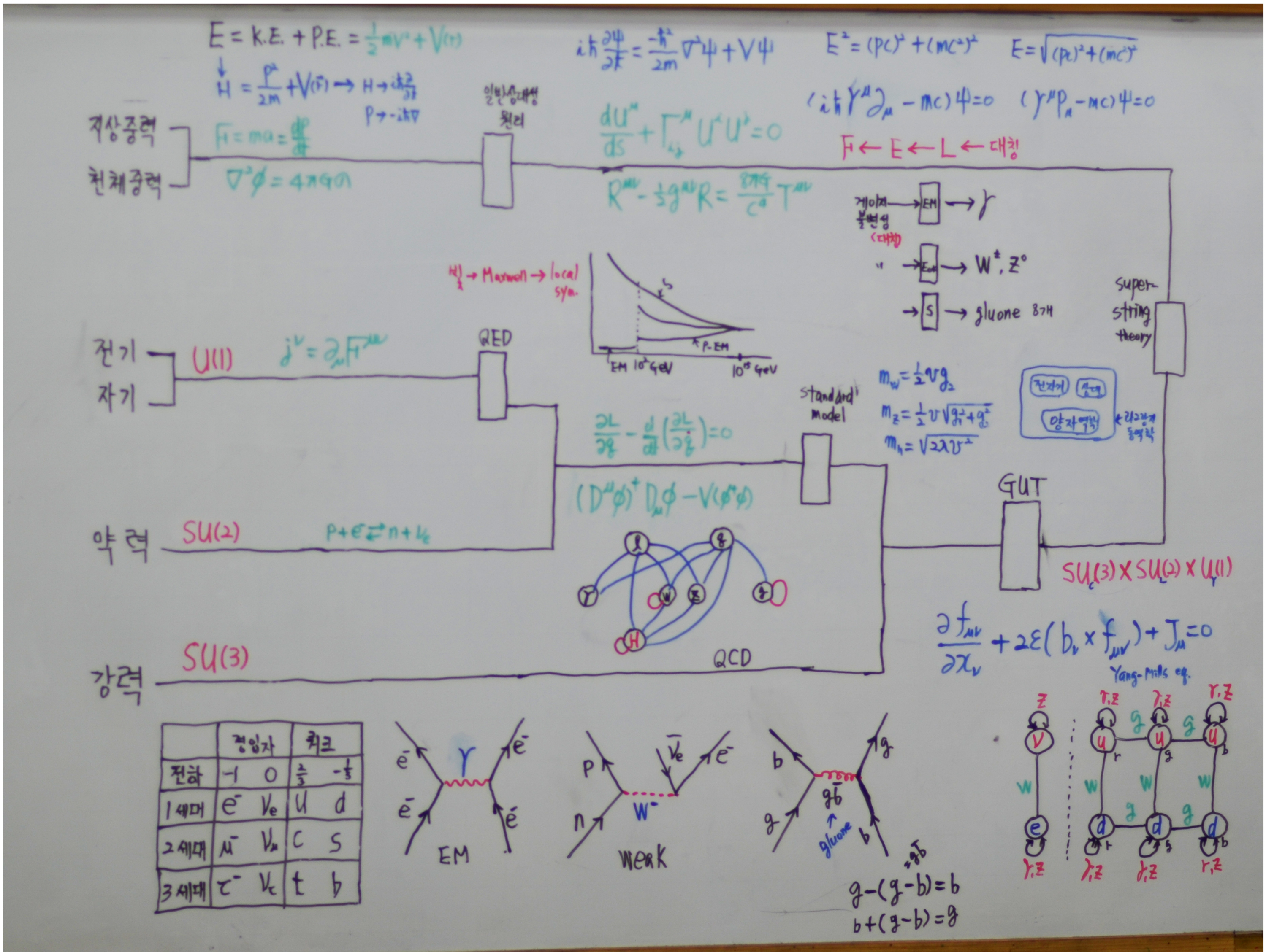
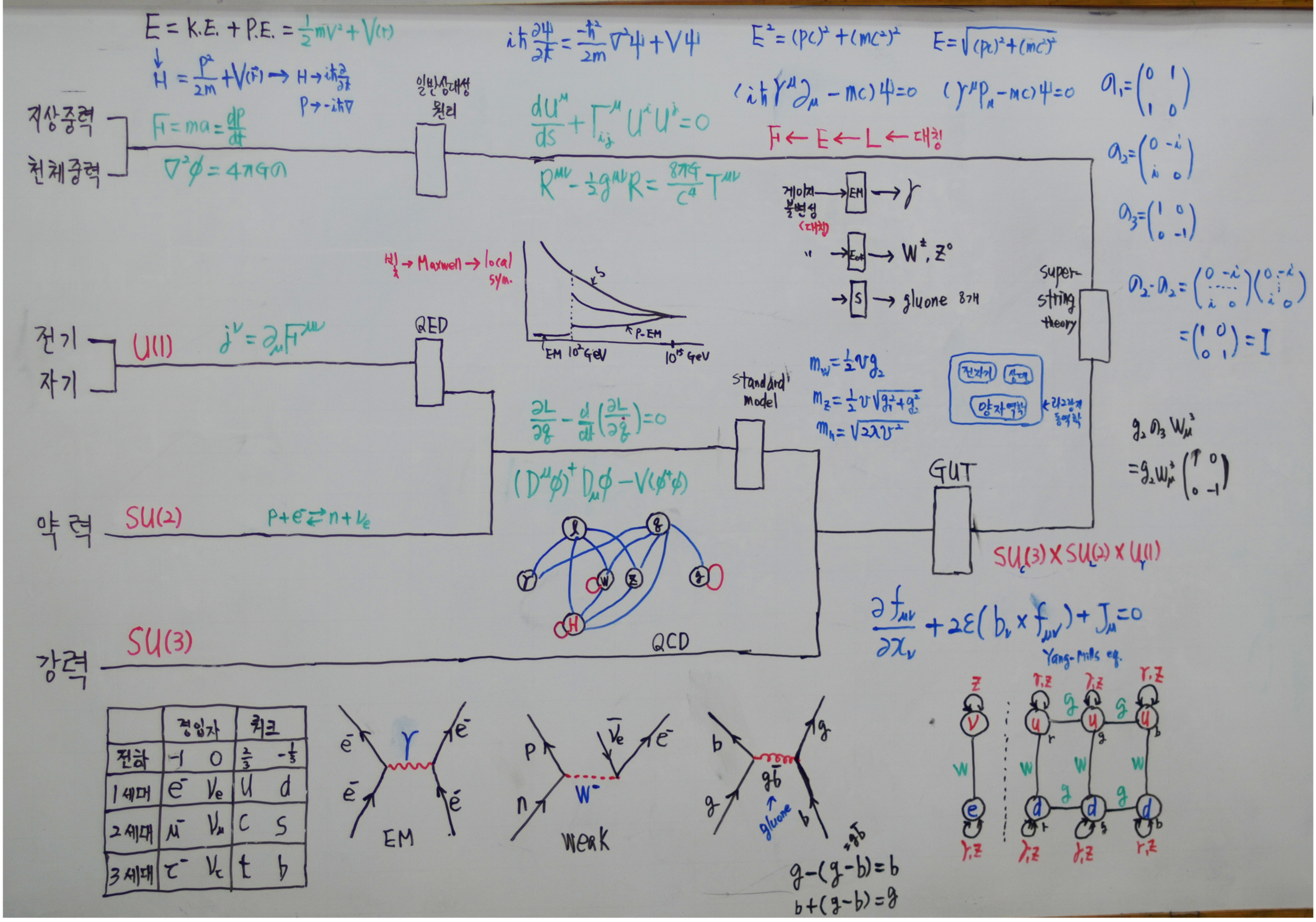


