Transparent Rings Atomic Model (TRAM): s,p,d,f notation made simple

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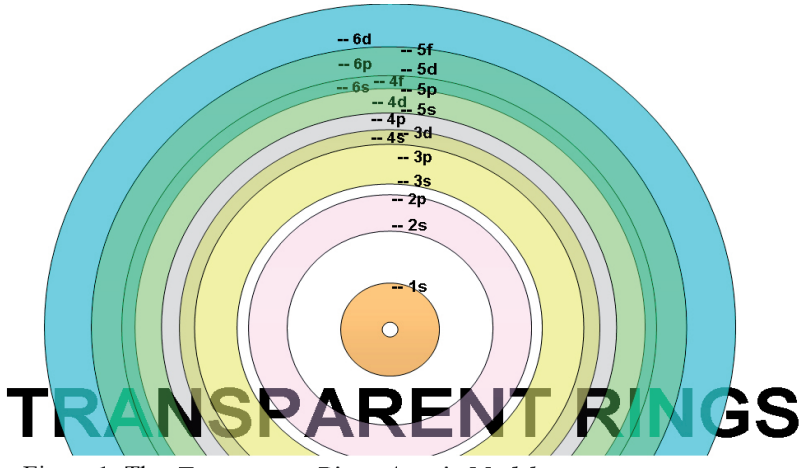
Introduction

One of the main reasons students opt out of school science, especially at high school and university levels, is that science is full of abstract concepts and processes, such as the concept of *evolution through natural selection,* or *photosynthesis,* or *gene,* or the concepts of *energy*, *wave*, *gravity*, and *atom*. These are just a few examples of a wide array of abstract ideas, which have baffled many students in the science classroom.

We can probably remember sitting in classes in which the teacher tried to make an abstract concept understandable using different strategies. I can still remember my biology teacher in Form 6 using a set of labeled coloured cards to explain *Chargaff's Principle.* In the chemistry classroom, the 'ball-and-stick' model is a commonly used strategy to teach the concepts of molecules, bonds, and atoms. Regardless of the subject area, physical models are very useful instructional tools, which can promote meaningful understanding of concepts.

This article describes the *Transparent Rings Atomic Model* (or TRAM) (Figure 1), a teaching model that I developed, to help students visualise atomic energy levels and understand the electronic structure of the atom in a meaningful way. The article begins with a discussion of some misconceptions that students have about core chemistry

Figure 1: The Transparent Rings Atomic Model



concepts. It then looks at the usefulness of the traditional 'zig-zag' algorithm as an instructional tool for teaching students how to write electronic configurations and how the TRAM can complement its use. A description of how to use this model in the classroom is included at the end of the article. Teachers of general science and chemistry in particular are encouraged to use this tool with their students.

Problematic science concepts

a) *The atom*

From my experience with teaching Pacific Island high school chemistry, I learned that many of my students had a simple 'solar system' perception of the atom: that electrons move around the nucleus in definite paths or *orbits* in the same manner the planets move around the sun. This is a common misconception as it is contrary to experimental evidence and to the *Heisenberg Uncertainty Principle*.

b) *Atomic orbitals*

To say that electrons are in paths or orbits would mean that we can be certain of their 'whereabouts' in the atom. It would also mean that we know exactly where they are moving to and that we can determine their precise positions at any particular instant. However, electrons do not occupy definite orbits. In fact, they inhabit regions of space or *orbitals*. In any particular time, an electron is *most likely* to be found in this region of space. Because electrons and protons are of opposite charges, the electrons in any orbital would tend to spend most of their time closer to the nucleus (where the protons are) than to any other part of the atom. The concept of *electron density* gives the probability that an electron will be found in any region of space in the atom.

