Int. to HEP - I

Nov. 27, 2007

* ~~CP~~, CPT

How to ~~tell~~ the distance intellegent creature Left or Right ?

Baryogenesis

* Hydrogen atom

& SUSY QM method

but would be defined as RH

$\underbrace{\text{LH}}$ to us

$\bar{n} \to \bar{p} + e^+ + \nu_e$

e^+	|	e^-
$\bar{p}$	|	p
$\bar{n}$	|	n

$n \to p + e^- + \underbrace{\bar{\nu}_e}_{\text{RH}}$

$\pi^+ \to \mu^+ \nu_\mu$

ν_μ LH μ^+ LH

$K_0 - \bar{K}_0$

$\Rightarrow$ $K_L = \frac{1}{\sqrt{1+|\epsilon|^2}}(|K_2\rangle + \epsilon|K_1\rangle)$

3π, 2π

5.2×10^{-8} sec $\tau_1 = 0.9\times10^{-10}$

$K_L \to 3\pi$ 34%

A unique definition of positive charge $\Leftarrow$ $\left\{ \begin{array}{l} \to \pi^+ + e^- + \bar{\nu}_e \\ \to \pi^- + e^+ + \nu_e \end{array} \right.$ 39% 1 : 1.0003

$CP|\pi^+ e^- \bar{\nu}_e\rangle$ (R)

$= \pi^- e^+ \nu_e$ (L)

$CP|K_1\rangle = |K_1\rangle$

$CP|K_2\rangle = -|K_2\rangle$

$CP|K_L\rangle = \frac{1}{\sqrt{1+|\epsilon|^2}}(-|K_2\rangle + \epsilon|K_1\rangle)$

Nov. 27

①

SUSY QM for S.H.O. & Hydrogen atom.

S.H.O.

$$H = -\frac{1}{2}\frac{d^2}{dx^2} + \frac{\omega^2}{2}x^2$$

$$a \equiv \frac{1}{\sqrt{2\omega}}\frac{d}{dx} + \sqrt{\frac{\omega}{2}}x, \quad a^+ \equiv -\frac{1}{\sqrt{2\omega}}\frac{d}{dx} + \sqrt{\frac{\omega}{2}}x$$

$$\Rightarrow H = \left(a^+a + \frac{1}{2}\right)\omega$$

also

$$[a, a^+] = 1, \quad [H, a] = -a\omega, \quad [H, a^+] = a^+\omega$$

$\because$ a adjoint to a^+ $\Rightarrow$ eigenvalue ~~of~~ a^+a can't be negative.

$\langle a^+a \rangle \geq 0$. or $|a|\psi_0\rangle|^2 = 0$ for lowest eigenvalue

$$\Rightarrow \left(\frac{1}{\sqrt{2\omega}}\frac{d}{dx} + \sqrt{\frac{\omega}{2}}x\right)\psi_0 = 0$$

or $\psi_0 = \left(\frac{\omega}{2\pi}\right)^{\frac{1}{4}} e^{-\frac{\omega}{2}x^2}$, $\omega a^+a|\psi_0\rangle = \left(H - \frac{\omega}{2}\right)|\psi_0\rangle = 0$

or $H|\psi_0\rangle = \frac{\omega}{2}|\psi_0\rangle = E_0|\psi_0\rangle$

~~$H a^+|\psi_0\rangle = \omega(a^+a+\frac{1}{2})a^+$~~

number operator $\hat{n} \equiv a^+a$

$$[\hat{n}, a] = \hat{n}a - a\hat{n} = -a$$

$$[\hat{n}, a^+] = \hat{n}a^+ - a^+\hat{n} = a^+$$

~~$n a^+ = a^+ (n$~~ $\quad \hat{n}|\psi_0\rangle = a^+a|\psi_0\rangle = 0$

$$\hat{n}a^+|\psi_0\rangle = a^+(\hat{n}+1)|\psi_0\rangle = 1\,\underbrace{a^+|\psi_0\rangle}_{\propto\psi_1}$$

$$\hat{n}a^+|\psi_1\rangle = n a^+a^+|\psi_0\rangle = a^+(\hat{n}+1)a^+|\psi_0\rangle$$

