CANONICAL QUANTIZATION PRINCIPLE.

2017/3/21

<<Quantum Mechanics in way of the Axiomatic Building>>.

This is not for amateur,but those who once had learned Quantum Mechanics.Only by **CANONICAL QUANTIZATION PRINCIPLE,**we can build structure of Quantum Mechanics and Quantum Field Dynamics.While all **Interaction forces** is derived by another strong pirnciple of **General Gauge Principle**(including **equivalent principle** by Einstein).

(0):Canonical Formulation in Classical Dynamics.

(a)Variational Principle and Lagrangean Formulation in Classical Dynamics.

$\mathcal{L} \equiv \mathcal{L}(q_j; dq_j/dt)$. where q_j is **general coordinate** and dq_j/dt is the time derivative.

$0 \equiv \delta \mathcal{L}. \rightarrow 0 = \partial \mathcal{L}/\partial q_j - {}_j(d/dt)[\partial \mathcal{L}/\partial (dq_j/dt)]$. <j=1,2,...,N>..... **Euler Equation.**

(b)Canonical Formulation.

$p_j = \partial \mathcal{L}(q_j; dq_j/dt)/\partial (dq_j/dt)$; **canonical conjugate momentum of "q_j".**

$H(q_j, p_j) \equiv \Sigma_j p_j \cdot (dq_j/dt) - \mathcal{L}(q_j; dq_j/dt)$. **Hamiltonian～energy of dynamical system.**

Hamilton's **Canonical Equation.**

$dq_j/dt = +\partial H/\partial p_j = [q_j, H]$; $dp_j/dt = -\partial H/\partial q_j = [p_j, H]$.

＊Poisson Bracket:

$[u(q,p), v(q,p)] \equiv \Sigma_j\{(\partial u/\partial q_j)(\partial v/\partial p_j) - (\partial u/\partial p_j)(\partial v/\partial q_j)\}$。

Canonical *Classical* Relation.

$[q_j, q_k] = [p_j, p_k] = 0$; $[q_j, p_k] = \delta_{jk}$.

(1)Experimental Background(Wave-Particle Duality of Quantum Phenomena>.

Historically,Quantum Mechanics was initiated by following impotant experiments.

Ⅰ:Radiation Wave Field reveals Particle-like Feature.

Plank's blackbody radiation(1900). $E = h\nu = \hbar\omega. \rightarrow \omega = E/\hbar$. <h=Plank's constant>

Ⅱ: Particle(electron) reveals Wave Field-like Feature.

De Broglie's matter wave(1924). $\lambda = h/p$. $\rightarrow k = 2\pi/\lambda = p/\hbar$.

Ⅲ:synthesising plane wave of **(quantrum) wave function** : $x_\mu = (ict, \mathbf{x})$, $p_\mu = (iE/c, \mathbf{p})$.

$\Psi(x,t) = \exp i(-\omega t + kx) = \exp\langle(Et - px)/i\hbar\rangle = \exp[(-x_\mu p_\mu)/i\hbar]$.

$E\Psi = i\hbar(\partial/\partial t)\Psi$, $p\Psi = (-i\hbar\partial/\partial x)\Psi$; $p^2/2m\Psi = [(-i\hbar\partial/\partial x)^2/2m]\Psi$。

$E = p^2/2m \rightarrow i\hbar(\partial/\partial t)\Psi = [(-i\hbar\partial/\partial x)^2/2m]\Psi$..... **(quantum) wave equation**.

Ⅳ:The First Success in Hydrogen Atom(1926) by Ervin.Schrödinger.

$E = p^2/2m + V(r) \rightarrow i\hbar(\partial/\partial t)\Psi = [(-i\hbar\partial/\partial x)^2/2m + V(r)]\Psi$.... Hydrogen Atom.

Ⅴ:The Conclusion<physical variable as ***operator*** and the operand of ***wave function*****>**

$E(=H) \Leftrightarrow i\hbar(\partial/\partial t)$; $p_x \Leftrightarrow (-i\hbar\partial/\partial x)$;

$H = p^2/2m + V(r) \rightarrow i\hbar(\partial/\partial t)\Psi = H\Psi$.... **Schrödinger Equation**.