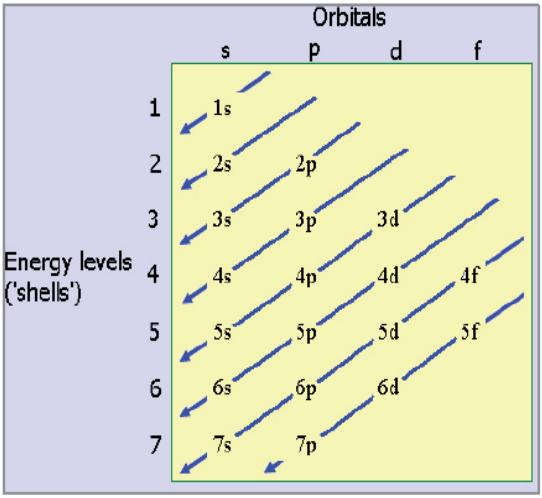
Due to the misconceived notion that electrons are in definite orbits, many students also have the erroneous belief that these orbits are equally spaced from one another. This second misconception, I believe, is further encouraged by the 'solar system' structure of the atom which is commonly found on many chemistry classroom walls and chalkboards.

Adjacent energy levels are not equally spaced. The further an energy level is from the nucleus, the closer it is to adjacent levels. As a consequence of this nature of the atom, there is a lot of overlapping of energy levels. The TRAM has an important advantage over traditional teaching strategies in that it can clearly show students how and where these overlappings occur.

Writing electron configurations

The misconceptions discussed above are, in my opinion, the cause of confusion in the minds of many students when it comes to writing the electron configurations of many-electron atoms. In the Pacific Islands, this is not really a problem at Forms 3, 4, and 5 since official curriculum documents for science and chemistry require students at these levels to deal only with the first 20 elements of the *Periodic Table*. At Form 6, and Form 7, however, students are required to understand the electronic structures of at least the first row transition metals (elements 21 to 30) at a deeper level. In the classrooms, the traditional 'zigzag' algorithm (Figure 2) is the most common instructional tool that teachers use to teach how to write electron configuration using the *s,p,d,f* notation. Unfortunately, however, this algorithm does not effectively show students where atomic orbitals overlap. Poor teaching skills, coupled with a patchy content knowledge of chemistry, mean that the benefit of this algorithm as a teaching aid cannot go beyond the examination venue.

Figure 2: The traditional 'zig-zag' algorithm



Problematic pedagogy

The challenges of understanding the core chemistry concepts discussed above are not limited to high school students. These misconceptions also appear to permeate the walls of tertiary science courses and programs. Recently, I used TRAM with my science teacher education students at the *University of the South Pacific* (USP).

Most of these students are currently doing their second year either for their *Bachelor of Science with Graduate Certificate in Education* (BScGCE) degree or *Bachelor of Education* (BEd) degree with a single major in either chemistry, or biology, or physics. In addition, a few of them had graduated with a first degree in science, have some experience in teaching high school science and chemistry, and are currently studying for a *Postgraduate Certificate in Education* (PGCE).

At first, I asked these students to write the electron configuration for five elements, using the s,p,d,f notation:

a) Carbon, C (Z = 6)

b) Fluorine, F (Z = 9)

c) Potassium, K (Z = 19)

d) Scandium, Sc (Z= 21)

e) Zinc, Zn (Z = 30)

The answers that I expected (by using the traditional 'zigzag' algorithm in Figure 2) were:

a) C = $1s^2\,2s^2\,2p^2$

b) F = $1s^2\,2s^2\,2p^5$

c) K = $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^1$

d) Sc = $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^1$

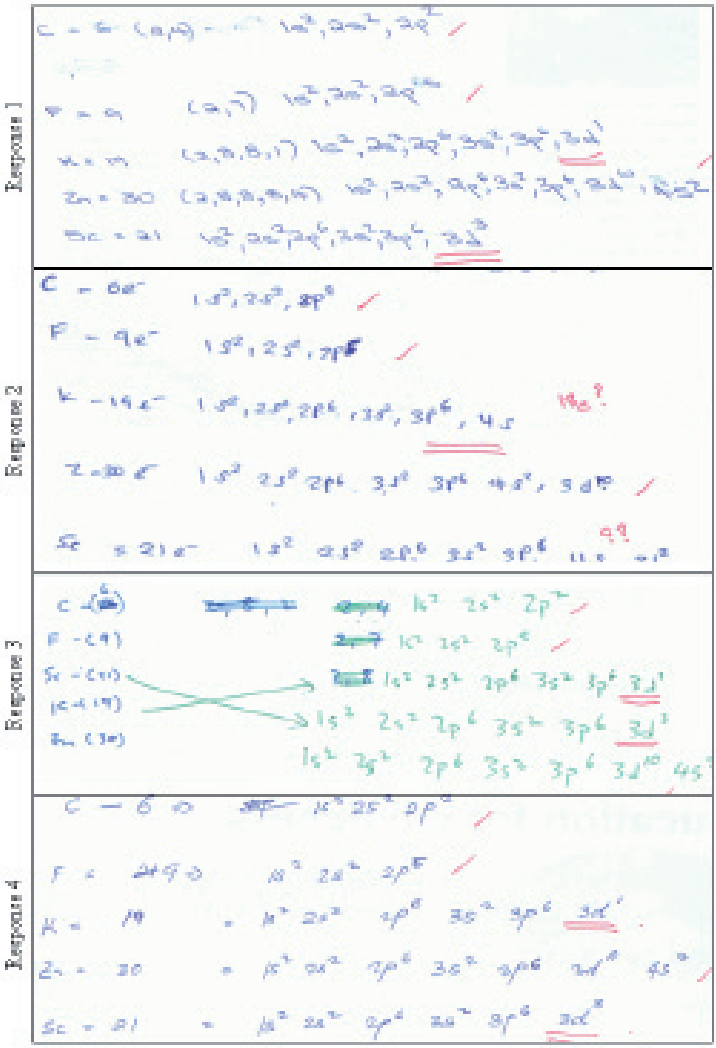
e) Zn = $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^{10}$

While the students were working, I walked around to see how they were doing. I could see that many of them were using the 'zigzag' algorithm in Figure 2 (or slightly different versions of it). Some of them were discussing the answers; some were smiling, perhaps amused by their current understanding of the concepts, and some were shaking their heads.

Ten minutes was adequate time. I collected the answers and marked them overnight.

The responses were very insightful. Although there were some very excellent answers, I was more interested in the problematic ones. Shown in Figure 3 are some of the typical mistakes that my students made. I provide them here because they provide an excellent window through which we can look into the students thinking processes and understanding of the relevant concepts.

Figure 3: Typical mistakes students make



All the responses in Figure 3 show that students had difficulty with the electron configurations of the two elements: Potassium (K) and Scandium (Sc). For both elements, many of the students tried to fill the 3d orbitals before the 4s orbital. Upon probing with a few questions to understand why, the following were the common reasons:

a) They did not remember the 'rules' for writing electron configuration;
b) They thought that all orbitals of the 3rd shell must be filled before electrons are put in the orbitals of the 4th shell; and
c) They did nott understand what the 'rules' mean.

I reflected on the first reply and what came to mind was that Figure 2 is an easy algorithm to remember and follow. One would just have to follow the blue arrows. As simple as that! But why did they make these common mistakes? Perhaps it has to do with something that is more abstract than just following this simple rule.

Replies (b) and (c), in my opinion, deserve serious thought. These could be attributed to so many reasons, but an important assertion would be that the students did not understand, in a meaningful way, why they had to fill the 4s orbital before the 3d orbitals. The effectiveness of the 'zigzag' algorithm as an instructional tool is now questionable, as the students acknowledged they did not understand what it means.

What the students did not understand is that electrons are put into the 4s orbitals because when the 3rd energy level is reached, the 4s orbital is overlapping with the 3d orbitals. From my experience with teaching Form 7 chemistry, my students' imagination had always been challenged by this overlapping idea. To be able to visualise this nature of the atom, I believe one must able to imagine the three dimensional orientation of the atom's energy levels and that region of space around the atom's nucleus.

The 'zigzag' algorithm has been mostly unsuccessful in breaking the opacity of the atom. The TRAM, however, gives the structure of the atom some 'transparency'. The transparent nature of the 'energy levels', the eye-catching colours, and the fact that students are actually going to physically handle and manipulate the 'energy levels', are some of the powerful pedagogical features of the TRAM.

