

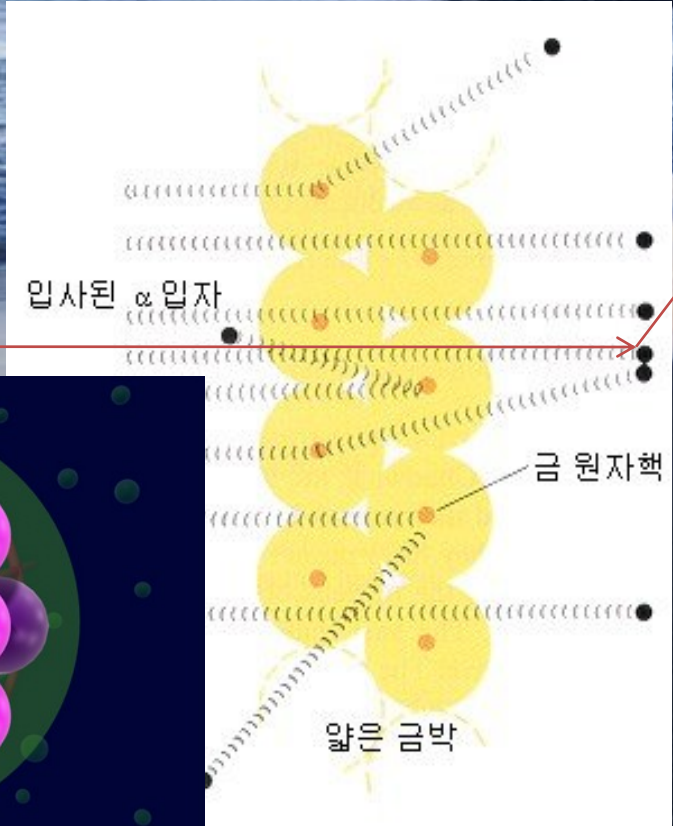
A high-speed train is shown traveling through a tunnel of cherry blossoms. The train is white with a blue front and is moving towards the viewer. The cherry blossoms are in full bloom, creating a beautiful and romantic atmosphere. The train is the central focus of the image, and the blossoms are scattered all around it, creating a sense of depth and movement.

# 유가와와 맛있는 중간자

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# Outline

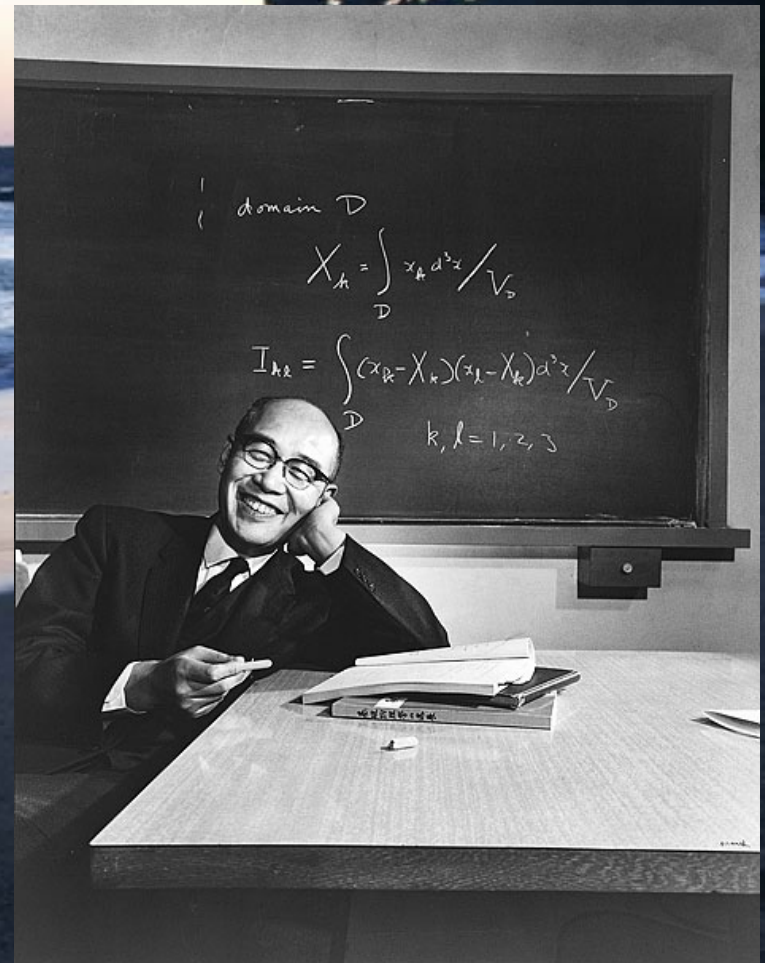
- History
- Yukawa potential
- Meson
  - Types of meson
  - Flavourless mesons & Flavourful mesons
  - List of mesons