(2)**An simple analogy(but not complete!)on Quantum Observation.**

State$=\Psi$ **and Observable**$=A_h, A_m, A_I$.

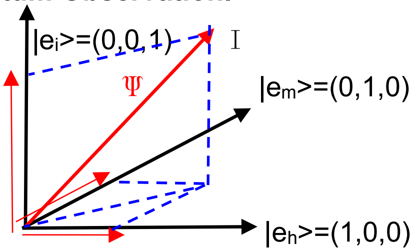
For example,persons characteristic could be described components in vector=Ψ.

$\Psi \equiv |\Psi\rangle \equiv$(height,money,iq)

∗height $=\langle e_h | A_h | \Psi \rangle$.

∗money$=\langle e_m | A_m | \Psi \rangle$.

∗ iq $=\langle e_i | A_i | \Psi \rangle$.



$\{|e_h\rangle, |e_m\rangle, |e_i\rangle\}$ are orthogonal unit vector.

An observing is ***measuring*** *each physical value,which is* ***projection operating*** *to each axis of the orthogonal unit vectors.*Thereby A is **projection operator**.

$\langle e | B \rangle$ is **vectors inner product**(=projection length),where $|B\rangle = A|\Psi\rangle$.

(3)**Physical Variables**(particle position=x,momentum=p,energy=E,)**are hermitian operator.**

The operand are function=Ψ(in function space).

$\Psi = \Sigma_j a_j |j\rangle, = \int dk.\, a(k)\, |k\rangle,$

,where $\{|j\rangle, |k\rangle$ are complete orthogonal vector set in Hilbert(function) Space$\}$.

∗Hermite definition:$\langle \chi | A \phi \rangle \equiv \int dx\, \chi^*(x) [A \phi(x)] \equiv \int dx [A \chi(x)]^* \phi(x) \equiv \langle \chi | \phi \rangle$.

"Eigen Value of hermite operator Q is real number".

$Q|j\rangle = q_j |j\rangle$, $(j=0, 1, 2, 3, \ldots,)$ $|j\rangle$ are Q**'s eigen function** with **eigne value** q_j,

$\langle i | j \rangle = \delta_{ij}$. complete orthogonal eigen function set as for observable Q.

$q_j = \langle j | Q j \rangle = q_j = \langle Q j | j \rangle = q_j^*$. ⟨this fact enables Q as physical variable⟩

(4)**Statistical Interpretation on quantum measurement.**

Observed Physical Value is $Q = \langle \Psi | Q | \Psi \rangle = \Sigma_j |a_j|^2 q_j$.,,where $\Psi = \Sigma_j a_j |j\rangle$,

$1 = \langle \Psi | \Psi \rangle = \Sigma_j |a_j|^2$, thereby $|a_j|^2$ is **probability** of observing q_j in **ensemble observing**.

☞:While each **sample observing**,we never fail,but observe **an eigen value of** Q.

This intepretation is to lead so called Shrödinger dog paradox in passive measurement.

http://www.777true.net/img007-Quick-Guide-to-Quantum-Stochastic-Mechanics.pdf

For example,**non conserving physical variable** such as electron position=x,we need interaction to get the position by injecting test photon,which is to cause so called **wave packet convergence(**instantaneous state transition by the interaction caused by us).While quantum state energy observing(conserving physical variable),we are to **passively** catch spontaneous emitting energy $\Delta E = E_{before} - E_{after}$.Then the state is to have been already and spontaneously determined as $E_{after.}$ at that time.

(5)CANONICAL QUANTIZATION PRINCIPLE for Particle Dynamics.

(a)**Special Theory of Relativity and the Coordinates.**

time & space coordinates $x_\mu=(ict,\mathbf{x})$ and the canonical conjugate variable $p_\mu=(iE/c,\mathbf{p})$ =momentum in Lorentz Covariant Formulation.<$i=\sqrt{(-1)}$, $\mu=0,1,2,3$>

(b)**Lagrangean formulation in Classical Dynamics.**

$\mathcal{L}\equiv\mathcal{L}(q_j;dq_j/dt)$. where q_j is general coordinate and dq_j/dt is the time derivative.

