### Spectroscopic Notation

The table gives the notation used to designate the atomic states in the first four shells.

There are two states for each my because m, = n =

-	r	-	Npoctru- scopic actation	Numerical and salaritate in sanda- salariti	Number of states in chest	Nhe (II
38.0	101	100	The second			- 16
200	100		200	5		100
3.0		(-0.00)	201	1.6		16.
	100		No			
10.0	. 10	-1,00,0	- North	1.0	110	48
	2	-2,-00,02	347	310		
- 1	100	STREET, SQUARE,	- 60			
	10	+0.00	Apr	3.6		
4.5	1	-2, -1,0,1,2	1847	10	10	200
		-0-2,-0,0,0,2,3	1.00	3.0		

## Hydrogen Electron Distributions For n = 1-4 (not to scale)

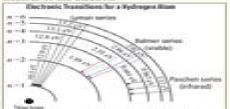
0		8	•		
Super-Br	Section 6	Secure de	Security 1		
	3		0	9	
Security 1	Sparrent .	Spanners II.	Self-month.	Set mercel.	Manual Control
0	8	0	9	5	0
Auto-O	April 1990	No. leave to \$1	-64 m - 6	Add months &	Addison-Addison
0	8	9	9		
10 m - 10	40 mm - 12	ACH THE	10 m - 0		

### Spectrum of Electronic Transitions for Hydrogen

- · When electrons transition from one energy level to auother, a photon is emitted whose energy is the difference in energy between the final and initial electron states.
- Energy of the emitted photon for hydrogen-like atoms:

$$E_y = (-13.6 \text{ eV})Z^2 \left( \frac{1}{m^2} - \frac{1}{m^2} \right)$$

Where n<sub>i</sub> (n<sub>i</sub>) is the initial (final) principal quantum mamber of the electron



FUNDAMENTAL QUANTITIES FOR A HYDROGEN ATOM		
Quantity	Victor	
Fine densities densities	$\alpha = \frac{\sigma^2}{4\pi c_0 \hbar c} = \frac{1}{137.036}$	
Dode radio	$a = \frac{4\pi v_0 h^2}{m_e c^2} = \frac{h}{\cos \mu} = 5.29177 \times 10^{-11} \text{ m}$	
Dentar productions	$E_n = \frac{m_{\rho} c^4}{2(4\pi \epsilon_0)^2 k^2 a^2} = \frac{E_1}{a^2} \cdot (n = 1, 2, 3,)$	
Photology chartest	$E_1 = -\frac{h^2}{2m_e a^2} - \frac{m^2 m_e c^2}{2} = -13.6057  \text{eV}$	
Convenient should be store from those	$\psi_0(r)\frac{1}{\sqrt{\pi r^2}}e^{-r/s}$	

- \* In classical physics, spin angular momentum is:
  - Due to the rotation of an object about an axis passing through its center of mass-
    - Orbital angular recommensum is due to revolutions of the center of mass about an axis that does not pass through the center of mass.
  - The same as the orbital angular momentum of the compoments of the object about its center of mass.
- In quantum mechanics, spin angular momentum of a particle is intrinsic to the particle and cannot be described as the orbital angular momentum of the components of the particle about the center of mass of the particle.
- Spin is strictly a quantum mechanical phenomenou.
- Spin operators are analogous to the angular momentum. operators (see the angular momentum operators in the Hydrogen Alum subsection, p. 5).

INTRINSIC SPIN OF SEVERAL SUBATOMIC PARTICLES				
Particle	Spin			
A morror	9			
Electron	1/2			
Photos	- 1			
A baryon	2 2			
Constitute	2			

- · The spin of particles remains the same in all systems, even if the angular reconsentum of the particle in a given system varies.
- The x, x; and x components of the spin operator do not commute:  $\{S_{+}, S_{+}\} = i\hbar S_{+}, \{S_{+}, S_{+}\} = i\hbar S_{+}, \text{ and } \{S_{+}, S_{+}\} = i\hbar S_{+}$
- The ic, ic, and it components of the spin operator commute with the operator for the spin squared  $(S^2 - S_c^2 + S_c^2 + S_c^2)$ :  $[s^2, s, 1 - [s^2, s, 1 - [s^2, s, 1 - 0]]$
- For a system spanned by spin eigenstates (4.49);  $S_{r}(s,m) = mh(s,m) \text{ and } S^{2}(s,m) = h^{2}s(s+1)(s,m)$ 
  - Where s is the total spin and m the z component of the spin

- The spin state is spanned by two eigenstates:
- Spin up: (†, \* †)
- Spin down: (\$.-\$)
- The magnitude of the spin is \(\frac{1}{2}\), so these kets are often
- For spin up: (1), (+), (+1), etc.
- For spin down: [1], [-], [-1], etc.
- The eigenvalues of  $S_1$  are  $+\frac{1}{2}h$  and  $-\frac{1}{2}h$ , respectively, so  $S_{s}[\frac{1}{2}, *\frac{1}{2}] = \frac{1}{2}h[\frac{1}{2}, *\frac{1}{2}] \text{ and } S_{s}[\frac{1}{2}, -\frac{1}{2}] = -\frac{1}{2}h[\frac{1}{2}, -\frac{1}{2}]$
- The eigenvalues of S<sup>2</sup> are <sup>3</sup>/<sub>2</sub>h<sup>2</sup>.