$$= a^+(2a^+ + a^+n)|\psi_0\rangle = 2\underbrace{(a^+)^2|\psi_0\rangle}_{\propto\psi_2}$$

$$\hat{n}(a^+)^m|\psi_0\rangle = m\underbrace{(a^+)^m|\psi_0\rangle}_{\propto\psi_m}$$

normalized to $|\psi_m\rangle = \frac{(a^+)^m}{\sqrt{m!}}|\psi_0\rangle$

$E_m = (m+\frac{1}{2})\omega$, $m = 0, 1, 2 \cdots$

$aa^+ = 1 + a^+a$

$$H a^+|\psi_0\rangle = \omega(a^+a + \tfrac{1}{2})a^+|\psi_0\rangle = \omega(\hat{n} + \tfrac{1}{2})a^+|\psi_0\rangle = \frac{3}{2}\omega\, a^+|\psi_0\rangle$$

$$|a^+|\psi_0\rangle|^2 = \langle\psi_0|aa^+|\psi_0\rangle = \langle\psi_0|1 + a^+a|\psi_0\rangle = \langle\psi_0|\psi_0\rangle = 1$$

$(1+a^+a)^2$

$$|(a^+)^2|\psi_0\rangle|^2 = \langle\psi_0|aaa^+a^+|\psi_0\rangle = \langle\psi_0|a(1+a^+a)a^+|\psi_0\rangle = 1 + \langle\psi_0|aa^+aa^+|\psi_0\rangle$$

$$= 2\langle\psi_0|\psi_0\rangle$$

for the Columb potential.

$$-\frac{\hbar^2}{2m}\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dR}{dr}\right)+\frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}R+V(r)R=ER$$

$$R=\frac{u}{r} \qquad \frac{1}{r^2}\left(r^2\left(\frac{u}{r}\right)'\right)'=\frac{1}{r^2}\left(r^2\left(\frac{u'}{r}-\frac{u}{r^2}\right)\right)'$$

$$=\frac{1}{r^2}\left[ru'-u\right]'=\frac{1}{r^2}\left(u'+ru''-u'\right)=\frac{u''}{r}$$

$$\Rightarrow \left[-\frac{\hbar^2}{2m}\frac{d^2}{dr^2}+\frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}-\frac{e^2}{r}\right]u=Eu$$

or $$\left(-\frac{d^2}{dr^2}+\frac{l(l+1)}{r^2}-\frac{2me^2}{\hbar^2 r}\right]u=\frac{2mE}{\hbar^2}u$$

can we cast it into the following form?

$$\Rightarrow \left(-\frac{d}{dr}-w\right)\left(\frac{d}{dr}-w\right)u=\cancel{\frac{2mE}{\hbar^2}}\,u \rightarrow E'$$

$$w=a+\frac{b}{r}, \qquad \rightarrow -\frac{d^2}{dr^2}+w^2+w' \qquad E'=\frac{2mE}{\hbar^2}+a^2$$

$$w^2+w'=a^2+\frac{2ab}{r}+\frac{b^2}{r^2}-\frac{b}{r^2}=\frac{b(b-1)}{r^2}+\frac{2ab}{r}+\underbrace{a^2}_{\text{extra constant}}$$

extra constant. That's fine.

$$\Rightarrow b=l+1, \quad a=-\frac{me^2}{\hbar^2(l+1)}$$

$\Rightarrow$ ground state energy $=0$, $E'=0$ or

$$0=\frac{2mE}{\hbar^2}+a^2=\frac{2mE}{\hbar^2}+\frac{m^2e^4}{\hbar^4(l+1)^2}=\frac{2m}{\hbar^2}\left(E+\frac{me^4}{2\hbar^2(l+1)^2}\right)$$

or $$E=-\frac{me^4}{2\hbar^2(l+1)^2}$$

$$\left(\frac{d}{dr}-w\right)u=0 \Rightarrow \left(\frac{d}{dr}+\frac{me^2}{\hbar^2(l+1)}-\frac{l+1}{r}\right)u=0$$

$$\frac{d}{dr}\ln u=\frac{l+1}{r}-\frac{me^2}{\hbar^2(l+1)}$$

or $$d\ln u=(l+1)d(\ln r)-\frac{me^2}{\hbar^2(l+1)}dr$$

$$u_0\propto r^{l+1}\exp\left(-\frac{me^2}{\hbar^2(l+1)}r\right), \quad \text{or } R\propto r^l\exp\left(-\frac{me^2}{\hbar^2(l+1)}r\right)$$