$H(q_j,p_j)=\Sigma_j p_j\cdot(dq_j/dt)-\mathcal{L}(q_j;dq_j/dt)$. <$j=1,2,3,\ldots,N$)

$p_j=\partial\mathcal{L}(q_j;dq_j/dt)/\partial(dq_j/dt)$.

Ⅰ:Canonical Commutation Relation as *Quantum Axiom*. $i\hbar 1\equiv[x_\mu, p_\mu]$.

The Commutation Relation is corresponding to that of classical of Poisson Bracket.

Thank to this,**momentum** is re-defined as space derivative operator.

$i\hbar 1\equiv[x_\mu, p_\mu=-i\hbar\partial/\partial x_\mu]$.← $[x_\mu(-\partial/\partial x_\mu)-(-\partial/\partial x_\mu)x_\mu]f(x)=f(x)$....**taughtology**

Ⅱ: Schrödinger Equation.

energy observable $p_0=iE/c$、E～**Hamiltonian**$=H$ and **Schrödinger Equation**.

$i\hbar 1\equiv[x_0, p_0=-i\hbar\partial/\partial x_0]=[ict,iE/c]=[t,-E]=[t,-H]=[t,-i\hbar\partial/\partial t]$.

＊Dimension of $\hbar$ is so called action,so canonical conjugate of **time** is energy$=E$.

In dynamics,energy observable is Hamiltonian$=H$.Only as for time,there are even two canonical conjugate variables.Both can not be entirely the same,but same action as for a certain **operand** of state function Ψ .That is, where $H(q_j,p_j)=H(q_j,-i\hbar\partial/\partial q_j)$.

$H\Psi=(i\hbar\partial/\partial t)\Psi$.

☞:However time evolutional Hamiltonian's Schrödinger Equation has **difficulty** in classical meaning.Hamiltonian is energy,while time and energy uncertainty principle never allow being of accurate values of those at the same time.In fact,time can **not be observable** in quantum mechanics.Because this is not exact : $i\hbar 1=[t,-H]$. Due to Rölich-Dixmier theorem,by employing certain uitary transform,such commutational variables are transformed to shrödinger type as $i\hbar 1=[t,-i\hbar\partial/\partial t]$.$-i\hbar\partial/\partial t$ can have the eigen value from $-\infty$ to $+\infty$. H can not have $-\infty$. Time evolutional Hamiltonian(～energy)can not be causalitics(＝information loss), but **stochastic operator**.

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(6)CANONICAL QUANTIZATION PRINCIPLE for Wave Field ϕ^a in Lagrangean formulation.

(a)**Lagrangean formulation of Quantum Field.**

$\mathcal{L} \equiv \mathcal{L}(\phi^a; \partial_\mu \phi^a)$. ← due to both principle of Lorentz and Gauge Covariance.

$0 \equiv \delta\mathcal{L} \equiv \delta\phi^a[\partial\mathcal{L}/\partial\phi^a] - \delta\phi^a[\partial_\mu[\partial\mathcal{L}/\partial(\partial_\mu\phi^a)] + \partial_\mu[(\delta\phi^a)\partial\mathcal{L}/\partial(\partial_\mu\phi^a)]$。

☞ : the last term must be zero at surface integral at infinity.

(b)**Euler Equations(field equations in c(lassical) number).**

$\partial\mathcal{L}/\partial\phi^a - \partial_\mu[\partial\mathcal{L}/\partial(\partial_\mu\phi^a)] = 0.$

(c)**Noether Current and the Charge Conservation Law**.

$0 = \partial_\mu[(\delta\phi^a)\partial\mathcal{L}/\partial(\partial_\mu\phi^a)] \equiv \partial_t\delta Q + \mathrm{div}\,\boldsymbol{\delta J}$.

☞ : Euelr Equation in (a) is varid at any space,so we can derive this.