$$V \approx g \bar{\Psi} \phi \Psi$$

$$V \approx g \bar{\Psi} \gamma^5 \phi \Psi$$



# Yukawa potential

$$S[\varphi, \psi] = \int d^d x [L_{\text{meson}}(\varphi) + L_{\text{Dirac}}(\psi) + L_{\text{Yukawa}}(\varphi, \psi)].$$

$$L_{\text{meson}}(\varphi) = \frac{1}{2} \partial^\mu \varphi \partial_\mu \varphi - V(\varphi).$$

$$L_{\text{Dirac}}(\psi) = \bar{\psi}(i\partial - m)\psi$$

$$L_{\text{Yukawa}}(\varphi, \psi) = -g\bar{\psi}\varphi\psi, \quad \text{for scalar mesons}$$

$$L_{\text{Yukawa}}(\varphi, \psi) = -g\bar{\psi}\gamma^5\varphi\psi, \quad \text{for pseudoscalar mesons}$$

**Classical potential**

$$V(r) = -\frac{g^2}{4\pi r} e^{-\mu r}$$

also called a *screened Coulomb potential*

# Meson

Quark      Anti-Quark



Composition :  
Quark+Anti-Quark  
Boson, Hardron  
Mass : 139 MeV/c<sup>2</sup> ~  
9,460 MeV/c<sup>2</sup>

.....

## Parity

$$P = (-1)^{L+1}$$

## C-parity

$$|q\bar{q}\rangle = |\bar{q}q\rangle$$

$$|q\bar{q}\rangle = -|\bar{q}q\rangle$$

## Flavour quantum numbers

$$Q = I_3 + \frac{1}{2}(B + S + C + B' + T),$$

$$S = -(n_s - n_{\bar{s}})$$

$$C = +(n_c - n_{\bar{c}})$$

$$B' = -(n_b - n_{\bar{b}})$$

$$T = +(n_t - n_{\bar{t}}),$$

$$I_3 = \frac{1}{2}[(n_u - n_{\bar{u}}) - (n_d - n_{\bar{d}})],$$

# Types of meson

Types of mesons<sup>[18]</sup>

Type	S	L	P	J	J <sup>P</sup>
Pseudoscalar meson	0	0	-	0	0 <sup>-</sup>
Pseudovector meson	0	1	+	1	1 <sup>+</sup>
Vector meson	1	0	-	1	1 <sup>-</sup>
Scalar meson	1	1	+	0	0 <sup>+</sup>
Tensor meson	1	1	+	2	2 <sup>+</sup>

# Flavourless mesons

$q\bar{q}$ content	$J^{PC} \rightarrow$ $I \downarrow$	$0^{-+}, 2^{-+}, 4^{-+}, \dots$	$1^{+-}, 3^{+-}, 5^{+-}, \dots$	$1^{--}, 2^{--}, 3^{--}, \dots$	$0^{++}, 1^{++}, 2^{++}, \dots$
$u\bar{d}$ $\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$ $d\bar{u}$	1	$\pi^+$ $\pi^0$ $\pi^-$	$b^+$ $b^0$ $b^-$	$\rho^+$ $\rho^0$ $\rho^-$	$a^+$ $a^0$ $a^-$
Mix of $u\bar{u}, d\bar{d}, s\bar{s}$	0	$\eta$ $\eta'$	$h$ $h'$	$\omega$ $\phi$	$f$ $f'$
$c\bar{c}$	0	$\eta_c$	$h_c$	$\psi^{\dagger\dagger}$	$\chi_c$
$b\bar{b}$	0	$\eta_b$	$h_b$	$\Upsilon$	$\chi_b$
$t\bar{t}$	0	$\eta_t$	$h_t$	$\theta$	$\chi_t$

$\dagger \wedge$  The C parity is only relevant to neutral mesons.

