Let's begin with,,,
숫자로 되돌아보는

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정기복

The discovery of asymptotic freedom and the emergence of QCD

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The progress of science is much more muddled than is depicted in most history books. This is especially true of theoretical physics, partly because history is written by the victorious. Consequently, historians of science often ignore the many alternate paths that people wandered down, the many false clues they followed, the many misconceptions they had. These alternate points of view are less clearly developed than the final theories, harder to understand and easier to forget, especially as these are viewed years later, when it all really does make sense. Thus, reading history one rarely gets the feeling of the true nature of scientific development, in which the element of farce is as great as the element of triumph.

The emergence of QCD is a wonderful example of the evolution from farce to triumph. During a very short period, a transition occurred from experimental discovery and theoretical confusion to theoretical triumph and experimental confirmation. In this Nobel lecture, I shall describe the turn of events that led to the discovery of asymptotic freedom, was divided into the study of the weak and the strong interactions, the two mysterious forces that operate within the nucleus. In the case of the weak interactions, there was a rather successful phenomenological theory, but not much new data. The strong interactions were where the experimental and theoretical action was, particularly at Berkeley. They were regarded as especially unfathomable. In hindsight, this was not surprising since nature was hiding her secrets. The basic constituents of hadrons (strongly interacting particles) were invisible. We now know that these are quarks, but no one had ever seen a quark, no matter how hard protons were smashed into protons. Furthermore, the "color" charges we now know are the source of the Chromodynamic fields, the analogs of the electric charge, were equally invisible. The prevalent feeling was that it would take a very long time to understand the nuclear force and that it would require revolutionary concepts. Freeman Dyson had asserted that "the correct theory will not be found in the next hundred years." For a young graduate student such as myself, this was that a powerful dogma emerged—that field theory was fundamentally wrong, especially in its application to the strong interactions.

The renormalization procedure, developed by R. Feynman, J. Schwinger, S. Tomanaga, and F. Dyson, which had eliminated the ubiquitous infinities that occurred in calculations by expressing physical observables in terms of physical parameters, was spectacularly successful in Quantum Electrodynamics (QED). However, the physical meaning of renormalization was not truly understood. The feeling of most was that renormalization was a trick. This was especially the case for the pioneering inventors of quantum field theory. They were prepared at the first appearance of divergences to renounce their belief in quantum field theory and to brace for the next revolution. However, it was also the feeling of the younger leaders of the field, who had laid the foundations of perturbative quantum field theory and renormalization in the late 1940s. The prevalent feeling was that renormalization simply swept the infinities under the rug, but that they were still there and rendered the notion of local fields meaningless. To

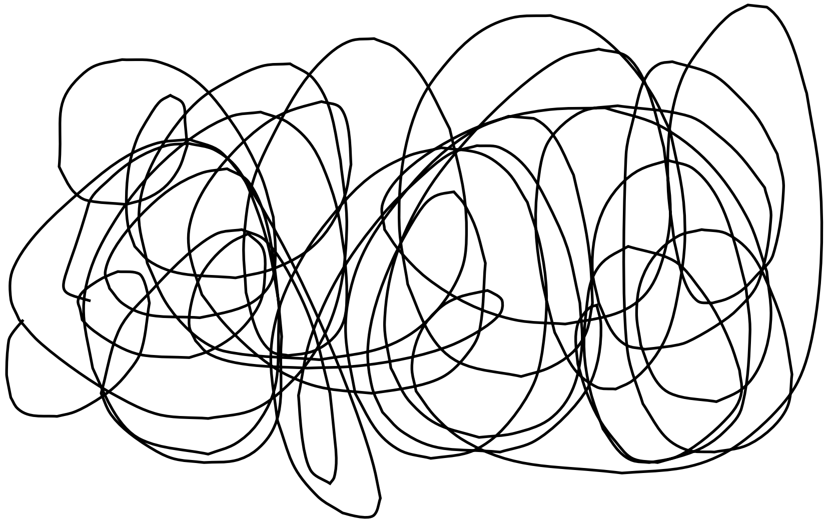
The Bootstrap

If field theory could not provide the theoretical framework for the strong interactions, what could? In the early sixties, a radically different approach emerged—S-Matrix theory and the bootstrap. The bootstrap theory rested

S-Matrix theory?

tant early success. Fermi formulated a powerful and accurate phenomenological theory of beta decay, which (although deficient at high energy) was to serve as a framework for exploring the weak interactions for three decades.