(d)canonical conjugate of momentum.

$\Pi^a \equiv \partial\mathcal{L}/\partial_t\phi^a = (ic)^{-1}\partial\mathcal{L}/\partial_0\phi^a$. canonical conjugate of momentum with $\phi^a(x)$.

(f)**the commutation(anti-commutation(spinor))relations<field variable algebra>.**

$I\hbar\delta^{ab}\delta(\mathbf{x}-\mathbf{y}) \equiv [\boldsymbol{\phi}^a(x_0, \mathbf{x}), \Pi^b(x_0, \mathbf{y})]_\pm$.

☞;field variables{$\boldsymbol{\phi}^a$, Π^a}becomes **operator** as q(uantum) number(→(g)).

(g)**operator formulation of spinor=$\phi(x)$ and gauge field=$A^a_\mu(x)$ in QFT.**

☞;time evolution is perpetual process of **annihilating present** and **creating future**.

Don't worry for the details,but notice on annihilation and creation operator in the colours,

Now author shows you how to describe elementary particle reactions in **Q**uantum **F**ield **T**heory.

$\bar{\phi} \equiv \Sigma_s \iiint dp^N\{\mathbf{b}(\mathbf{p};\mathbf{s})\bar{v}(\mathbf{p};\mathbf{s})\exp(-px/i\hbar) + \mathbf{a}^+(\mathbf{p};\mathbf{s})\bar{u}(\mathbf{p};\mathbf{s})\exp(+px/i\hbar)\}.$

$\phi \equiv \Sigma_s \iiint dp^N\{\mathbf{a}(\mathbf{p};\mathbf{s})u(\mathbf{p};\mathbf{s})\exp(-px/i\hbar) + \mathbf{b}^+(\mathbf{p};\mathbf{s})v(\mathbf{p};\mathbf{s})\exp(+px/i\hbar)\}.$

☞;$0 = (\hbar\gamma^\mu\partial_\mu + mc)u(p;s)\exp(-px/i\hbar)$.

$u(p;s)\exp(-px/i\hbar)$ =free particle state of **spinor**(electron,quark,...,elementary particles).

$v(p;s)\exp(+px/i\hbar)$ =free anti-particle state of **spinor.**

☞;$\mathbf{a}^+(\mathbf{p};\mathbf{s})|0\rangle$=creating particle of $u(p;s)\exp(-px/i\hbar)$ from vacuum.$|0\rangle$=vacuum state.

$a^{+}(p;s)$ = "**operator**" of creating a particle(**p;s**)of momentum and other physical value=s.

$a(p;s)$ = "**operator**" of annihilating a particle(**p;s**)of momentum and other physical value.

$b^{+}(p;s)$ = creating an anti-particle(**p;s**)of momentum & other physical value.

$b(p;s)$ = annihilating an anti-particle(**p;s**)of momentum & other physical value.

$$A^{a}_{\mu}(x) \equiv \Sigma_{\lambda} \iiint dp^{N} \sqrt{}(1/2|q_0|)\, \varepsilon_{\mu}(q;\lambda)\{c^{a}(q;\lambda)\exp(-qx/i\hbar) + c^{a+}(q;\lambda)\exp(+qx/i\hbar)\}.$$

☞; $0 = \Box\, \varepsilon_{\mu}(q;\lambda)\exp(-qx/i\hbar)$.

$\varepsilon_{\mu}(q;\lambda)\exp(-qx/i\hbar)$ = free particle state of gauge particle of momentum=q and other physical value= λ. ε_{μ} = polarization vector of EM field.

(h)**Lagrangean ,Hamiltonian Density and the State Evolution Equation.**

QGD Lagrangean the definition.