The 'zigzag' algorithm is a useful instructional tool. Its simplicity and great potential to improve students test marks are unquestionable. The TRAM, however, was developed to substantiate traditional pedagogies and to give students imagination a jump-start so that they are able to 'see' the overlapping energy levels and hence appreciate fully the 'zigzag' algorithm. I have a lot of confidence that when TRAM is used alongside the 'zigzag' algorithm, teaching and learning about the atom and other related concepts can become not only more meaningful but worthwhile, and fun as well.

I am aware of some of the pedagogical and content limitations of the TRAM. For example, it provides only a 2-dimensional model of the atom, or it may help to

unnecessarily oversimplify the complex nature of the concepts. Nevertheless, I believe that TRAM is an important pedagogical step towards understanding the relevant concepts in a more meaningful way.

The Transparent Rings Atomic Model (TRAM)

This model can be prepared by following the steps below.

What you need:

1. A4-size coloured transparent (clear) plastic sheets (3 sheets per group of students). These can be obtained by cutting up cheap *Clear Bag* Folders, which are available in bookstores, into A4 size sheets. If these are unavailable, overhead projector transparencies or Photocopy films can be used.
2. a maths set (e.g. Oxford Mathematical Instrument Set)
3. an OHP pen
4. a pair of scissors (or cutting blade)
5. drawing pins (or tag pins)
6. a piece of white cardboard (A4 size or bigger).

Preparation of Transparent Rings 'Energy levels':

1. On one of the coloured plastic sheets, draw two concentric circles (see diagram below): one with a 1.5 cm radius and the other with a 0.5 radius. Use the compass point and OHP pen to do this.
2. Use the scissors (or blade) to cut along the circumference of the outside circle. What you should have now is a transparent ring (see below).

3. Repeat what you did in 1 and 2 to produce different sized rings using the following measurements:
   a) Concentric circles: 4.5 cm radius and 3.5 cm radius;
   b) Concentric circles: 6.8 cm radius and 5 cm radius;
   c) Concentric circles: 6.8 cm radius and 5 cm radius;
   d) Concentric circles: 9.5 cm radius and7.4 cm radius;
   e) Concentric circles: 11 cm radius and 8.2 cm radius;

4. Use the OHP pen to mark the centre of each ring.
   Note: In the following steps, you should have the 'zigzag' algorithm nearby to help you label the orbitals on the rings. Use the OHP pen for labelling.

5. Follow the steps below to label the orbitals on the rings:

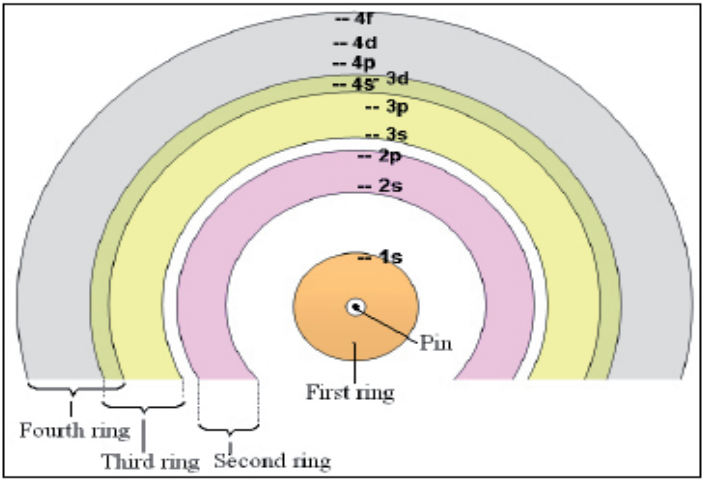
   v. At the centre of the smallest ring, use a drawing pin to pin the ring down onto the piece of cardboard. Close to the outside edge of the ring, use a short dash (-) to mark the 1s orbital. Label this dash 1s.

   vi. Remove the pin, and place the second smallest ring on the first ring. Make sure that the centres of the rings match. Pin the rings down. Close to the outside edge of this ring, label the 2p orbital. Label the 2s orbital close to the inside edge.

   vii. Remove the pin, and place the third smallest ring on the other two rings. Make sure that the centres of the rings match. Pin the rings down. Close to the outside edge of this ring, label the 3d orbital. Label the 3s orbital close to the inside edge; the 3p orbital in between the 3d and 3s orbitals (see diagram below).

   viii. Remove the pin, and place the fourth smallest ring on the other three rings. Again, make sure that the centres of the rings match. Pin the rings down.
   Note: At this stage, the overlapping of the 3rd and 4th energy levels can be observed. From this step on, the 'zigzag' algorithm will help you label the orbitals on the rings correctly.

