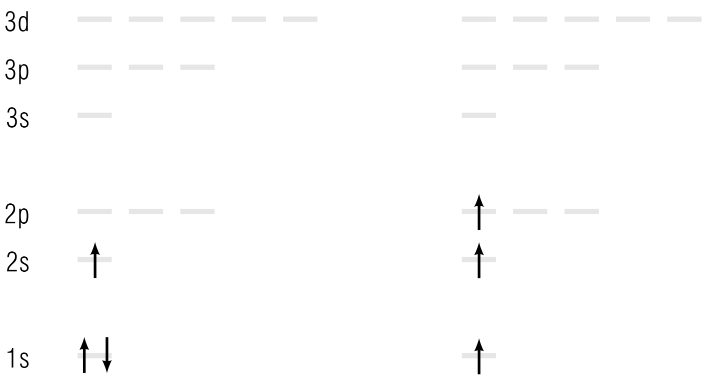
THE PAULI PRINCIPLE AND THE PERIODIC TABLE OF THE ELEMENTS



Project PHYSNET Physics Bldg. Michigan State University East Lansing, MI

THE PAULI PRINCIPLE AND THE PERIODIC TABLE
OF THE ELEMENTS

by

J. H. Hetherington

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Title: **The Pauli Principle and the Periodic Table of the Elements**

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Length: 3 hr; 12 pages

Input Skills:

1. Descibe atomic energy states using spectroscopic notation (MISN-0-244).

Output Skills (Knowledge):

K1. State the Pauli exclusion principle.

K2. Define "electron shell" and "electron sub-shell" in terms of the quantum numbers of the energy states that comprise shells or sub-shells.

K3. Arrange the elements in the periodic table given the order of filling of electron sub-shells.

Output Skills (Problem Solving):

S1. Determine the number of electrons that can occupy a given shell or a given sub-shell.

External Resources (Required):

1. Weidner and Sells, *Elementary Modern Physics*, alt. 2nd ed., Allyn and Bacon (1973). For access, see this module's *Local Guide*.

Post-Options:

1. "The Spectrum of Sodium" (MISN-0-314).
2. "The Spectrum of Helium and Calcium" (MISN-0-316).
3. "X-ray Spectra" (MISN-0-317).

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1. Background

One of the major accomplishments of quantum physics is the explanation of the chemical properties of the elements of the periodic table. This explanation is based on the shells (orbits) of electrons in the atom. These in turn can be described in terms of the quantum numbers of the single electron atom.

It is interesting that one might expect naively that the atom would be more complicated and show less regularities because the electrons around an atom would be expected to form a rather jumbled mess, expecially since they repel each other with a Coulomb force. One might expect that the electrons would best be modeled as some kind of soup which adheres to the central positive core.

However, because of the Pauli principle and the "way things work out," the many-electron atom is dominated by a shell structure. In fact, it is better to approximate the electrons as non-interacting, and to imagine the atom to be built of electrons each occupying some single particle orbit. The energy of this orbit is more directly controlled by the average distribution of the other electrons rather than by detailed collisions between them.

2. Reading and Discussion

Read Section 7.9 in WSM[1] at this time because the description which follows is meant only as a rephrasing of that discussion.

One can therefore picture the many-electron atom as shells filled with electrons. Only the outer electrons have much effect on the chemical properties of the element. This is because only the outer electrons actually "contact" other atoms. The Pauli principle, which prevents more than two electrons from existing in one quantum state, also prevents electrons from two atoms from overlapping significantly. Therefore, chemical properties are determined by the electrons which are at the surface of the atom.

One way of systematizing the structure of the periodic table is to draw an "energy level" diagram for a hypothetical atom. The order of the levels tells the order of the filling of shells. Note that we do not have an actual level diagram for any actual atom and therfore we do not put any actual numerical value on the energies of the levels. However note that the $n = 3$ and $n = 4$ levels are ordered very much like the corresponding levels of sodium. Figure 1 shows this hypothetical level diagram.

Now the Pauli principle states that no more than two electrons can reside in a single state. There are $(2\ell + 1)$ states associated with each level shown in Fig. 1. Therefore in s levels there are 2 possible electrons, in p levels 6, in d levels 10, in f levels 14.

