IDENTICAL PARTICLES

The Periodic Table:

The ground state electron configurations for heavier atoms can be pieced together in much the same way.

To first approximation (ignoring their mutual repulsion altogether) the individual electrons occupy one-particle hydrogenic states (n, l, m), called **orbitals**, in the Coulomb potential of a nucleus with charge Ze.

If electrons were bosons (or distinguishable particles) they would all shake down to the ground state (1, 0, 0), but electrons are in fact identical fermions, subject to the Pauli exclusion principle, so only *two* can occupy any given orbital (one with spin up, and one with spin down—or, more precisely, in the singlet configuration).

There are n^2 hydrogenic wave functions (all with the same energy E_n) for a given value of n, so the $n = 1$ **shell** has room for two electrons, the $n = 2$ shell holds eight, $n = 3$ takes 18, and in general the nth shell can accommodate $2n^2$ electrons.

IDENTICAL PARTICLES

The Periodic Table:

Qualitatively, the horizontal rows on the **Periodic Table** correspond to filling out each shell (if this were the whole story, they would have lengths 2, 8, 18, 32, 50, etc., instead of 2, 8, 8, 18, 18, etc.; we'll see in a moment how the electron–electron repulsion throws the counting off).

Group → / Period ↓	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
			**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

IDENTICAL PARTICLES

The Periodic Table:

With helium, the $n = 1$ shell is filled, so the next atom, lithium ($Z = 3$), has to put one electron into the $n = 2$ shell. Now, for $n = 2$ we can have $\ell = 0$ or $\ell = 1$; which of these will the third electron choose?

In the absence of electron–electron interactions, they have the same energy (the Bohr energies depend on n, remember, but not on ℓ). But the effect of electron repulsion is to favor the lowest value of ℓ, for the following reason.

Angular momentum tends to throw the electron outward, and the farther out it gets, the more effectively the inner electrons **screen** the nucleus (roughly speaking, the innermost electron "sees" the full nuclear charge Ze, but the outermost electron sees an effective charge hardly greater than e).

Within a given shell, therefore, the state with lowest energy (which is to say, the most tightly bound electron) is $\ell = 0$, and the energy increases with increasing ℓ. Thus the third electron in lithium occupies the orbital (2,0,0). The next atom (beryllium, with $Z = 4$) also fits into this state (only with "opposite spin"), but boron ($Z = 5$) has to make use of $\ell = 1$.

IDENTICAL PARTICLES

The Periodic Table:

For reasons known best to nineteenth-century spectroscopists:

$\ell = 0$ is called *s* (for "sharp")

$\ell = 1$ is *p* (for "principal"),

$\ell = 2$ is *d* ("diffuse"),

$\ell = 3$ is *f* ("fundamental").

It continues alphabetically (*g*, *h*, *i*, skip *j*, *k*, *l*, etc.)

The state of a particular electron is represented by the pair $n\ell$, with n (the number) giving the shell, and ℓ (the letter) specifying the orbital angular momentum.

The magnetic quantum number m is not listed, but an exponent is used to indicate the number of electrons that occupy the state in question. Thus the configuration:

$$(1s)^2\,(2s)^2\,(2p)^2$$

There are two electrons in the orbital (1,0,0), two in the orbital (2,0,0), and two in some combination of the orbitals (2,1,1), (2,1,0), and (2,1,-1). This happens to be the ground state of carbon.

IDENTICAL PARTICLES

The Periodic Table:

The carbon configuration: $(1s)^2\,(2s)^2\,(2p)^2$

There are two electrons in the orbital (1,0,0), two in the orbital (2,0,0), and two in some combination of the orbitals (2,1,1), (2,1,0), and (2,1,-1). This happens to be the ground state of carbon.

There exist rituals, known as **Hund's Rules** for figuring out what *total* orbital angular momentum quantum number, *L,* the *total* spin quantum number *S, and* the *grand* total (orbital plus spin), *J*, will be, for a particular atom.

The result is recorded as the following:

$$^{2S+1}L_J\,,$$

The ground state of carbon happens to be $^3P_0$: the total spin is 1 (hence the 3), the total orbital angular momentum is 1 (hence the *P*), and the *grand* total angular momentum is zero (hence the 0).