**Announcement**

**Course webpage**
http://highenergy.phys.ttu.edu/~slee/2402/

**Textbook** *Modern Physics, 2/E*
Randy Harris, University of California, Davis
©2008 • Addison-Wesley • Cloth, 656 pp
Published 07/26/2007 • Instock

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**Physics Colloquium**

Thursday, April 9th at 3:40PM in SC 234

Featuring:
Dr. Wayne Myrvold
Brock University
Ontario, Canada

“Probabilities in Statistical Physics: What are they?”

There’s something amazing about the way that probabilities are treated in standard statistical mechanics texts. They are introduced because of incomplete knowledge of the state of a system, which means that the probabilities have to do with what we do and don’t know, rather than with the physical system under investigation. On the other hand, they are used to generate random predictions, which suggests that we think of them as something physical. In this talk, I will present a reading of these probabilities that makes sense of both aspects and, I claim, does justice to the way we use probabilities in statistical physics.

Refreshments at 3:15PM in SC 140

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**PHYS-2402**

**Lecture 21**

Apr. 9, 2015

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**Schedule**

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<td>Ch.11,12</td>
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<td>Presentations 9:00 – 12:30</td>
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<td>[Quiz.3: Ch. 8/9]</td>
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<td>5/5 [Summary]</td>
<td>5/9 Final Exam 4:300 - 7:00pm</td>
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Note 1: Term paper presentation (10 min. = 8+2 (Q&A))

Note 2: Term paper due (5/5)

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**Quantized so far:**

- The projection of angular momentum to z-axis
  \[
  L_z = m_\ell \hbar \quad (m_\ell = 0, \pm 1, \pm 2, \ldots, \pm l)
  \]

- The magnitude of (orbital) angular momentum
  \[
  |L| = \sqrt{L^2} = \sqrt{l(l+1)} \hbar \quad (l = 0, 1, 2, \ldots)
  \]

Note: \[m_\ell = \text{MAGNETIC QUANTUM NUMBER}\]

Note: \[l = \text{ORBITAL QUANTUM NUMBER}\]
**Chapter. 8**

**Spin & Atomic Physics**

**Outline:**
- Evidence of Angular Momentum Quantization
- Identical Particles
- The Exclusion Principle
- Multi-electron Atoms & the Periodic Table
- Characteristic X-Rays

It's open said that in Q.M. there're only 3 bound-state problems solvable (w/o numerical approximation tech.)
Most real application: multiple system. so, start an atom with multiple electrons

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**Hydrogen atom potential energy**

\[ U(r) = -\frac{e^2}{4\pi\epsilon_0 r} \]  \hspace{1cm} \text{(6-9)}

**Hydrogen atom wave function**

\[ \psi(r, \theta, \phi) = R(r)\Theta(\theta)\Phi(\phi) \]

**Energy of the Hydrogen Atom**

\[ E = -\frac{m_e^4}{2(4\pi\epsilon_0)^2\hbar^2 n^2} \]  \hspace{1cm} (\( n = 1, 2, 3, \ldots \))

\[ |L| = \sqrt{\ell(\ell + 1)} \hbar \]  \hspace{1cm} (\( \ell = 0, 1, 2, \ldots, n - 1 \))

\[ L_z = m_\ell \hbar \]  \hspace{1cm} (\( m_\ell = 0, \pm 1, \pm 2, \ldots, \pm \ell \))

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**Electron Probability densities in the hydrogen atom, through \( n = 3 \)**

<table>
<thead>
<tr>
<th>Letter</th>
<th>( s )</th>
<th>( p )</th>
<th>( d )</th>
<th>( f )</th>
<th>( g )</th>
<th>( h )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of ( \ell )</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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\( L = \sqrt{l(l + 1)} \hbar = 0 \)

\( L = \sqrt{l(l + 1)} \hbar = \sqrt{2} \hbar \)
Ground State:

The Electron is **NOT** Orbiting around the proton

Classical Physics:

The Electron is Orbiting around the Proton

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**Ground States:**

\[ L_{\text{GroundState}} = \sqrt{l(l+1)} \hbar = 0 \]

\[ L_s = \sqrt{l(l+1)} \hbar = 0 \]

\[ L_p = \sqrt{l(l+1)} \hbar = \sqrt{2} \hbar \]

---

**Orbiting in Classical Physics**

Conventional current is opposite electron motion

2 right-hand rules:

\[ \mu = IA \]

\[ L = r \times p \]

A charge with angular \( m/m \) has a magnetic dipole moment

\[ \mu = \frac{e}{T} \pi r^2 \]

\[ L = \frac{e}{2m_e} \]

Potential energy of a dipole \( \mu \) in a magnetic field \( B \)

\[ U = -\mu \cdot B \]

Magnetic Dipole Moment

\[ \mu_L = -\frac{e}{2m_e} L \]
Magnetic force on a system with dipole moment $\mu$

$$F = -\nabla(-\mu \cdot B) = \nabla(\mu_x B_x + \mu_y B_y + \mu_z B_z)$$

$U$

$F = \text{negative gradient of potential energy}$

$F \text{ can be measured}$

The Stern-Gerlach Experiment

An atom with a magnetic dipole moment passing through a non-uniform B-field

The Stern-Gerlach Experiment

Classical Expectation

$$F = \mu_z \frac{\partial B_z}{\partial z} \hat{z}$$

$$F = \left(-\frac{e}{2m_c} L_z\right) \frac{\partial B_z}{\partial z} \hat{z}$$

Classical expectation ($L \neq 0$)

Quantum Theory Expectation

$$F = \mu_z \frac{\partial B_z}{\partial z} \hat{z}$$

$$F = \left(-\frac{e}{2m_c} L_z\right) \frac{\partial B_z}{\partial z} \hat{z}$$

$$F = -\frac{e}{2m_c} (m_l \hbar) \frac{\partial B_z}{\partial z} \hat{z}$$

($m_l = -\ell, \ldots, +\ell$)

Ground State $\rightarrow$ $l = 0$ $\rightarrow$ $L = 0$ $\rightarrow$ $F = 0$
Quantum Theory Expectation

Ground State $\rightarrow l = 0 \rightarrow L = 0 \rightarrow F = 0$

$F = -\frac{e}{2m_e} (m_\ell \hbar) \frac{\partial B_x}{\partial z} \frac{\hbar}{2}$ ($m_\ell = -\ell, \ldots, +\ell$)

Surprise: Real Experimental Result

Ground State $\rightarrow l = 0 \rightarrow L = 0 \rightarrow F = 0$ (???)

The Solution:

INTRINSIC MAGNETIC MOMENT and ANGULAR MOMENTUM called “SPIN”

is “carried” by every electron

SPIN

$\mu_s = -\frac{e}{2m_e} L$

related to intrinsic angular $\frac{m}{m}$, $S$

gyromagnetic ratio

$\mu_s = -g_e \frac{e}{2m_e} S$ ($g_e \approx 2$)

Like for $L$:

$L = \sqrt{\ell(\ell + 1)} \hbar$

$S = \sqrt{s(s + 1)} \hbar$

$s$ – the quantum number of SPIN

Intrinsic property of a particle
For and electron: $s = 1/2$

Intrinsic angular momentum:

$$S = \sqrt{s(s + 1)} \hbar$$

$$S = \sqrt{\frac{1}{2}(\frac{1}{2} + 1)} \hbar = \frac{\sqrt{3}}{2} \hbar.$$ 

e.g. for proton $s = 1/2$, for W $s = 1$, 
see Table 8.1 (p295)