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$$\mathcal{L}_{QGD} \equiv -c\bar{\phi}[\hbar\gamma^{\mu}(\partial_{\mu} + gA^{a}_{\mu}\mathbf{Q}_{a}) + mc]\phi + icB^{a}\partial_{\mu}A^{a}_{\mu} + ½\alpha^{a}B^{a}B^{a}$$

$$-(1/2\eta)(\partial_{\mu}A^{a}_{\nu} - \partial_{\nu}A^{a}_{\mu} + gf_{b\ c}^{\ a}A^{b}_{\mu}A^{c}_{\nu})^{2} + \chi\bar{C}^{a}\cdot\partial_{\mu}(\partial_{\mu}C^{a} + f_{b\ c}^{\ a}A^{b}_{\mu}C^{c}).$$

$$= -c\bar{\phi}[\hbar\gamma^{\mu}(\partial_{\mu} + gA^{a}_{\mu}\mathbf{Q}_{a}) + mc]\phi - (1/2\eta)(\partial_{\mu}A^{a}_{\nu} - \partial_{\nu}A^{a}_{\mu})^{2}$$

$$-(/\eta)gf_{b\ c}^{\ a}A^{b}_{\mu}A^{c}_{\nu}(\partial_{\mu}A^{a}_{\nu} - \partial_{\nu}A^{a}_{\mu}) - (1/2\eta)(gf_{b\ c}^{\ a}A^{b}_{\mu}A^{c}_{\nu})^{2}$$

$$+ icB^{a}\partial_{\mu}A^{a}_{\mu} + ½\alpha^{a}B^{a}B^{a} - \chi\partial_{\mu}\bar{C}^{a}\cdot(\partial_{\mu}C^{a} + gf_{b\ c}^{\ a}A^{b}_{\mu}C^{c}).$$

$$\mathcal{H}_{QGD} \equiv \Pi^{a}\cdot\partial_{t}\phi^{a} - \mathcal{L}. \rightarrow H \equiv \iiint dx^{N}\mathcal{H}. \rightarrow \quad H\Psi = i\hbar\partial\Psi/\partial t.$$

QGD Hamiltonian of free terms and interaction terms.

$$\mathcal{H}_{QGD} \equiv \mathcal{H}^{0}_{QGD} + \mathcal{H}^{I}_{QGD} \equiv \mathcal{H}^{0}_{QGD} + \Gamma^{a}_{\mu}A^{a}_{\mu}.$$

$$= c\hbar\bar{\phi}\gamma^{k}\partial_{k}\phi + \bar{\phi}mc^{2}\phi$$

$$-\{(1/2\eta)(\partial_{0}A^{a}_{k} - \partial_{k}A^{a}_{0})^{2} + (1/2\eta)(\partial_{k}A^{a}_{1} - \partial_{1}A^{a}_{k})^{2}\} - (1/\eta)(\partial_{0}A^{a}_{k} - \partial_{k}A^{a}_{0})\partial_{k}A^{a}_{0}.$$

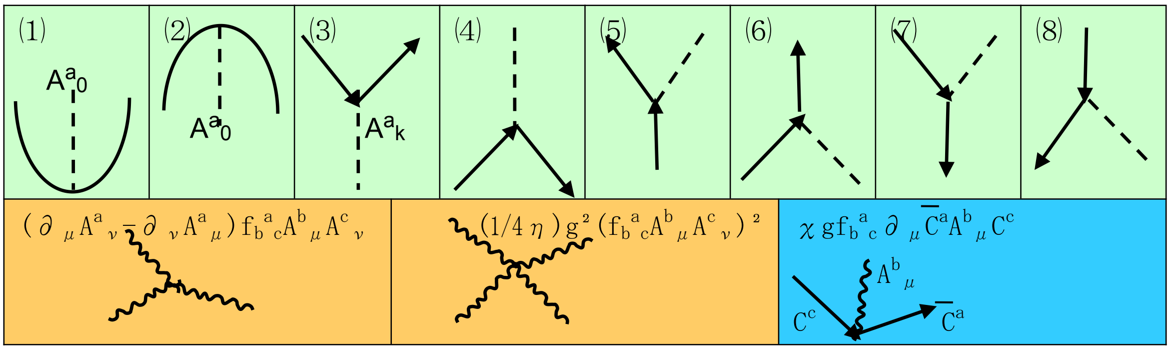
$$-icB^{a}\partial_{k}A^{a}_{k} - (\alpha^{a}/2)B^{a}B^{a} + \chi\partial_{k}\bar{C}^{a}\partial_{k}C^{a}$$