$\dagger\dagger \wedge$  For  $J^{PC}=1^{--}$ , the  $\psi$  is often called the  $J/\psi$



# Flavourful mesons

antiquark → quark ↓	up	down	strange	charm	bottom	top
up	—	—	$K^+$	$\bar{D}^0$	$B^+$	$\bar{T}^0$
down	—	—	$K^0$	$D^-$	$B^0$	$T^-$
strange	$K^-$	$\bar{K}^0$	—	$D_s^-$	$B_s^0$	$T_s^+$
charm	$D^0$	$D^+$	$D_s^+$	—	$B_c^+$	$\bar{T}_c^0$
bottom	$B^-$	$\bar{B}^0$	$\bar{B}_s^0$	$B_c^-$	—	$T_b^+$
top	$T^0$	$T^+$	$T_s^-$	$T_c^0$	$T_b^-$	—

# List of mesons-pseudoscalar


Pseudoscalar mesons

Particle name	Particle symbol <a href="#">[W]</a>	Antiparticle symbol <a href="#">[W]</a>	Quark content	Rest mass (MeV/c <sup>2</sup> ) <a href="#">[W]</a>	I <sup>3</sup> <a href="#">[W]</a>	J <sup>PC</sup> <a href="#">[W]</a>	S <a href="#">[W]</a>	C <a href="#">[W]</a>	B' <a href="#">[W]</a>	Mean lifetime (s) <a href="#">[W]</a>	Commonly decays to (>5% of decays)
Pion <sup>[5]</sup>	$\pi^+$	$\pi^-$	$u\bar{d}$	$139.57018 \pm 0.00035$	1 <sup>-</sup>	0 <sup>-</sup>	0	0	0	$2.6033 \pm 0.0005 \times 10^{-8}$	$\mu^+ + \nu_\mu$
Pion <sup>[5]</sup>	$\pi^-$	Self	$\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$	$134.9766 \pm 0.0006$	1 <sup>-</sup>	0 <sup>++</sup>	0	0	0	$8.4 \pm 0.6 \times 10^{-17}$	$\gamma + \gamma$
Eta meson <sup>[7]</sup>	$\eta$	Self	$\frac{u\bar{u}+d\bar{d}-2s\bar{s}}{\sqrt{6}}$	$547.853 \pm 0.024$	0 <sup>-</sup>	0 <sup>++</sup>	0	0	0	$5.0 \pm 0.3 \times 10^{-19}$ <sup>[8]</sup>	$\gamma + \gamma$ or $\pi^+ + \pi^+ + \pi^-$ or $\pi^+ + \pi^- + \pi^-$
Eta prime meson <sup>[9]</sup>	$\eta'(958)$	Self	$\frac{u\bar{u}+d\bar{d}+s\bar{s}}{\sqrt{3}}$	$957.66 \pm 0.24$	0 <sup>-</sup>	0 <sup>++</sup>	0	0	0	$3.2 \pm 0.2 \times 10^{-21}$ <sup>[8]</sup>	$\pi^+ + \pi^- + \eta$ or $(\rho^+ + \gamma) / (\pi^+ + \pi^- + \gamma)$ or $\pi^+ + \pi^- + \eta$
Charmed eta meson <sup>[9]</sup>	$\eta_c(1S)$	Self	$c\bar{c}$	$2,980.3 \pm 1.2$	0 <sup>-</sup>	0 <sup>++</sup>	0	0	0	$2.5 \pm 0.3 \times 10^{-23}$ <sup>[8]</sup>	See $\eta_c$ decay modes <a href="#">[W]</a>
Bottom eta meson <sup>[10]</sup>	$\eta_b(1S)$	Self	$b\bar{b}$	$9,300 \pm 40$	0 <sup>-</sup>	0 <sup>++</sup>	0	0	0	Unknown	See $\eta_b$ decay modes <a href="#">[W]</a>