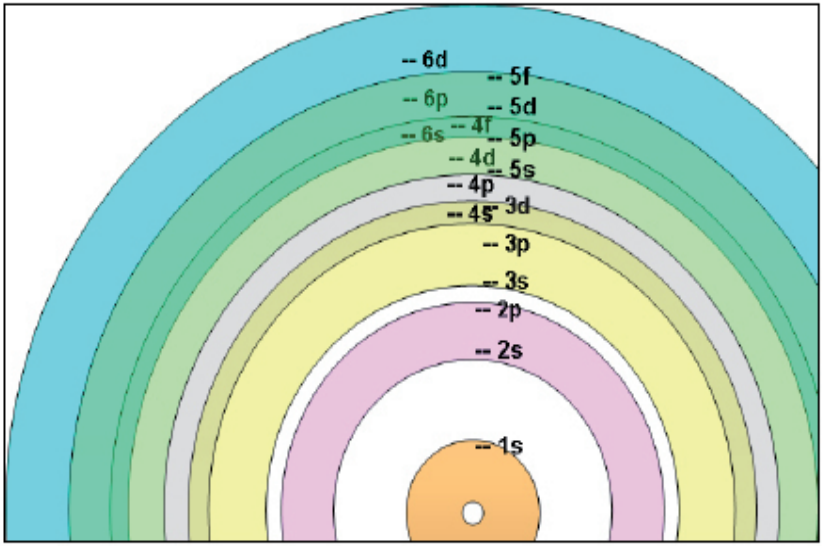
   v. Close to the outside edge of this fourth ring, label the 4f orbital. Label the 4s orbital close to the inside edge. (Note: the 4s is slightly lower than 3d). Label 4p and 4s orbitals in between the 4s and 4f orbitals (see diagram below).



vi) For the last two rings, repeat what you've done for the first four rings. The 'zigzag' algorithm will help in ensuring the overlapping orbitals are placed at the best positions.

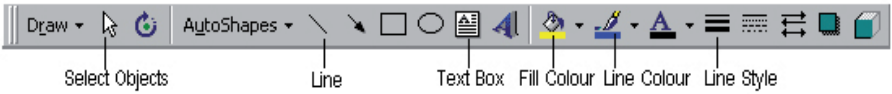
Using TRAM as an instructional tool

1. Prepare the rings in advance. Your students can help you do this.
2. Note that it is best that students are put in groups of 3 or 4. This not only would encourage active participation and discussion but you would also be saving on the costs of resources.
3. Instruct students to arrange the rings as shown in the diagram below.
4. **Before** using the 'zigzag' algorithm, use the rings to teach the energy levels, and the order in which electrons are assigned into orbitals. Draw the students' attention to the areas of overlapping orbitals (see the diagram below):
   a) 4s is filled before 3d
   b) 5s is filled before 4d and 4f
   c) 6s is filled before 4f, 5d, and 5f
   d) 6p is filled before 5f.

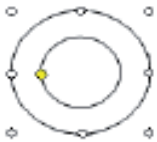


Computer and MS Word enhanced TRAM

1. Open a new Word document.
2. In the Draw menu, click on Grid and type in 2mm for both Horizontal and Vertical spacing. Tick Display grid line on screen, Use grid margin and Snap object to grid.