Fermi theory?



Landau and colleagues concluded, on the basis of their approximations, that this effect is so strong that the physical charge, as measured at any finite distance, would vanish for any value of the bare charge. They stated: "We reach the conclusion that within the limits of formal electrodynamics a point interaction is equivalent, for any intensity whatever, to no interaction at all" (2).

This is the famous problem of zero charge, a startling result that implied for Landau that "weak coupling electrodynamics is a theory, which is, fundamentally, logically incomplete" (3).

. . .

ergy. However, Landau believed that this phenomenon was more general, and would occur in all field theories. Why?

. . .

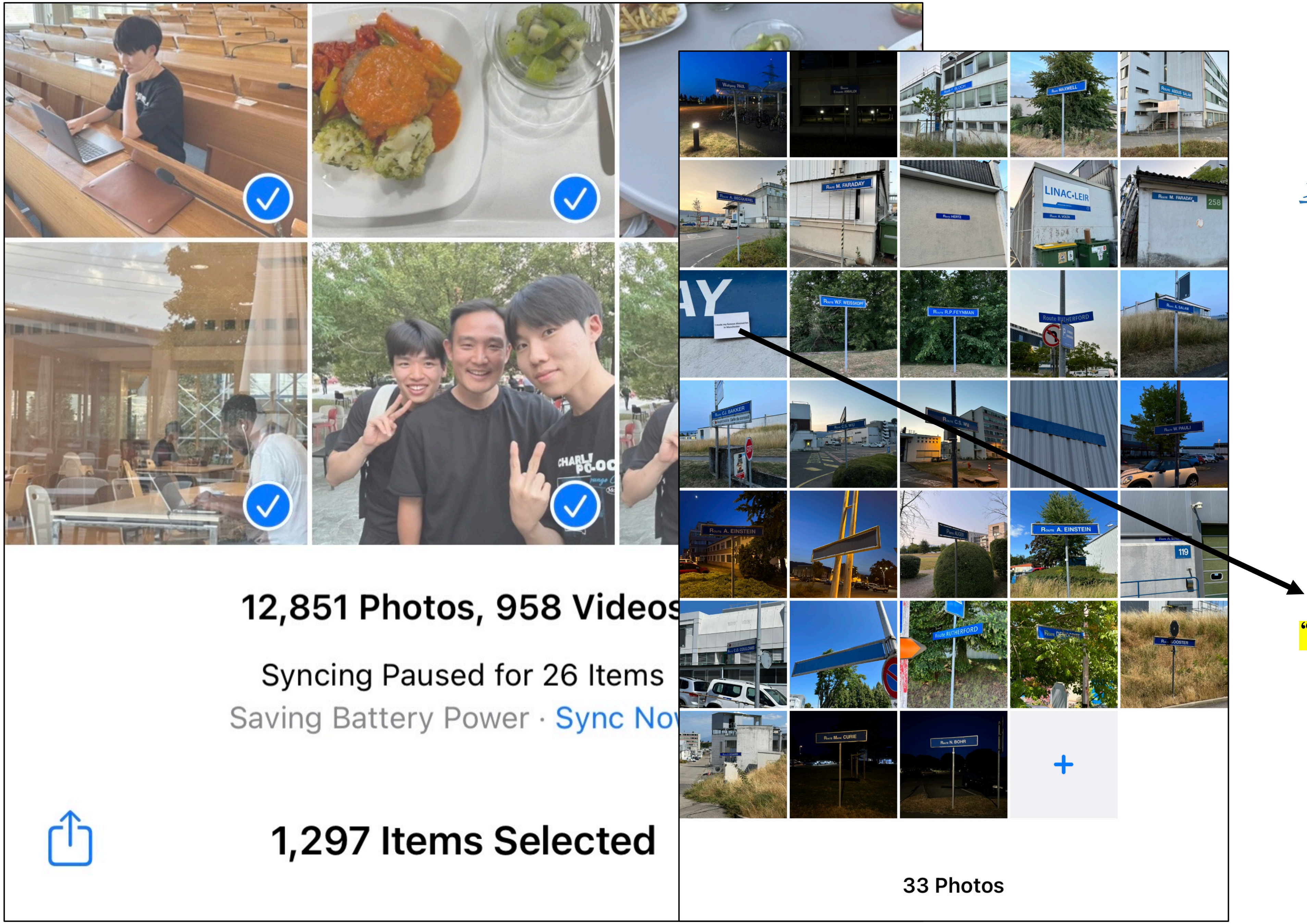
Landau decreed that "We are driven to the conclusion that the Hamiltonian method for strong interaction is dead and must be buried, although of course with deserved honor" (4).

