6.79	6.74
Cr	3-2-6	3		1/3.5 * 1/7	6.76	6.766
Mn	3-2-7	4		1/3 * 1/8	7.84	7.435
Fe	3-2-8	4		1/2.5 * 1/9	7.97	7.870
Co	3-2-9	4		1/2.5 * 1/9.5	7.86	7.86
Ni	3-3-(8)	4		1/2.5 * 1/10.5+	7.67	7.635
Cu	3-3-(7)	4		1/2.5 * 1/7.5§	7.67	7.726
Zn	3-3-(6)	4		1/4 * 1/3¶	9.33	9.394
Ga	3-3-(5)		4¶	1/4 * 1/4	7.52	5.999
Ge	3-3-(4)	4		1/4 * 1/51 .	8.21	7.899

				Specific Speed	**E_I in eV**	
Element	**Displacement**	**c/v_m**	**c/v_e**	**Trans. Eff.**	**Calculated**	**Observed**
As	3-3-(3)		6¶	1/4 * 1/4	9.70	9.81
Se	3-3-(2)		7¶	1/3.5 * 1/3.5	11.36	
		4		1/3.5 * 1/6.5¶	7.95	
			Av.		9.66	9.752
Br	3-3-(l)		8¶	1/4 * 1/3.5	11.87	11.814
Kr	3-3-0		9¶	1/3.5 * 1/3.5	13.12	13.999
Rb	3-3-1		2	1/4 * 1/4	4.34	4.177
Sr	3-3-2		3	1/4 * 1/4	6.14	5.695
Y	3-3-3		4	1/4 * 1/4	7.52	6.38
Zr	3-3-4	4		1/4 * 1/5	8.21	6.84
Nb	3-3-5	4		1/4 * 1/6	7.84	6.88
Mo	3-3-6	4		1/4 * 1/7	7.55	7.099
Tc	3-3-7	4		1/4 * 1/8	7.30	7.28
Ru	3-3-8	4		1/3.5 * 1/8.5	7.43	7.37
Rh	3-3-9	4		1/3.5 * 1/9.5	7.23	7.46
Pd	4-3-(8)	5		1/3.5 * l/8.5§	8.31	8.34
Ag	4-3-(7)	4		1/4.5 * 1/7.5§	7.20	7.576
Cd	4-3-(6)	4		1/5 * 1/3¶	8.82	8.993
In	4-3-(5)		4¶	1/5 * 1/4	7.11	5.786
Sn	4-3-(4)	4		1/5 * 1/5¶	7.76	7.344
Sb	4-3-(3)	5		1/4 * 1/6¶	8.77	8.641
Te	4-3-(2)	5		1/3.5 * 1/6.5¶	8.89	9.009
I	4-3-(l)		8¶	1/5 * 1/4	10.86	10.451
Xe	4-3-0		9¶	1/4.5 * 1/3.5	12.32	12.130
Cs	4-3-1		2	1/5 * 1/4	4.12	3.894
Ba	4-3-2		3	1/5 * 1/4	5.80	5.212
La	4-3-3		4	1/5 * 1/4	7.11	5.577
Dy	4-3-12	4		1/5 * 1/13	6.11	5.93
Ho	4-3-13	4		1/5 * 1/14	6.00	6.02
Er	4-3-14	4		1/5 * 1/15	5.90	6.10
Tm	4-3-15	4		1/4.5 * 1/15.5	6.01	6.18
Yb	4-3-16	4		1/4.5 * 1/16.5	5.91	6.254
Lu	4-4-(15)	4+		1/5 * 1/18+	5.64	5.426
Hf	4-4-(14)	5		1/4.5 * 1/14.5§	6.83	7.0
Ta	4-4-(13)		4¶¶	1/4.5 * 1/4.5	7.09	7.89
W	4-4-(12)		5¶¶	1/5 * 1/4.5	7.97	7.98
Re	4-4-(ll)	5		1/5 * 1/6¶¶	8.29	7.88
Os	4-4-(10)		7¶¶	1/5 * 1/5	9.51	
		5		1/5 * 1/7¶¶	7.98	
			Av.		8.74	8.7
Ir	4-4-(9)		8¶¶	1/5 * 1/5	10.27	
		5		1/4.5 * 1/7.5¶¶	8.05	
			Av.		9.16	9.1
Pt	4-4-(8)			1/5 * 1/5	10.98	

				Specific Speed	**E_I in eV**	
Element	**Displacement**	**c/v_m**	**c/v_e**	**Trans. Eff.**	**Calculated**	**Observed**
		5		1/5 * 1/9¶¶	7.49	
			Av.		9.23	9.0
Au	4-4-(7)	5		1/5 * 1/8 §	7.72	
		5		1/5 * 1/2¶	10.91	
			Av.		9.31	9.225
Hg	4-4-(6)	5		1/4.5 * 1/2.5¶	10.60	10.437
T1	4-4-(5)		4¶	1/5 * 1/5	6.72	6.108
Pb	4-4-(4)		5¶	1/5 * 1/5	7.76	7.416
Bi	4-4-(3)	5		1/5 * 1/6¶	8.29	7.289
Po	4-4-(2)	5		1/4.5 * 1/6.5¶	8.35	8.42
Rn	4-4-0		9¶	1/5 * 1/5	10.98	10.748
Ra	4-4-2		3	1/5 * 1/5	5.49	5.279
Ac	4-4-3		4	1/5 * 1/4.5	6.90	6.9
Th	4-4-4		5	1/5 * 1/5	1.16	6.95

Note:

+	Alternative all-positive displacement
§	Inverse electric speed (in transverse effect only)
¶	8-unit zero-shift (in the electric dimension)
¶¶	16-unit zero-shift