$$\left.\begin{aligned} &+ gc\hbar\bar{\phi}\gamma^{\mu}A^{a}_{\mu}\mathbf{Q}_{a}\phi \\ &+ (1/\eta)gf_{a\ b}^{\ c}A^{a}_{\mu}A^{b}_{\nu}(\partial_{\mu}A^{c}_{\nu} - \partial_{\nu}A^{c}_{\mu}) \\ &+ (1/2\eta)(g^{2}f_{a\ c}^{\ f}f_{d\neq a\ e}^{\ \ f}A^{a}_{\mu}A^{c}_{\nu}A^{d}_{\mu}A^{e}_{\nu}) \\ &+ \chi gf_{a\ b}^{\ c}\partial_{\mu}\bar{C}^{c}A^{a}_{\mu}C^{b}. \end{aligned}\right\} \mathcal{H}^{I}_{QGD} \equiv \Gamma^{a}_{\mu}A^{a}_{\mu}.$$

$$*\ \{-(1/2\eta)(\partial_{0}A^{a}_{k} - \partial_{k}A^{a}_{0})^{2} + (1/2\eta)(\partial_{k}A^{a}_{1} - \partial_{1}A^{a}_{k})^{2}\} \equiv \{\mathbf{E}^{a}\mathbf{D}^{a} + \mathbf{H}^{b}\mathbf{B}^{b}\}/2$$

(i)**elementary 1^{st} order reactions by Feymann Diagram in Hamiltonian.**

Feynman Diagram of $\mathcal{H}^I_{QGD} \equiv \Gamma^a_\mu A^a_\mu$.



☞; 1^{st} order reaction has a cross point of $\{\phi, A^a_\mu, \phi\}$. Multi-order ones has multi-cross points.

Example-1)

Calculation for deriving **Feymann Diagram** of spinor×gauge interaction{(1), ... , (8)}.

$$\mathcal{H}^I_{QGD} = \bar{\phi} \gamma^\mu A^a_\mu \mathbf{Q}_a \phi = \Sigma_s \oiiint dp^N \{b(p;s) v(p;s) \exp(-px/i\hbar) + a^+(p;s) u(p;s) \exp(+px/i\hbar)\}.$$

$$\times \gamma^\mu \times \Sigma_\lambda \oiiint dp^N \sqrt{}(1/2|q_0|)\, \varepsilon_\mu(q;\lambda) \{c^a(q;\lambda) \exp(-qx/i\hbar) + c^{a+}(q;\lambda) \exp(+qx/i\hbar)\}$$

$$\mathbf{Q}_a \times \Sigma_s \oiiint dp^N \{a(p;s) u(p;s) \exp(-px/i\hbar) + b^+(p;s) v(p;s) \exp(+px/i\hbar)\}$$

$$= [A a^+(p;s) + B b(p;s)]$$
$$\times [C c^{a+}(q;\lambda) + D c^a(q;\lambda)]$$
$$\times [E b^+(p;s) + F a(p;s)]$$

Each line has two term of **creation** and annihilation op,
So the 3 lines product make <u>8 terms</u> in following box.
Note Boson means gauge particle.

$a^+(p;s) c^{a+}(q;\lambda) b^+(p;s)$	vacuum creation from nothing	(1)
$b(p;s) c^a(q;\lambda) a(p;s)$	vacuum annihilation into null	(2)
$a^+(p;s) c^a(q;\lambda) b^+(p;s)$	pair creation by Boson	(3)
$b(p;s) c^{a+}(q;\lambda) a(p;s)$	pair annihilation to Boson	(4)
$a(p;s) c^{a+}(q;\lambda) a^+(p;s)$	Boson emission by particle	(5)
$a(p;s) c^a(q;\lambda) a^+(p;s)$	Boson absorption by particle	(6)
$b(p;s) c^{a+}(q;\lambda) b^+(p;s)$	Boson emission by -particle	(7)
$b(p;s) c(q;\lambda) b^+(p;s)$	Boson absorption by -particle	(8)

(j)Higher Order Reactions<outline of the algorithm>.

