

Commentary

Lanthanum (La) and Actinium (Ac) Should Remain in the d-Block

by Laurence Lavelle

There have been hundreds of ways to present the elements in a systematic arrangement known as the periodic table (1, 2). This paper focuses on the placement of lanthanum (La) and actinium (Ac) in the d-block versus the f-block, and lutetium (Lu) and lawrencium (Lr) in the f-block versus the d-block. Some general chemistry textbooks (for example 3, 4) have adopted the placement of lanthanum (La) and actinium (Ac) in the f-block and lutetium (Lu) and lawrencium (Lr) in the d-block. Other texts including general chemistry and specialized ones such as *Advanced Inorganic Chemistry* (5), widely considered a landmark inorganic textbook for 45 years, place lanthanum (La) and actinium (Ac) in the d-block and lutetium (Lu) and lawrencium (Lr) in the f-block.

The placing of lutetium (Lu) and lawrencium (Lr) in the d-block below yttrium (Y) in group 3 (IIIB) has been justified on the basis of periodic trends and electron configuration (6–11). To be more exact, these publications have justified the placement of lutetium (Lu) in group 3 (IIIB) based on periodic trends and electron configuration, whereas lawrencium (Lr) is placed in the same group as a result of its predicted electron configuration.

Overlooking the distinction that the electron configuration of lutetium (Lu) is empirically known whereas that of lawrencium (Lr) is predicted, based on their electron configurations lutetium (Lu), $[\text{Xe}]4f^{14}5d^16s^2$, and lawrencium (Lr), $[\text{Rn}]5f^{14}6d^17s^2$, could be part of the d-block as they both have one electron in a d-orbital. Although more recent work suggests that lawrencium (Lr) may not have an electron in a 6d orbital (14–17 and references therein)¹. However, for lanthanum (La), $[\text{Xe}]5d^16s^2$, and actinium (Ac), $[\text{Rn}]6d^17s^2$, there is no ambiguity with their empirically known and confirmed electron configurations. They do have one electron in a d-orbital and no electrons in f-orbitals outside their inert gas core, [Xe] and [Rn] respectively.

Another justification for switching the positions of lanthanum (La) and actinium (Ac) with lutetium (Lu) and lawrencium (Lr), with the latter below yttrium (Y) in group 3 (IIIB), is that this arrangement gives similar periodic trends in several physical properties (atomic radii, sum of the first two ionization potentials, melting point, and electronegativity) when comparing the first three periods of the d-block (6). In other words this applies to *only* lutetium (Lu). That is, the atomic radius, sum of the first two ionization potentials, melting point, and electronegativity of lutetium (Lu) are more similar to scandium (Sc) than lanthanum (La). On this basis lutetium (Lu) and lawrencium (Lr) have been placed in the same group as scandium (Sc) (6–8). With respect to lutetium (Lu), this in itself is reasonable. However many elements with similar properties or similar trends in properties are not placed in the same group. For example, the well known diagonal relationships as found in lithium (Li) and magnesium (Mg), beryllium (Be) and aluminum (Al), and boron (B) and silicon (Si), would, applying the same reasoning,

result in lithium (Li) and magnesium (Mg) in the same group because they have similar physical and chemical properties. For example their respective atomic radii are 1.57 Å and 1.60 Å and both react directly with nitrogen to form nitrides. Similarly for boron (B) and silicon (Si), which are metalloids, with electronegativities of 2.0 and 1.9 respectively (Pauling scale). Why not place them in the same group? In fact why not place all the metalloids in the same group as they have similar properties? The answer is a resounding no. As the above examples illustrate, similarity (or trends) of properties is not the *de facto* standard for placing elements in the same group. The placing of elements in the periodic table is currently accepted as a combination and balance of factors including the following empirical observations: atomic number, properties, periodic trends, and atomic ground-state electron configuration.