$E = K.E. + P.E. = \frac{1}{2}mv^2 + V(r)$
$H = \frac{p^2}{2m} + V(\vec{r}) \rightarrow H \rightarrow i\hbar\frac{\partial}{\partial t}$, $p \rightarrow -i\hbar\nabla$
$i\hbar\frac{\partial\psi}{\partial t} = \frac{-\hbar^2}{2m}\nabla^2\psi + V\psi$
$E^2 = (pc)^2 + (mc^2)^2$
$E = \sqrt{(pc)^2 + (mc^2)^2}$
$(i\hbar\gamma^\mu\partial_\mu - mc)\psi = 0$
$(\gamma^\mu p_\mu - mc)\psi = 0$
지상중력
천체중력
$\vec{F} = ma = \frac{dp}{dt}$
$\nabla^2\phi = 4\pi G\rho$
일반상대성 원리
$\frac{du^\mu}{ds} + \Gamma^\mu_{\alpha\beta}u^\alpha u^\beta = 0$
$R^{\mu\nu} - \frac{1}{2}g^{\mu\nu}R = \frac{8\pi G}{c^4}T^{\mu\nu}$
F ← E ← L ← 대칭
게이지 불변성 (대칭) → EM → γ
" → EW → $W^\pm, Z^0$
→ S → gluone 8개
빛 → Maxwell → local sym.
EM, 10^2 GeV, 10^{15} GeV, P-EM, S
super string theory
전기
자기
U(1)
$j^\nu = \partial_\mu F^{\mu\nu}$
QED
$\frac{\partial L}{\partial q} - \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) = 0$
$(D^\mu\phi)^+ D_\mu\phi - V(\phi^+\phi)$
standard model
$m_W = \frac{1}{2}vg_2$
$m_Z = \frac{1}{2}v\sqrt{g_1^2 + g_2^2}$
$m_h = \sqrt{2\lambda v^2}$
전자기 / 상대 / 양자역학 ← 리그랑지 동역학
GUT
약력
SU(2)
$p + e^- \rightleftarrows n + \nu_e$
$SU_c(3) \times SU_L(2) \times U_Y(1)$
$\frac{\partial f_{\mu\nu}}{\partial x_\nu} + 2\varepsilon(b_\nu \times f_{\mu\nu}) + J_\mu = 0$
Yang-Mills eq.
강력
SU(3)
QCD
ℓ, q, γ, W, Z, g, H
	경입자		쿼크	
전하	-1	0	$\frac{2}{3}$	$-\frac{1}{3}$
1세대	e^-	ν_e	u	d
2세대	μ^-	ν_μ	c	s
3세대	τ^-	ν_τ	t	b
e^-, e^-, γ, e^-, e^-
EM
p, n, W^-, $\bar{\nu}_e$, e^-
weak
b, g, $g\bar{b}$, gluone, b, g
$g - (g - b) = b$
$b + (g - b) = g$
Z, γ,Z, W, v, e, u, d, g, r, b