With respect to the chemical properties it is usually the electrons in the state of highest principle quantum number n which are important. Therefore we may derive (with a few exceptions) the whole periodic table of elements by referring to Fig. 1.

Some seemingly arbitrary rules must be used: Except for helium the noble gases always occur when a p-shell is closed. It is not terribly obvious a priori why it is the closure of the p-shell which leads to the fantastic chemical stability of the noble gases. Also the chemical properties are most connected with the electrons of highest principle quantum number n. The reason for this rule, however, can be explained on the basis that these electrons extend further from the nucleus than electrons of lower n (even when the lower n electrons have higher angular momentum).

Acknowledgments

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[1] R. T. Weidner and R. L. Sells, *Elementary Modern Physics* 3rd ed., Allyn and Bacon, Boston (1980). For access, see this module's *Local Guide*.

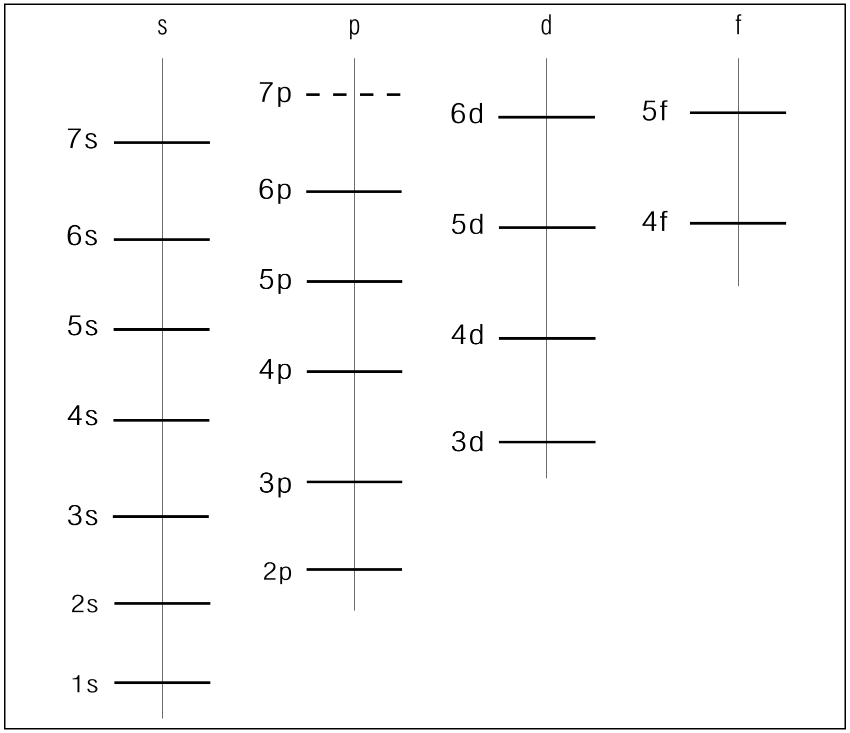
s
p
d
f
7p
7s
6d
5f
6p
6s
5d
4f
5p
5s
4d
4p
4s
3d
3p
3s
2p
2s
1s

Figure 1. An energy level diagram for a hypothetical atom.

LOCAL GUIDE

The readings for this unit are on reserve for you in the Physics-Astronomy Library, Room 230 in the Physics-Astronomy Building. Ask for them as "The readings for CBI Unit 318." Do **not** ask for them by book title.

PROBLEM SUPPLEMENT

1. How many electrons could be put into the 5g sub-shell if atoms of sufficiently high Z existed?
2. How many electrons are in the closed 2p sub-shell?

Brief Answers:

1. $\ell = 4$ for the g shell, so: $2 \times (2\ell + 1) = 18$ electrons can be put in that shell.
2. $2(2\ell + 1) = 6$

MODEL EXAM

1. State the Pauli exclusion principle.
2. The order of filling of electron sub-shells is: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, 4f, 5d, 6p, 7s, 6d, 5f, 7p. How many elements are there in the periodic table between the elements Sr (has a closed 5s sub-shell) and Ba (has a closed 6s sub-shell)?
3. What is the maximum number of electrons that can occupy a 4p sub-shell?

Brief Answers:

1. See this module's *text*.
2. 17, not including Sr or Ba.
3. 6