However even if we consider the special case of placing lutetium (Lu) and lawrencium (Lr) in the d-block below yttrium (Y) in group 3 (IIIB) because of similar periodic trends when comparing the first three periods of the d-block, where do lanthanum (La) and actinium (Ac) end up? In the f-block, and neither of them have electrons in f-orbitals outside their inert gas core. The remedy leads to an even worse outcome. The entire modern basis of the periodic table is the grouping of elements by occupied outer orbital type giving rise to the s-block (two outer electrons in an s-orbital and two groups), the p-block (six outer electrons in three p-orbitals and six groups), the d-block (ten outer electrons in five d-orbitals and ten groups), and the f-block (14 outer electrons in seven f-orbitals and 14 groups).² The placing of lanthanum (La) and actinium (Ac) in the f-block is not justified and causes even more problems.³ Lanthanum (La) and actinium (Ac) should be where the IUPAC² periodic table (18) and the NIST periodic table (19) places them, below yttrium (Y) in group 3 (IIIB).

To conclude there are many examples of elements with similar properties in different groups and many examples of elements with different properties in the same group. However placing lanthanum (La) and actinium (Ac) in the f-block is the only case where a pair⁴ of elements that belong in the same group are systematically placed in a group that results in their being part of a block with no outer electrons in common with that block. Please leave lanthanum (La) and actinium (Ac) where they belong, in the d-block.

Notes

1. It is unfortunate that current publications (e.g., 12, 13) continue to indirectly reference outdated literature such as (6) as the reason for placing lutetium (Lu) and lawrencium (Lr) below yttrium (Y) in the d-block. In fact the Jensen 1982 paper (6) is often considered the one and only reference needed for continued justification of their group 3 (IIIB) d-block placement in the periodic table. This 1982 publication cites literature up to 1975, resulting in a 33-year

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gap between research done then and now. If one must use predicted properties to justify the placement of an element in the periodic table, then it would be prudent to read the literature that in the case of lawrencium (Lr) suggests its atomic ground state is $[\text{Rn}]5f^{14}7s^27p^1$ (e.g., 14, 15 and earlier references therein), or strongly suggests it "...there are little doubts today about the $7s^27p^2P_{1/2}$ ground level of atomic lawrencium..." quoted from (16). As a result of this ground state, the computed properties of lawrencium (Lr) and its compounds are more like thallium (Tl) (e.g., 17). Therefore if one is to use predictions when empirical observations are not available, then these predictions would justify placing lawrencium (Lr) below thallium (Tl) in group 13 (IIIA) making it part of the p-block and not below yttrium (Y) in group 3 (IIIB) in the d-block. However neither of these placements are suitable which is why lawrencium (Lr) should remain in the f-block, and one should emphasize the use of well established empirical observations to determine what to include in the periodic table and where to place elements in the periodic table (21).

2. Placing lanthanum (La), actinium (Ac), lutetium (Lu), and lawrencium (Lr) all in the f-block is not suitable for the reasons discussed here and for the additional reason that the f-block would then have 15 groups when it should have 14 groups. It should be noted that the periodic table adopted by the IUPAC (18) and the physics laboratory of the NIST (19) do place lanthanum (La) and actinium (Ac) below yttrium (Y) in group 3 (IIIB). See Letter to the Editor, page 1491, for further discussion (20).

3. After discussing electron configurations and the periodic table, you might ask your general chemistry class the question, "The following two elements with ground state electron configurations of $[\text{Xe}]5d^16s^2$ and $[\text{Rn}]6d^17s^2$ are in the same group. Where in the periodic table would you expect to find them?" If you are using a textbook with a periodic table that places them [lanthanum (La) and actinium (Ac)] in the f-block, then this causes all sorts of problems.

4. Thorium (Th), with its ground state electron configuration of $[\text{Rn}]6d^27s^2$, is best placed in the f-block because cerium (Ce), which is above it and in the same group has the ground state electron configuration $[\text{Xe}]4f^15d^16s^2$. One would expect thorium (Th) to have the ground state electron configuration $[\text{Rn}]5f^16d^17s^2$, but since it does not, that is not reason enough to move thorium (Th) to the d-block. Similarly one also does not see suggestions to move copper (Cu), $[\text{Ar}]3d^{10}4s^1$, silver (Ag), $[\text{Kr}]4d^{10}5s^1$, and gold (Au), $[\text{Xe}]4f^{14}5d^{10}6s^1$, to the s-block be-

cause they do not have the expected d^9 electron configuration. Proposals such as these are not considered a balanced approach to the placement of elements in the periodic table.

Acknowledgements

The periodic table is often a topic of conversation, and I look forward to ongoing communications with Herbert Kaesz, Eric Scerri, Richard Kaner, Peter Atkins, Loretta Jones, David Oxtoby, and Pat Gillis.

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