Kaon <sup>[11]</sup>	$K^+$	$K^-$	$u\bar{s}$	$493.677 \pm 0.016$	$\frac{1}{2}$	0 <sup>-</sup>	1	0	0	$1.2380 \pm 0.0021 \times 10^{-8}$	$\mu^+ + \bar{\nu}_\mu$ or $\pi^+ + \pi^0$ or $\pi^+ + e^+ + \nu_e$ or $\pi^+ + \pi^-$
Kaon <sup>[12]</sup>	$K^0$	$\bar{K}^0$	$d\bar{s}$	$497.614 \pm 0.024$	$\frac{1}{2}$	0 <sup>-</sup>	1	0	0	<sup>[8]</sup>	<sup>[8]</sup>
K-Short <sup>[13]</sup>	$K_S^0$	Self	$\frac{d\bar{s}-s\bar{d}}{\sqrt{2}}$	$497.614 \pm 0.024$ <sup>[8]</sup>	$\frac{1}{2}$	0 <sup>-</sup>	(*)	0	0	$8.953 \pm 0.005 \times 10^{-11}$	$\pi^+ + \pi^-$ or $\pi^0 + \pi^0$
K-Long <sup>[14]</sup>	$K_L^0$	Self	$\frac{d\bar{s}+s\bar{d}}{\sqrt{2}}$	$497.614 \pm 0.024$ <sup>[8]</sup>	$\frac{1}{2}$	0 <sup>-</sup>	(*)	0	0	$5.116 \pm 0.020 \times 10^{-8}$	$\pi^+ + e^+ + \nu_e$ or $\pi^+ + \mu^+ + \nu_\mu$ or $\pi^+ + \pi^+ + \pi^-$ or $\pi^+ + \pi^- + \pi^-$
D meson <sup>[15]</sup>	$D^+$	$D^-$	$c\bar{d}$	$1,869.62 \pm 0.20$	$\frac{1}{2}$	0 <sup>-</sup>	0	+1	0	$1.040 \pm 0.007 \times 10^{-12}$	See $D^+$ decay modes <a href="#">[W]</a>
D meson <sup>[16]</sup>	$D^0$	$\bar{D}^0$	$c\bar{u}$	$1,864.84 \pm 0.17$	$\frac{1}{2}$	0 <sup>-</sup>	0	+1	0	$4.101 \pm 0.015 \times 10^{-13}$	See $D^0$ decay modes <a href="#">[W]</a>
strange D meson <sup>[17]</sup>	$D_s^+$	$D_s^-$	$c\bar{s}$	$1,968.49 \pm 0.34$	0	0 <sup>-</sup>	+1	+1	0	$5.00 \pm 0.07 \times 10^{-13}$	See $D_s^+$ decay modes <a href="#">[W]</a>
B meson <sup>[18]</sup>	$B^+$	$B^-$	$u\bar{b}$	$5,279.15 \pm 0.31$	$\frac{1}{2}$	0 <sup>-</sup>	0	0	+1	$1.638 \pm 0.011 \times 10^{-12}$	See $B^+$ decay modes <a href="#">[W]</a>
B meson <sup>[19]</sup>	$B^0$	$\bar{B}^0$	$d\bar{b}$	$5,279.53 \pm 33$	$\frac{1}{2}$	0 <sup>-</sup>	0	0	+1	$1.530 \pm 0.009 \times 10^{-12}$	See $B^0$ decay modes <a href="#">[W]</a>
Strange B meson <sup>[20]</sup>	$B_s^+$	$\bar{B}_s^+$	$s\bar{b}$	$5,366.3 \pm 0.6$	0	0 <sup>-</sup>	-1	0	+1	$1.470^{+0.026}_{-0.027} \times 10^{-12}$	See $B_s^+$ decay modes <a href="#">[W]</a>
Charmed B meson <sup>[21]</sup>	$B_c^+$	$B_c^-$	$c\bar{b}$	$6,276 \pm 4$	0	0 <sup>-</sup>	0	+1	+1	$4.6 \pm 0.7 \times 10^{-13}$	See $B_c^+$ decay modes <a href="#">[W]</a>

