电子自旋的发现
—— Uhlenbeck & Goudsmit

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首次提出电子自旋

- Compton 首次公开发表“也许存在电子的量化旋转”（《富兰克林学院学报》）
  - “But the reasons he had given were wrong and unconvincing.” – Goudsmit
- Goudsmit 对物理史学家们的讽刺
  - 他们总是试图证明有成就的物理学家家学渊源
  - Goudsmit的家庭:祖父是荷兰海牙的一名导游,母亲在饰品店上班,父亲从事批发业
  - “Admittedly, there are cases like Heisenberg, Dirac and Einstein, there are some **exceptions**. But for most of us **luck** plays a very important role.”

实验1: 碱金属双线(1890)

- 主线系是从nP到2S的跃迁,谱线间距变化; 锐线系是从nS到2P的跃迁,谱线间距不变.
- 说明P能级分裂, 而不是S能级.
- $l = 1$ 产生 $j = 1/2, 3/2$ 两个状态.

- (无外加磁场)由轨道运动产生的磁场与自旋磁矩相互作用产生的附加能量. ——“自旋-轨道耦合”

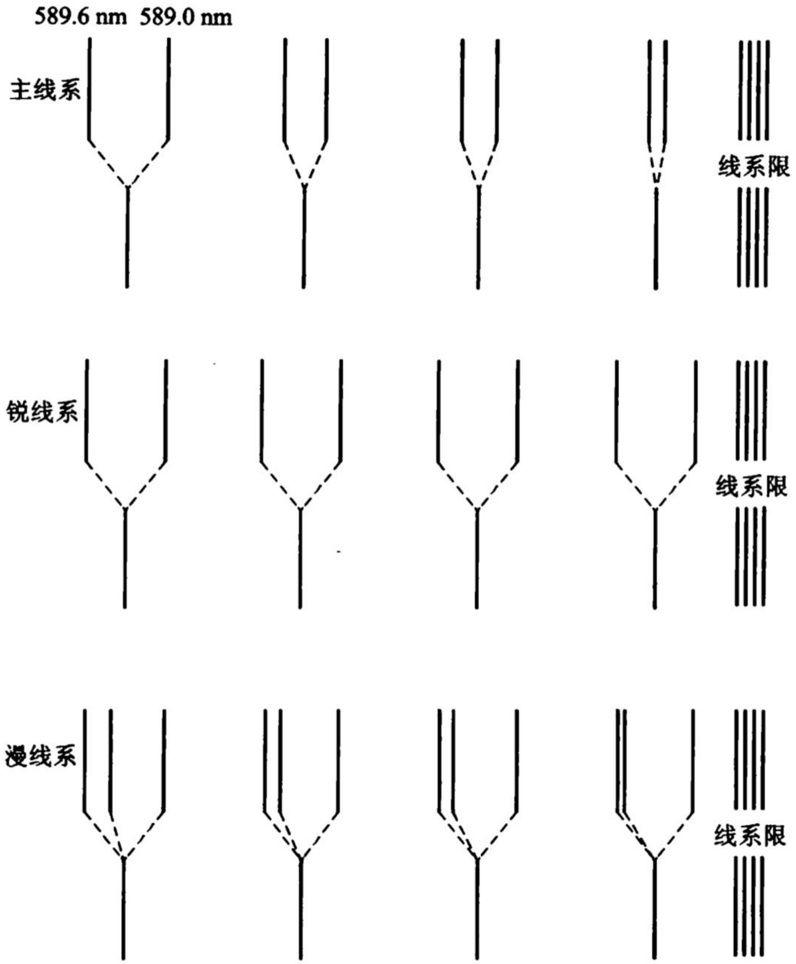
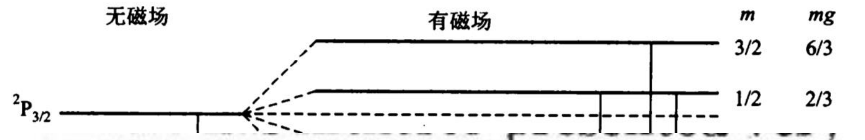


图 21.1 碱金属的双线

实验2: 反常塞曼效应(Preston,1897)