An interesting feature of writing physics in this way

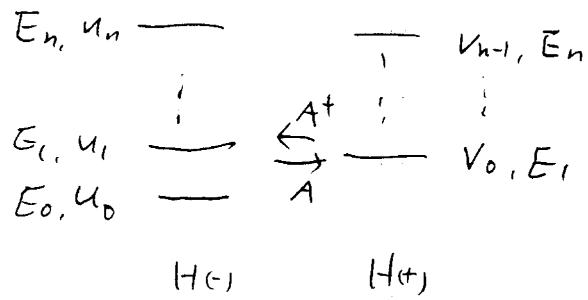
$$H_{(-)} = A^+A. \qquad A^+ = -\frac{d}{dr} - W, \quad A = \frac{d}{dr} - W$$

$$[A, A^+] = -2\frac{d}{dr}W = -2W'$$

$$H_{(+)} = AA^+ = A^+A - 2W' = H_{(-)} - 2W'$$

Say if we have found out all the solutions u_i & E_i for $H_{(-)}$,

Then $H_{(-)} u_i = E_i u_i$



$$H_{(+)} A u_n = \underbrace{AA^+}A u_n = A H_{(-)} u_n = E_n \underbrace{A u_n}$$

$\Rightarrow$ Au_n is an eigenfunction of $H_{(+)}$ with eigenvalue E_n

~~similarly~~, $\Rightarrow$ $V_{n-1} = \frac{1}{\sqrt{E_n}} A u_n$

~~$H_{(+)}$~~

similarly A^+ bring V_{n-1} to u_n and they are degenerated.

So, let's ~~try~~ look at $H_{(+)}$ for Columb problem

$$H_{(+)} = AA^+ = A^+A - 2W' = \left(-\frac{d^2}{dr^2} + \frac{\ell(\ell+1)}{r^2} - \frac{2me^2}{\hbar^2 r}\right) - 2\left(-\frac{(\ell+1)}{r^2}\right)$$

$$= \left(-\frac{d^2}{dr^2} + \frac{(\ell+1)(\ell+2)}{r^2} - \frac{2me^2}{\hbar^2 r}\right)$$

The ~~diff~~ transformation can be read.

$$b = \ell+1 \longrightarrow b = \ell+2,$$

so,
$$E^{(0)}_{(+)} = -\frac{me^4}{2\hbar^2(\ell+2)^2}, \text{ and } R^{(0)}_{(+)} \propto r^{\ell+1} \exp\left(-\frac{me^2}{\hbar^2(\ell+2)} r\right)$$

or ~~R~~ $R^1_{(-)} \propto A^+\left(r^{\ell+1} \exp\left(\frac{-me^2}{\hbar^2(\ell+2)} r\right)\right) = \left(-\frac{d}{dr} + \frac{\ell+2}{r} - \frac{me^2}{\hbar^2(\ell+2)}\right)\left(r^{\ell+1} \exp\left(\frac{-me^2}{\hbar^2(\ell+2)} r\right)\right)$

$$\propto r^\ell \exp\left(\frac{-me^2}{\hbar^2(\ell+2)} r\right)$$

$\Rightarrow$ 主量子数 $n = n_r + l + 1$

$$\boxed{E_n = -\frac{me^4}{2\hbar^2 n^2}} = -\frac{13.6\,eV}{n^2} \qquad n = 1, 2, 3 \cdots$$

$l = 0, \quad 1, \quad 2, \quad \cdots$

$\quad s \quad p \quad d \quad f \quad \cdots$

for a given $n = n_r + l + 1$ $\qquad l = (n-1), \cdots 0.$

the degeneracy is therefore

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

$$E_{photon} = h\nu = E_{ni} - E_{nf} = -\frac{me^2}{2\hbar^2}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

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