

I. • Introduced

$$\Psi(\vec{r}_1, \vec{r}_2, t)$$

III The EPR paradox

• The symmetrization requirement:

For identical particles  $\psi$

satisfies

$$\psi(\vec{r}_1, \vec{r}_2) = \pm \psi(\vec{r}_2, \vec{r}_1) \left\{ \begin{array}{l} + \text{ for bosons} \\ - \text{ for fermions} \end{array} \right.$$

• The spin and statistics connection

- all particles with integer spin are bosons, and
- " " with half-integer spin are fermions.

• Pauli exclusion principle

Identical fermions cannot occupy

the same state.

II We have been ignoring spin. The complete wavefunction of an electron is

$$\psi(\vec{r}) \chi.$$

If we consider two electrons, it is the whole

state, not just  $\psi(\vec{r})$ , that must be antisymmetric under exchange.

Result  $\left\{ \begin{array}{l} \frac{1}{\sqrt{2}} (\uparrow\downarrow - \downarrow\uparrow) \quad \text{singlet} \\ \uparrow\uparrow \\ \frac{1}{\sqrt{2}} (\uparrow\downarrow + \downarrow\uparrow) \quad \text{triplet} \\ \downarrow\downarrow \end{array} \right.$

So the singlet is anti-symmetric under exchange and the spatial

It is building on these ideas that allows us to gain a physical understanding of the periodic table.

A decent approximation is to take the electrons of an atomic element to be in hydrogenic states  $\psi_{n\ell m}$

wavefunction must be  $P^{2/4}$  symmetric. On the other hand the triplet states are symmetric and the spatial wave function is antisymmetric.

These differences actually lead to bonding (singlet) and anti-bonding (triplet) in chemistry.

These are called orbitals. But, their fermionic nature forces orbitals to fill in an interesting way

There are

$$\sum_{\ell=0}^{n-1} (2\ell+1) = 2 \cdot \frac{(n-1)n}{2} + n = n^2$$

degenerate energy levels.

Each of these levels can accept two electrons - one spin up and one spin down (really a singlet).

So each shell has

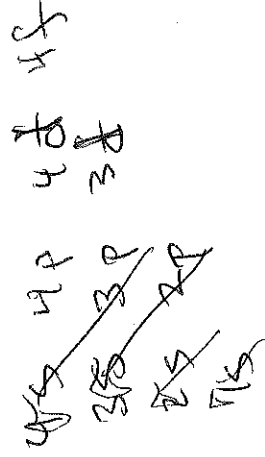
$$n=1 \quad 2 \text{ elec.s}$$

$$n=2 \quad 8 \text{ elec.s}$$

$$n=3 \quad 18 \text{ elec.s}$$

$$n \quad 2n^2 \text{ elec.s}$$

A useful way to track how orbitals is filled is



Aufbau principle or "diagonal rule"

## Nomenclature

P3/4

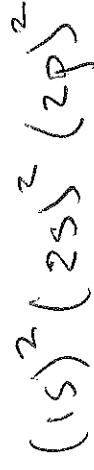
$l=0$  "s" for sharp

$l=1$  "p" for principle

$l=2$  "d" for diffuse

$l=3$  "f" for fundamental

~~$l=4$~~  "g" for abstractly



for Carbon. This naturally

leads into a discussion of

Hund's rules, which I leave

see you to study.

## III Bohr's version



Pions are spin zero and so, the decay is the positron spin gets

$$\frac{1}{\sqrt{2}} (\uparrow_{-} \downarrow_{+} - \downarrow_{-} \uparrow_{+})$$

Each time you measure the electrons and when you get spin you can get

~~50%~~ BUT whenever you get  $\uparrow_{-}$  50% and

The results of the measurements are perfectly correlated.

This does not depend on how separated the measurements are! Einstein, Podolsky and Rosen didn't count "spooky action-at-a-distance" it cannot be written and concluded that the realist as the product of Stence was the only tenable one two states — hence that Q.M. was incomplete.

The singlet state is what we call an entangled state — (you'll prove this on the HW).

$$\chi_{r(1)} \chi_{s(2)}$$

Someone measuring  $P^{4/4}$  the positron spin gets