

Section 4: Observation 2: X-ray emission

Although we can now conclude that an atom has a nuclear structure, with positive charge concentrated in a very small nucleus and a number of electrons moving about the nucleus in a much larger volume, we do not have any information on how many electrons there are in an atom of any given element or whether this number depends on the type of atom. Does a gold atom have the same number of electrons as a silver atom? All we can conclude from the data given is that the number of positive charges in the nucleus must exactly equal the number of electrons moving outside the nucleus, since each atom is neutral. Our next difficulty is that we do not know what these numbers are.

The relevant observation seems unrelated to the previous observations. In this case, we examine the frequency of x-rays emitted by atoms which have been energized in an electrical arc. Each type of atom (each element) emits a few characteristic frequencies of x-rays, which differ from one atom to the next. The lowest x-ray frequency emitted by each element is found to increase with increasing position in the periodic table.

Most amazingly, there is an unexpected relationship between the frequency and the relative mass of each atom. Let's rank order the elements by atomic mass, and assign an integer to each according to its ranking in order by mass. In the Periodic Table, this rank order number also corresponds to the element's position in the Periodic Table. For example, Hydrogen is assigned 1, Helium is assigned 2, etc. If we now plot the lowest frequency versus the position number in the periodic table, we find that the frequency increases directly as a simple function of the ranking number. This is shown here, where we have plotted the square root of the x-ray frequency as a function of the ranking number. After a single correction, there is a simple straight-line relationship between these numbers. (The single correction is that the rankings of Argon and Potassium must be reversed. These elements have very similar atomic masses. Although Argon atoms are slightly more massive than Potassium atoms, the Periodic Law requires that we place Argon before Potassium, since Argon is a member of the inert gas group and Potassium is a member of the alkali metal group. By switching their order to correspond to the Periodic Table, we can maintain the beautiful relationship shown here.)

Why is this simple relationship a surprise? The integer ranking of an element by mass would not seem to be a physical property. We simply assigned these numbers in a listing of the elements which we constructed. However, we have discovered that there is a simple quantitative relationship between a real physical quantity (the x-ray frequency) and the ranking number we assigned. Moreover, there are no "breaks" in the straight line shown here, meaning that all of the elements in our mass list must be accounted for. Both observations reveal that the ranking number of each atom must also be a real physical quantity itself, directly related to a structural property of each atom. We now call the ranking number the atomic number, since it is a number which uniquely characterizes each atom.

Furthermore, we know that each atom must possess an integer number of positive charges. Since the x-ray data demonstrates a physical property, the atomic number, which is also an integer, the simplest conclusion is that the atomic number from the x-ray data is the number of positive charges in the nucleus. Since each atom is neutral, the atomic number must also equal the number of electrons in a neutral atom.

We now know a great deal about the structure of an atom. We know that the atom has a nuclear structure, we know that the positive charges and mass of the atom are concentrated in the nucleus, and we know how many protons and electrons each atom has. However, we do not yet know anything about the positioning and movement of the electrons in the vast space surrounding the nucleus.

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