- $h\nu' = h\nu + (m_2 g_2 - m_1 g_1)\mu_B B$
- $\Delta m = \pm 1,0$

- “**<u>朗德因子不为1</u>**可以解释”



grave difficulties. However, these difficulties disappear at once when, as assumed, the electron has a spin and the ratio between magnetic moment and angular momentum of this spin is different from that corresponding to the revolution of the electron in an orbit large compared with its own size. On this assumption the spin axis of an electron not affected by other forces would precess with a frequency different from the Larmor rotation. It is easily

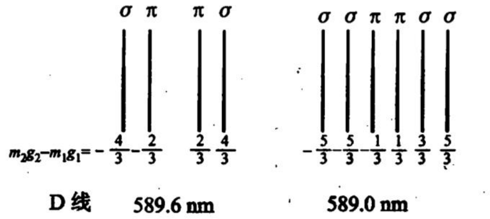


图 22.6 钠 D 线的塞曼效应

Uhlenbeck G E, Goudsmit S. Spinning electrons and the structure of spectra[J]. Nature, 1926, 117(2938): 264-265.

实验3: Stern-Gerlach实验(1921)

- 说明原子在磁场中的取向是量子化的.
- 然而氢原子的结果却是偶数条谱线.
- **<u>假设另一种角动量,并令朗德因子为2</u>**
- 计算得单电子g_j,以及$m_j g_j$

表 20. 2 施特恩－盖拉赫实验结果

原　子	基态	g	mg	相片图样
Zn, Cd, Hg, Pd	$^1S_0$	—	0	丨
Sn, Pb	$^3P_0$	—	0	丨
H, Li, Na, K, Cu, Ag, Au	$^2S_{1/2}$	2	±1	丨　丨
Tl	$^2P_{1/2}$	2/3	±1/3	丨 丨