$\mathcal{H}\equiv\Pi^a\cdot\partial_t\phi^a-\mathcal{L}.\ \to\ H\equiv\iiint dx^N\mathcal{H}.\to\ \ H(t)\Psi(t)=i\hbar\,\partial\Psi(t)/\partial t\equiv i\hbar\,\partial_t\Psi(t).$

$\to\ \Psi(t)=\ \Psi(t_0)+(1/i\hbar)\int_{t0}{}^{t}du\mathbf{H(u)}\Psi(u)$

$=\ \Psi(t_0)+(1/i\hbar)\int_{t0}{}^{t}du_1\mathbf{H(u_1)}\langle\Psi(t_0)+(1/i\hbar)\int_{t0}{}^{u1}du_2\mathbf{H}(u_2)\Psi(u_2)\rangle$

$=\ \Psi(t_0)+(1/i\hbar)\int_{t0}{}^{t}du_1\mathbf{H(u_1)}\langle\Psi(t_0)+(1/i\hbar)\int_{t0}{}^{u1}du_2\mathbf{H}(u_2)\langle\Psi(t_0)+(1/i\hbar)\int_{t0}{}^{t}du_3\mathbf{H(u_3)}\Psi(u_3)\rangle$

$=\ \Psi(t_0)+(1/i\hbar)\int_{t0}{}^{t}du_1\mathbf{H(u_1)}\Psi(t_0)+(1/i\hbar)^2\int_{t0}{}^{t}du_1\int_{t0}{}^{u1}du_2\mathbf{H(u_1)H(u_2)}\Psi(t_0)+$

$+(1/i\hbar)^3\int_{t0}{}^{t}du_1\int_{t0}{}^{u1}du_2\int_{t0}{}^{u2}du_3\mathbf{H(u_1)H(u_2)H(u_3)}\Psi(t_0)+\ldots\ldots$

☞;time integral in above is a style of $\int_{-\infty}{}^{\infty}dx_0\exp[x_0(p_0+q_0+..)/i\hbar]=\delta(p_0+q_0+..).$

It is **energy conservation law** between initial(t= −∞) and final state(t=−∞).

In actual,time can not be finite,but rather definite as −∞(initial state)<t<+∞(final state).

A quantum time in the past quantum physics is confused,but not definite in classical dynamics.

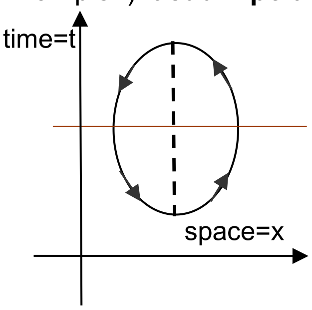
☞: $\partial\Psi/\partial t=(i\hbar)^{-1}H\Psi.\to\Psi(t)=T\exp[((i\hbar)^{-1}\int_{t0}{}^{t}duH(u)]\Psi(t_0).$ <T=time ordered operator>

$\exp[A]\equiv 1+A^2/2!+A^3/3!+\ldots\ldots+A^n/n!+\ldots..$

Thus **higher order reactions** are described **multi-product of Hamiltonians** the time ordered.

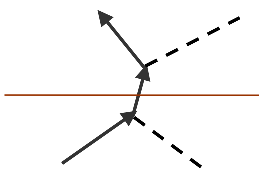
Those are cascaded 1^{st} order reactions as follows.

Example2)**vacuum polarization reaction** of cascade (1)→(2).



vacuum polarization is creation from nothing toward pair annihilation into nothing.This reaction is very fundamental of **space transportation** of matter(particles).Also **Coulomb interaction** is due to also this reaction in non-localized field. Note the dot line of $A^a{}_{\mu=0}$ is longitudinal gauge field with negative energy(attraction force between electron & positron).

Example3)electron photon scattering **reaction** of cascade (6)→(5).