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$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$
$\sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$
$\sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$
$\sigma_2 \cdot \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = I$
$g_2\sigma_3 W^3_\mu = g_2 W^3_\mu \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$
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$g - (g - b) = b$
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$\sigma_i \Rightarrow$ 무한 연속 회전 연산자

$\sigma_x \cdot \sigma_y = i\sigma_z$

$\sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = I$

$$D_\mu = \partial_\mu + \frac{i}{2} g_1 Y B_\mu + i g_2 \vec{\tau} \cdot \vec{W}_\mu$$

$$= \partial_\mu + \frac{i}{2} g_1 Y B_\mu + \frac{i}{2} g_2 \vec{\sigma}_i \cdot \vec{W}_\mu$$

$$= \partial_\mu + \frac{i}{2} g_1 Y B_\mu + \frac{i}{2} g_2 (\sigma_1 W_\mu^1 + \sigma_2 W_\mu^2 + \sigma_3 W_\mu^3)$$

$$= \partial_\mu + \frac{i}{2} (g_1 Y B_\mu + g_2 \sigma_3 W_\mu^3) + \frac{i}{2} g_2 (\sigma_1 W_\mu^1 + \sigma_2 W_\mu^2)$$

$$= \partial_\mu + \frac{i}{2} \left[\begin{pmatrix} g_1 Y B_\mu & 0 \\ 0 & g_1 Y B_\mu \end{pmatrix} + \begin{pmatrix} g_2 W_\mu^3 & 0 \\ 0 & -g_2 W_\mu^3 \end{pmatrix} \right] + \frac{i}{2} g_2 (\sigma_1 W_\mu^1 + \sigma_2 W_\mu^2)$$

$$= \partial_\mu + \frac{i}{2} \begin{pmatrix} g_1 Y B_\mu + g_2 W_\mu^3 & 0 \\ 0 & g_1 Y B_\mu - g_2 W_\mu^3 \end{pmatrix} + \frac{i}{2} g_2 (\sigma_1 W_\mu^1 + \sigma_2 W_\mu^2)$$

$$g_1 B_\mu = -g_1 Z_\mu \sin\theta_w + e A_\mu$$

$$g_2 W_\mu^3 = g_2 Z_\mu \cos\theta_w + e A_\mu$$

$$W_\mu^\pm = \frac{1}{\sqrt{2}} (W_\mu^1 \mp i W_\mu^2)$$

$$g_1 = \sqrt{g_1^2 + g_2^2} \sin\theta_w \qquad g_2 = \sqrt{g_1^2 + g_2^2} \cos\theta_w$$

$$= \partial_\mu + \frac{i}{2} \begin{pmatrix} -g_1 Y Z_\mu \sin\theta_w + eYA_\mu + g_2 Z_\mu \cos\theta_w + eA_\mu & 0 \\ 0 & -g_1 Y Z_\mu \sin\theta_w + eYA_\mu - g_2 Z_\mu \cos\theta_w - eA_\mu \end{pmatrix} + \frac{i}{2} \underbrace{g_2 (\sigma_1 W_\mu^1 + \sigma_2 W_\mu^2)}_{\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} W_\mu^1 + \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} W_\mu^2} = \frac{i}{2} g_2 \begin{pmatrix} 0 & W_\mu^1 - W_\mu^2 \\ W_\mu^1 + W_\mu^2 & 0 \end{pmatrix}$$

$$D_\mu = \partial_\mu + \frac{i}{2} e \begin{pmatrix} Y+1 & 0 \\ 0 & Y-1 \end{pmatrix} A_\mu - \frac{i}{2} \begin{pmatrix} g_1 Y \sin\theta_w - g_2 \cos\theta_w & 0 \\ 0 & g_1 Y \sin\theta_w + g_2 \cos\theta_w \end{pmatrix} Z_\mu + \frac{i}{2} g_2 \ldots$$