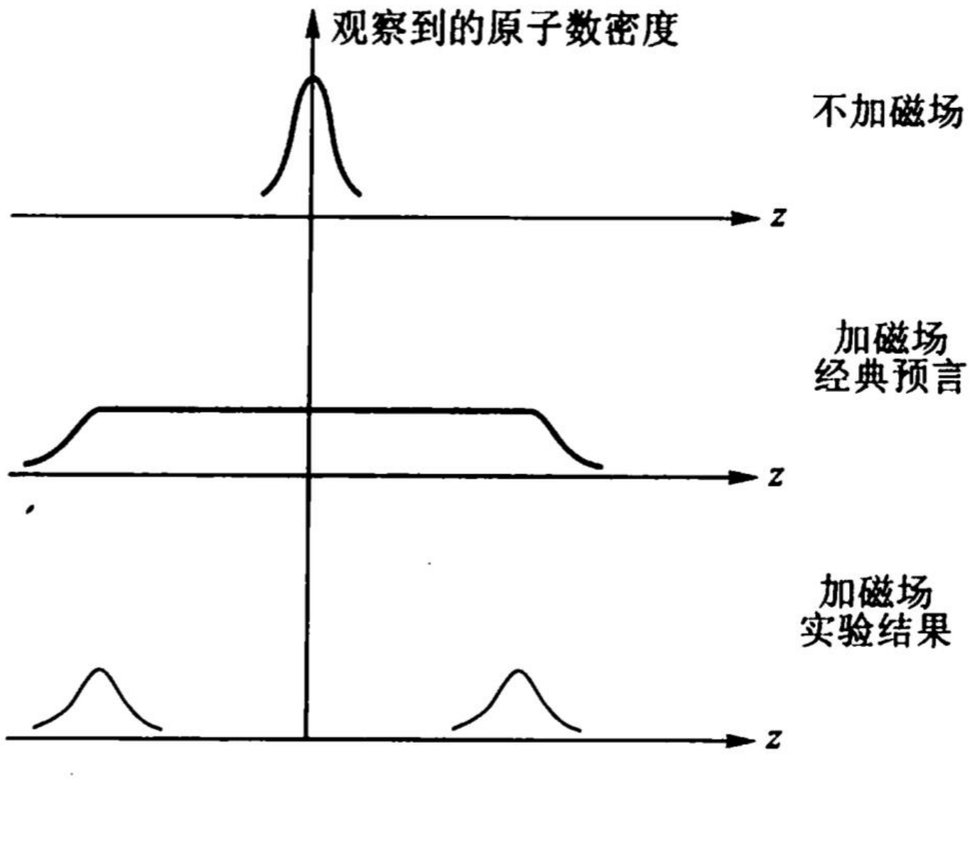


图 19. 3　施特恩－盖拉赫实验对氢原子的结果

Goudsmit 研究早期

- 两个尚不清楚的研究成果
  - 跟随Paschen研究光谱，发现禁线 forbidden line （即本不应该存在的谱线）
  - 双线公式（和索末菲对x光双线的研究结果一致）
    - 发表论文“which was published in Holland in french to be sure that nobody would read it.”
    - 两年后，美国的密立根用实验验证
- 引入不同量子数，但是**<u>没有想到对应的物理图像为电子自旋</u>**

开始与Uhlenbeck 合作

- I had introduced those quantum numbers, but if I had been a good physicist, then I would have noticed already in May 1925 that this implied that the electron possessed spin. 那些新的量子数可是我引进的😂.要是我是个好物理学家,我早就发现自旋了! 😠
- But I was no good physicist, I am no good physicist and thus I did not realize this.

但我以前不是、现在也不是, 所以我没发现.😭

- That was all in the spring of 1925. Then Uhlenbeck appears on the scene.

直到1925年那个春天,我邂逅了乌伦贝克先生.（摘自Goudsmit回忆）

论文发表与质疑

- Uhlenbeck与Goudsmit提出第四自由度——电子自旋
  - 并且认为自旋的Lande因子为2,进而提出新的量子数J.(见右图)

It seems possible on these lines to develop a quantitative theory of the Zeeman effect, if it is assumed that the ratio between magnetic moment and angular momentum due to the spin is twice the ratio corresponding to an orbital revolution. At present, however, it seems difficult to reconcile this assumption with a quantitative analysis of our explanation of the fine structure of levels. In fact it leads, in a pre-