Reference in website:

Quantum field theory and the Standard Model W. Hollik,Max Planck Institut für Physik

https://cds.cern.ch/record/1281946/files/p1.pdf

Quantum Field Theory - damtp - University of Cambridge

http://www.damtp.cam.ac.uk/user/tong/qft/qft.pdf

Introduction to Quantum Field Theory Matthew Schwartz,Harvard University

http://isites.harvard.edu/fs/docs/icb.topic521209.files/QFT-Schwartz.pdf

*All of those are big books of paintaking works. More simplified structual sequnce may be,

(1)**Non Interaction Field Equations**<Special Theory of Relativity with the defiitions>

$x_\mu = (x_0 = ict, x_1, x_2, x_3)$.<$i = \sqrt{(-1)}$, μ=0,1,2,3>.

Bosorn: $0 = p_\mu p_\mu + (mc)^2. \rightarrow\ p_\mu = -i\hbar\partial_\mu. \rightarrow\ [-\hbar^2\Box + (mc=0)^2] A^a{}_\mu(x) = 0.$

Spinor: $0 = [-\hbar^2\Box + (mc)^2] = (-i\hbar\gamma^\mu\partial_\mu + mc)(+i\hbar\gamma^\nu\partial_\nu + mc). \rightarrow. 0 = (i\hbar\gamma^\nu\partial_\nu + mc)\phi(x).$

$A^a{}_\mu(x) \equiv \Sigma_\lambda \oiiint dp^N \sqrt{}(1/2|q_0|)\ \varepsilon^a{}_\mu(q;\lambda)\{c^a(q;\lambda)\exp(-qx/i\hbar) + c^{a+}(q;\lambda)\exp(+qx/i\hbar)\}.$

$\phi(x) \equiv \Sigma_s \oiiint dp^N \{a(p;s)u(p;s)\exp(-px/i\hbar) + b^+(p;s)v(p;s)\exp(+px/i\hbar)\}.$

(2)**Canonical Quantization of Field and the operator algebra.**

$\{\phi_{\alpha\beta}(x_0, x), i\hbar\phi^*{}_\beta(x_0, x')\}^+ = i\hbar\delta^{\alpha\beta}\ \delta(x'-x),$

$[A^a{}_0(x_0, x), B^b(x_0, x')] = i\hbar\delta^{ab}\ \delta(x'-x),$

. . . .

(3)**General Gauge Interaction Filed.**

*R.Utiyama,Phys.Rev.**101**(1956),1597<Invariant theoretical interpretatio of interaction>.

*http://www.777true.net/GRAVITY_FIELD_as_GUAGE_one.pdf

Gravity Field becomes Gauge one in localized **linear coordinate**(1993 by author).

The Principle of Equivalent had become expressed as localized Lorentz Invariant.

Then localized Lorentz invaiant has same transform as general gauge one<SO(11;1)>.

*L.D.Faddeev&V.N.Popov,Phys Lett,**25B**(1967),29.<Quantization of General Gauge Field in Path Integral Formulation>.

QGD Lagrangean the definition.

$$\mathcal{L}_{QGD} \equiv -c\bar{\phi}[\hbar\gamma^\mu(\partial_\mu + gA^a{}_\mu \mathbf{Q}_a) + mc]\phi + icB^a\partial_\mu A^a{}_\mu + \tfrac{1}{2}\alpha^a B^a B^a$$
$$-(1/2\eta)(\partial_\mu A^a{}_\nu - \partial_\nu A^a{}_\mu + gf_b{}^a{}_c A^b{}_\mu A^c{}_\nu)^2 + \chi\bar{C}^a\cdot\partial_\mu(\partial_\mu C^a + f_b{}^a{}_c A^b{}_\mu C^c).$$

(4)**All the information on QGD is derived only from $\mathcal{L}_{QGD}$.**

http://www.777true.net/img008-Quick-Guide-to-Quantum-Gravitational-Dynamics.pdf

http://www.777true.net/Energy-Creation-Process-from-QED-to-QGD.pdf