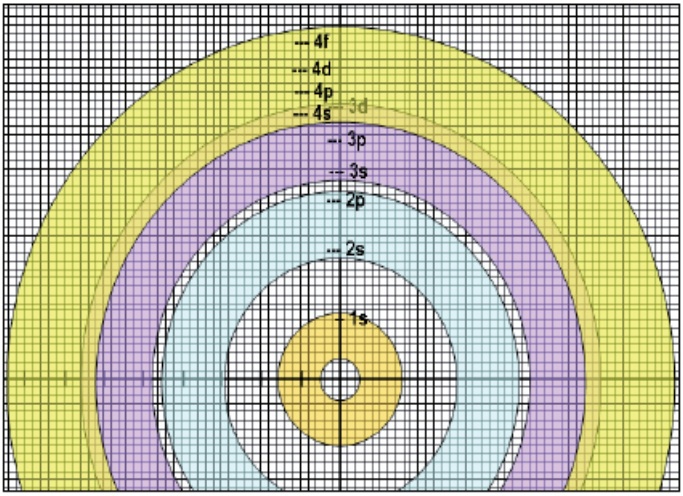
3. Activate the Drawing toolbar (see above). Use Line \ and draw two lines, making a large plus sign **+** in the middle of the grid. To make the lines thicker, select each one and then select 1pt in Line Style. Where the two lines meet is where you will centre your circles.
   Click on AutoShapes, then Basic Shapes and then the donut. Draw a donut. Centre it and then resize the diameters of both circles to the correct measurements. To resize the outer circle: right-click on the donut, select Format AutoShape, click on the Size tab, and type in the desired diameter (in millimeters) for both Height and Width. To resize the inner circle, put the pointer on the small yellow diamond and adjust, using the grid with its 2 mm^2 squares to measure.

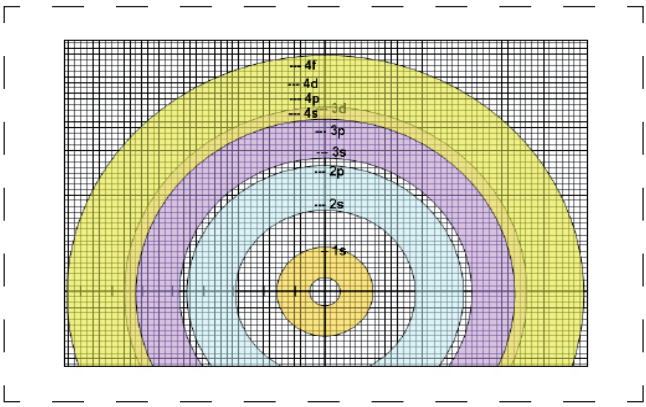


4. Use the Fill Colour function to fill the donut with a colour of your choice. While it is still selected, right click, go to Format AutoShape and set the transparency to 60%.
5. Label the circle. To do this, create a small Text Box and type in the label, e.g. 1s. Remove the box lines by selecting the text box, opening the Line Colour menu and then click on No Line.
6. Move (click and drag) the label into position in the circle. Make small adjustments by holding down the Control key and pressing the arrow keys on your keyboard. The table shows some possible locations for the labels.

Ring	Location of orbitals
First ring (first energy level)	1s, 2mm from outside edge
Second ring (second energy level)	2s, 2mm from inside edge 2p, 2mm from inside edge
Third ring (third energy level)	3s, 2mm from inside edge 3p, 8mm from inside edge 3d, 2mm from outside edge
Fourth ring (fourth energy level)	4s, 2mm from inside edge 4p, 8mm from inside edge 4d, 14mm from inside edge 4f, 2mm from outside edge
Fifth ring (fifth energy level)	5s, 1mm from inside edge 5p, 7mm from inside edge 5d, 14mm from inside edge 5f, 2mm from outside edge
Soxth ring (sixth energy level)	6s, 2mm from inside edge 6p, 10mm from inside edge 6d, 18mm from inside edge

The diagram below shows how the first four energy levels should appear.



7. Once you have drawn all the rings, remove the drawing grid. To do this, click *Draw,* and select *Grid*, and remove the tick from *Display gridlines on screen*.

8. Finally, group the TRAM. Click on the white arrow in the Draw toolbar, take your cursor to the top left hand corner of an imaginary square around the TRAM (as shown below), hold the left-mouse down and move diagonally to the opposite corner of the imaginary square. This selects everything inside the square. Open the Draw menu and select *Group.* All parts of the TRAM will now remain together.