# List of mesons-vector

Vector mesons

Particle name	Particle symbol <a href="#">[M]</a>	Antiparticle symbol <a href="#">[M]</a>	Quark content	Rest mass (MeV/c <sup>2</sup> ) <a href="#">[M]</a>	I <sup>G</sup> <a href="#">[M]</a>	J <sup>PC</sup> <a href="#">[M]</a>	S <a href="#">[M]</a>	C <a href="#">[M]</a>	B' <a href="#">[M]</a>	Mean lifetime (s) <a href="#">[M]</a>	Commonly decays to (>5% of decays)
Charged rho meson <sup>[22]</sup>	$\rho^+(770)$	$\rho^-(770)$	$u\bar{d}$	$775.4 \pm 0.4$	1 <sup>+</sup>	1 <sup>-</sup>	0	0	0	$\sim 4.5 \times 10^{-24\text{fs}}$	$\pi^+ + \pi^-$
Neutral rho meson <sup>[22]</sup>	$\rho^0(770)$	Self	$\frac{u\bar{u}-d\bar{d}}{\sqrt{2}}$	$775.49 \pm 0.34$	1 <sup>+</sup>	1 <sup>--</sup>	0	0	0	$\sim 4.5 \times 10^{-24\text{fs}}$	$\pi^+ + \pi^-$
Omega meson <sup>[23]</sup>	$\omega(782)$	Self	$\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$782.65 \pm 0.12$	0 <sup>-</sup>	1 <sup>--</sup>	0	0	0	$7.75 \pm 0.07 \times 10^{-23\text{fs}}$	$\pi^+ + \pi^- + \pi^0$ or $\pi^0 + \gamma$
Phi meson <sup>[24]</sup>	$\phi(1020)$	Self	$s\bar{s}$	$1,019.445 \pm 0.020$	0 <sup>-</sup>	1 <sup>--</sup>	0	0	0	$1.55 \pm 0.01 \times 10^{-22\text{fs}}$	$K^+ + K^-$ or $K_S^+ + K_L^-$ or $(\rho + \pi) / (\pi^+ + \pi^- + \pi^0)$
J/Psi <sup>[25]</sup>	$J/\psi$	Self	$c\bar{c}$	$3,096.916 \pm 0.011$	0 <sup>-</sup>	1 <sup>--</sup>	0	0	0	$7.1 \pm 0.2 \times 10^{-21\text{fs}}$	See <a href="#">J/ψ(1S) decay modes</a> <a href="#">[M]</a>
Upsilon meson <sup>[26]</sup>	$Υ(1S)$	Self	$b\bar{b}$	$9,460.30 \pm 0.26$	0 <sup>-</sup>	1 <sup>--</sup>	0	0	0	$1.22 \pm 0.03 \times 10^{-20\text{fs}}$	See <a href="#">Υ(1S) decay modes</a> <a href="#">[M]</a>
Kaon <sup>[27]</sup>	$K^{*+}$	$K^{*-}$	$u\bar{s}$	$891.66 \pm 0.026$	½	1 <sup>-</sup>	1	0	0	$\sim 7.35 \times 10^{-20\text{fs}}$	See <a href="#">K*(892) decay modes</a> <a href="#">[M]</a>
Kaon <sup>[27]</sup>	$K^{*0}$	$\bar{K}^{*0}$	$d\bar{s}$	$896.00 \pm 0.025$	½	1 <sup>-</sup>	1	0	0	$7.346 \pm 0.002 \times 10^{-20\text{fs}}$	See <a href="#">K*(892) decay modes</a> <a href="#">[M]</a>
D meson <sup>[28]</sup>	$D^{*+}(2010)$	$D^{*-}(2010)$	$c\bar{d}$	$2,010.27 \pm 0.17$	½	1 <sup>-</sup>	0	+1	0	$6.9 \pm 1.9 \times 10^{-21\text{fs}}$	$D^+ + \pi^0$ or $D^+ + \pi^-$
D meson <sup>[29]</sup>	$D^{*0}(2007)$	$\bar{D}^{*0}(2007)$	$c\bar{u}$	$2,006.97 \pm 0.19$	½	1 <sup>-</sup>	0	+1	0	$>3.1 \times 10^{-22\text{fs}}$	$D^+ + \pi^0$ or $D^+ + \gamma$
strange D meson <sup>[30]</sup>	$D_s^{*+}$	$D_s^{*-}$	$c\bar{s}$	$2,112.3 \pm 0.5$	0	1 <sup>-</sup>	+1	+1	0	$>3.4 \times 10^{-22\text{fs}}$	$D^{*+} + \gamma$ or $D^{*+} + \pi^0$
B meson <sup>[31]</sup>	$B^{*+}$	$B^{*-}$	$u\bar{b}$	$5,325.1 \pm 0.5$	½	1 <sup>-</sup>	0	0	+1	Unknown	$B^+ + \gamma$
B meson <sup>[31]</sup>	$B^{*0}$	$\bar{B}^{*0}$	$d\bar{b}$	$5,325.1 \pm 0.5$	½	1 <sup>-</sup>	0	0	+1	Unknown	$B^0 + \gamma$
Strange B meson <sup>[32]</sup>	$B_s^{*0}$	$\bar{B}_s^{*0}$	$s\bar{b}$	$5,412.8 \pm 1.3$	0	1 <sup>-</sup>	-1	0	+1	Unknown	$B_s^0 + \gamma$
Charmed B meson <sup>†</sup>	$B_c^{*+}$	$B_c^{*-}$	$c\bar{b}$	Unknown	0	1 <sup>-</sup>	0	+1	+1	Unknown	Unknown

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- 유가와는 과연 중간자가 맛이 있었을까?



Thank you for your attention!

추운 봄이 이젠 좀 누그러 들고 주말엔 여기저기서 꽃 축제들이 있다니까 어두침침한 공부는 좀 쉬고 다들 꽃놀이 가서 노세요... 시험공부는 평소에 틈틈이 하시고 시험공부 핑계로 여자친구 심심하게 하면 못 써요.