$$S^{2}\left[\frac{1}{2}, *\frac{1}{2}\right] = h^{2}\left(*\frac{1}{2}\right)\left(\frac{1}{2} *1\right)\left(\frac{1}{2}, *\frac{1}{2}\right) = \frac{1}{4}h^{2}\left(\frac{1}{2}, *\frac{1}{2}\right)$$
  
 $S^{2}\left[\frac{1}{2}, -\frac{1}{2}\right] = h^{2}\left(*\frac{1}{2}\right)\left(*\frac{1}{2} *1\right)\left(\frac{1}{2}, -\frac{1}{2}\right) = \frac{1}{4}h^{2}\left[\frac{1}{2}, -\frac{1}{2}\right)$ 

### Pauli Spin Matrices

• The kets  $\left[\frac{1}{2}, +\frac{1}{2}\right]$  and  $\left[\frac{1}{2}, -\frac{1}{2}\right]$  may be represented as column

$$\begin{vmatrix} \frac{1}{2}, -\frac{1}{2} \end{vmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$
 and  $\begin{vmatrix} \frac{1}{2}, -\frac{1}{2} \end{vmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$ 

- In matrix form, the operators S<sub>x</sub>, S<sub>y</sub>, and S<sub>y</sub> are:  $S_s = \frac{1}{2}\sigma_s$ ,  $S_s = \frac{1}{2}\sigma_s$ , and  $S_s = \frac{1}{2}\sigma_s$

$$\sigma_z = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$
,  $\sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$ , and  $\sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ 

• The operator  $S^2 = S_x^2 + S_y^2 + S_z^2$  is:  $S^2 = \frac{3}{4}h \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ 

### Time-Independent Perturbation Theory

## Consider a Hamiltonian with a small perturbation

potential: 
$$H - H^{(0)} + F$$
, where  $H^{(0)}[n^{(0)}] - E_n^{(0)}[n^{(0)}]$ .

$$H - H^{(0)} + \Gamma$$
, where  $H^{(0)} | n^{(0)} \rangle = E_{\alpha}^{(0)} | n^{(0)} \rangle$ .

$$M(n) = E_n(n)$$
, and  $V \ll E_n^{(n)}$ 

Where function to first-order precision 
$$|a\rangle - |a^{0}\rangle + \sum_{n} \frac{\left\langle an^{(n)} |x| |a^{(n)}\rangle}{E^{(n)} - E^{(n)}} |an^{(n)}\rangle$$

Second-order shift in energy due to the perturbation F:

$$E_{\alpha}^{(2)} \sim \sum_{m} \frac{\left|\left\langle m^{(0)} \left| F \right| m^{(0)} \right\rangle\right|^2}{E_{\alpha}^{(0)} - E_{\alpha}^{(0)}}.$$

d-todat procision:

$$|a\rangle - |a^{\mu}\rangle + \sum_{m,m} \frac{\langle \omega^{(m)}|F|\omega^{(m)}\rangle}{E_{m}^{(m)} - E_{m}^{(m)}} |\omega^{(m)}\rangle$$
  
 $+ \sum_{m} \sum_{m} \frac{\langle \omega^{(m)}|F|P^{(m)}\rangle \langle P^{(m)}|F|\omega^{(m)}\rangle}{\langle E_{m}^{(m)} - E_{m}^{(m)}\rangle \langle E_{m}^{(m)} - E_{m}^{(m)}\rangle} |\omega^{(m)}\rangle$   
 $- \sum_{m} \frac{\langle \omega^{(m)}|F|\omega^{(m)}\rangle \langle \omega^{(m)}|F|\omega^{(m)}\rangle}{\langle E_{m}^{(m)} - E_{m}^{(m)}\rangle \langle \omega^{(m)}\rangle} |\omega^{(m)}\rangle} |\omega^{(m)}\rangle$ 

### Quadratic Stack Effect

Consider a ground-state hydrogen atom in a uniform electric field F in the x direction.

$$H = -i\frac{\hbar}{2m}\frac{d^2}{da^2} - \frac{e^2}{4m\epsilon_0 r} + \frac{(-e)\mathcal{E}e}{r}$$

First-order shift in energy due to the perturbation I'

$$E_{\alpha}^{(1)} = \left\langle \alpha^{(2)} \middle| F \middle| \alpha^{(2)} \right\rangle = \left( -e \mathcal{E} \right) \left\langle \Psi_{100} \middle| \underbrace{\mathbb{E}}_{\text{from}} \left\langle \Psi_{100} \middle| \underbrace{\mathbb{E}}_{\text{from}} \right\rangle = 0$$

Second-order shift in energy due to the perturbation

$$E_{ij}^{(n)} = \sum_{j} \frac{\left[ (m^{(n)} | x^{j} | x^{j})^{n} + (m^{j})^{n} \sum_{j} \frac{\left[ (m^{(n)} | x^{j} | x^{j})^{n} + (n^{(n)} | x^{j})^{n} \right]}{E_{ij}^{(n)} - E_{ij}^{(n)}} = -2.294 \pm 0.00$$

• Induced dipole moment:  $d = -\frac{\partial \Delta E}{\partial \xi'} = 4.5 a_0^3 \xi'$ [Example College Dille

Gives the not of docay  $\Gamma$  of an initial quantum state  $T_i$ subjected to a perturbation 11.

$$\Gamma = \frac{2\pi}{\hbar^2} \sum_{\substack{N \in \mathbb{N} \text{min} \\ \text{states } \ell}} \left| \langle \psi_{\ell} | \mathcal{F} | \psi_{\ell} \rangle \right|^2 \delta \left( \mathcal{E}_{\ell} - \mathcal{E}_{\ell} \right)$$

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