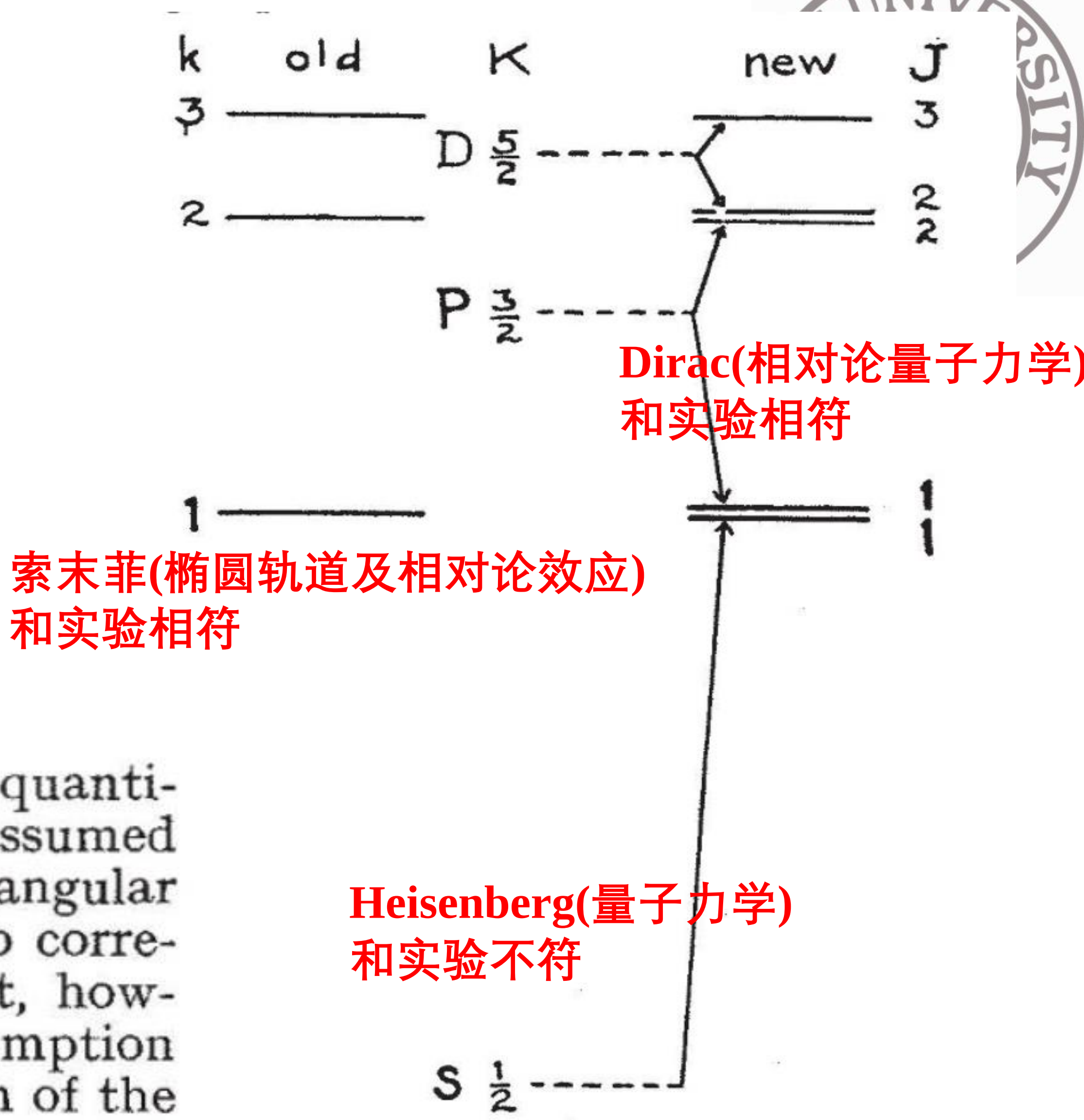


FIG. 1.

Uhlenbeck G E, Goudsmit S. Spinning electrons and the structure of spectra[J]. Nature, 1926, 117(2938): 264-265.

论文发表与质疑

- Heinsenberg质疑推导“自旋-轨道相互作用”时由坐标系转换引入的因子
- Thomas的工作: 证明电子坐标系与核坐标系中的自旋-轨道相互作用差因子1/2. (他的论文还挺难懂的)
- Pauli同样质疑该因子. 在Thomas得出正确结果之后,Pauli才写信给玻尔,表示信服电子自旋的概念.

the spin axis will precess about the instantaneous normal to the orbital plane with angular velocity

$$\frac{e}{mc^2}[\mathbf{E}\times\mathbf{v}]. \quad . \quad . \quad . \quad . \quad \text{(B)}$$

Lorents 变换展开到一阶项

so the rate of precession is

$$\frac{e}{2mc^2}[\mathbf{E}\times\mathbf{v}], \quad . \quad . \quad . \quad . \quad \text{(C)}$$

just half the expression (B).

THOMAS, L. The Motion of the Spinning Electron. *Nature* **117,** 514 (1926).

假设的验证

- 相对论量子力学建立. Dirac 给出$g_s = 2$
- Kusch, Foley (1947) 的实验 (精度为5/100000) 发现有微小偏离 $g_s = 2(1 + 0.00115(4))$ ——反常磁矩
- Schwinger : 电子本身带电产生的电磁场对自身也有作用

目前电子 g_s 因子的最新实验数据是*

$$g_s = 2.002\ 319\ 304\ 362\ 2 \pm 0.000\ 000\ 000\ 001\ 5$$

若定义

$$a = \frac{|g_s| - 2}{2}$$

则

$$a_{\exp} = 0.001\ 159\ 652\ 181\ 1(8)$$

而最新的理论计算值**为:

$$a_{\mathrm{th}} = 0.001\ 159\ 652\ 302(112)$$

它们之间的差值,好像是把全世界人口数一遍只差一个人;这样的精确度在自然科学中是空前的.

来自Ehrenfest的鼓励

- 论文投稿之前, Uhlenbeck反驳,若从经典角度理解电子自旋,电子表面速度将超过光速,产生矛盾.

- The one thing I remember is that Ehrenfest said to me: “Well, that is a nice idea, though it may be wrong. But you don‘t yet have a reputation, so you have nothing to lose”. That is the only thing I remember.
- 这是个漂亮的idea, 哪怕它可能是错的!
- 你无名无利,还害怕失去什么!

参考文献 (按对该报告的贡献排序)

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谢谢！