스칼라 입자 $\phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ h+v \end{pmatrix}$ $Y=1$

$$D_\mu \phi = \frac{1}{\sqrt{2}} \partial_\mu \begin{pmatrix} 0 \\ h+v \end{pmatrix} + ie \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} A_\mu \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ h+v \end{pmatrix} - \frac{i}{2} \begin{pmatrix} g_1 \sin\theta_w - g \ldots \\ 0 \quad g_1 \sin\theta \ldots \end{pmatrix}$$

$$= \frac{1}{\sqrt{2}} \partial_\mu h - \frac{i}{2\sqrt{2}} \begin{pmatrix} 0 \\ \sqrt{g_1^2 + g_2^2} \end{pmatrix} Z_\mu (h+v) + \frac{i}{\sqrt{2}} g_2 \begin{pmatrix} W_\mu^+ \\ 0 \end{pmatrix} (h+v)$$

$$(D^\mu \phi)^\dagger = \frac{1}{\sqrt{2}} \partial^\mu h + \frac{i}{2\sqrt{2}} (0, \sqrt{g_1^2 + g_2^2}) Z^\mu (h+v) - \frac{i}{\sqrt{2}} g_2 (W^{\mu -}, 0)(h+ \ldots$$

$$(D^\mu \phi)^\dagger (D_\mu \phi) = \frac{1}{2} \partial^\mu h \partial_\mu h + \frac{1}{8} (g_1^2 + g_2^2) Z^\mu Z_\mu \underbrace{(h+v)^2}_{h^2 + 2hv \ldots} + \ldots$$

$\Rightarrow$ v^2 계수

$$\frac{1}{8} (g_1^2 + g_2^2) v^2 Z^\mu Z_\mu + \frac{1}{8} g_2^2 [\ldots$$

$$m_Z^2 = \frac{1}{4} (g_1^2 + g_2^2) v^2$$

$$m_W^2 = \frac{1}{4} g_2^2 v^2 \longrightarrow$$

$$+ i g_2 \vec{\tau} \cdot \vec{W}_\mu$$

$$D_\mu = \partial_\mu + \frac{i}{2} e \begin{pmatrix} Y+1 & 0 \\ 0 & Y-1 \end{pmatrix} A_\mu - \frac{i}{2} \begin{pmatrix} g_1 Y \sin\theta_w - g_2 \cos\theta_w & 0 \\ 0 & g_1 Y \sin\theta_w + g_2 \cos\theta_w \end{pmatrix} Z_\mu + \frac{i}{2} g_2 \sqrt{2} \begin{pmatrix} 0 & W_\mu^+ \\ W_\mu^- & 0 \end{pmatrix}$$

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$$= \frac{1}{\sqrt{2}} \partial_\mu h - \frac{i}{2\sqrt{2}} \begin{pmatrix} 0 \\ \sqrt{g_1^2 + g_2^2} \end{pmatrix} Z_\mu (h+v) + \frac{i}{\sqrt{2}} g_2 \begin{pmatrix} W_\mu^+ \\ 0 \end{pmatrix} (h+v)$$

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$$(D^\mu \phi)^\dagger (D_\mu \phi) = \frac{1}{2} \partial^\mu h \partial_\mu h + \frac{1}{8} (g_1^2 + g_2^2) Z^\mu Z_\mu \underbrace{(h+v)^2}_{h^2 + 2hv + v^2} + \frac{1}{4} g_2^2 (W^{-\mu} W_\mu^+)(h+v)^2$$

$\Rightarrow$ v^2 계수

$$\frac{1}{8} (g_1^2 + g_2^2) v^2 Z^\mu Z_\mu + \frac{1}{8} g_2^2 [(W^{+\mu})^* W_\mu^+ + W^{-\mu} (W_\mu^-)^*] v^2$$

$$m_Z^2 = \frac{1}{4} (g_1^2 + g_2^2) v^2 \longrightarrow m_Z = \frac{1}{2} v \sqrt{g_1^2 + g_2^2}$$

$$m_W^2 = \frac{1}{4} g_2^2 v^2 \longrightarrow m_W = \frac{1}{2} v g_2$$