Under the influence of Landau and Pomeranchuk, a generation of physicists was forbidden to work on field theory.

이럴수가!!

현지적응

R1에서 식사 24회



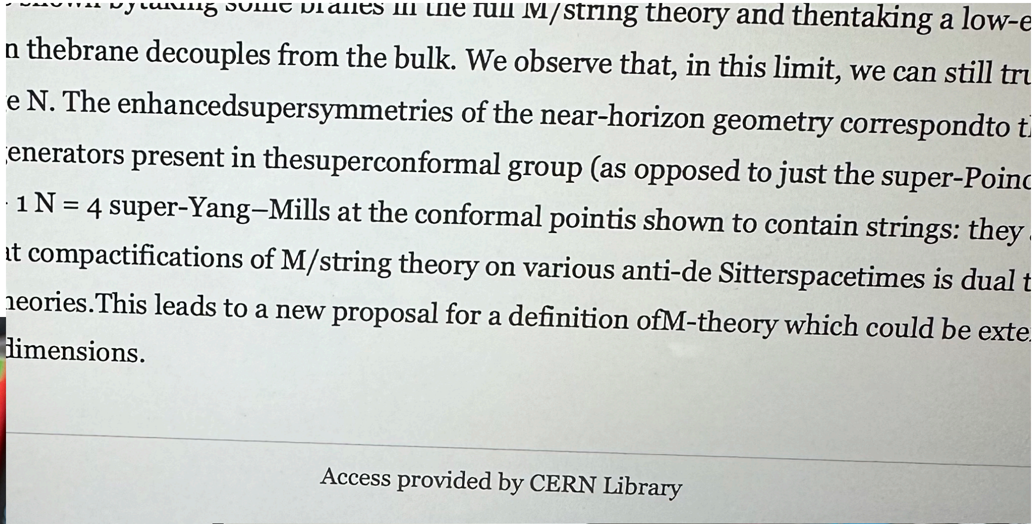
찰칵

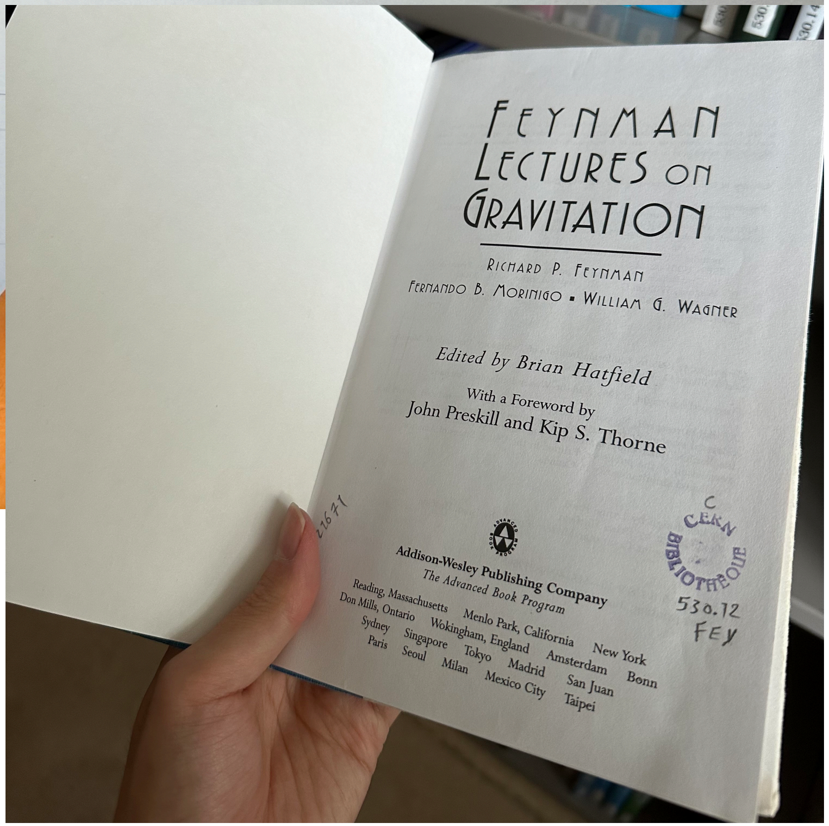
중복 제외 1100+장
표지판 32개

"I made my famous discoveries
In Manchester"

학술정보 활용

논문 다운로드 2편





Tong said,,
“Landau pole…”

참여

오전 프로그램 27개
오후 프로그램 16개

Perfect attendance award (개근상)

Aus dem Englischen übersetzt - Eine Auszeichnung für perfekte Anwesenheit wird traditionell am Ende des Schuljahres an US-amerikanischen Schulen vergeben, um Schüler zu ehren, die während dieses Jahres oder in einigen Fällen über mehrere Jahre hinweg an jedem Schultag anwesend waren. Wikipedia (Englisch)

Ursprüngliche Beschreibung aufrufen

질문

오전 프로그램 5개
오후 프로그램 4개

We can derive the Fermi current-current contact interactions by "integrating out" the gauge bosons, i.e., by replacing in the Lagrangian the W's by their equation of motion. Here is a simple derivation:
(a better one should take taking into account the gauge kinetic term and the proper form of the fermionic current that we'll figure out tomorrow, for the moment, take it as a heuristic derivation)

$$\mathcal{L} = -m_W^2 W_\mu^+ W_\nu^- \eta^{\mu\nu} + g W_\mu^+ J_\nu^- \eta^{\mu\nu} + g W_\nu^- J_\nu^+ \eta^{\mu\nu}$$

$$J^{+\mu} = \bar{n}\gamma^\mu p + \bar{e}\gamma^\mu \nu_e + \bar{\mu}\gamma^\mu \nu_\mu + \ldots \qquad \text{and} \qquad J^{-\mu} = \left(J^{+\mu}\right)^*$$

The equation of motion for the gauge fields: $\frac{\partial \mathcal{L}}{\partial W_\mu^+} = 0 \quad \Rightarrow \quad W_\mu^- = \frac{g}{m_W^2} J_\mu^-$

Plugging back in the original Lagrangian, we obtain an *effective Lagrangian* (valid below the mass of the gauge bosons):

$$\boxed{\mathcal{L} = \frac{g^2}{m_W^2} J_\mu^+ J_\nu^- \eta^{\mu\nu}}$$

질문 1.

Kinetic term을 무시하는 건
W boson의 Dynamics를 무시하는 것으로 이해했는데 맞나요?

→ Kinetic term이란 오른쪽과 같은 친구들! : $-\frac{1}{4}F_{\mu\nu}F^{\mu\nu}(F_{\mu\nu} = 2\partial_{[\mu}A_{\nu]}),\ -\frac{1}{2}\partial_\mu\phi\partial^\mu\phi$
Dynamics = 시간에 따른 변화

질문 2.

그 정당성을 Time-Energy Uncertainty principle로
이해해도 괜찮을까요?

→ $\Delta T \Delta E \simeq \hbar$

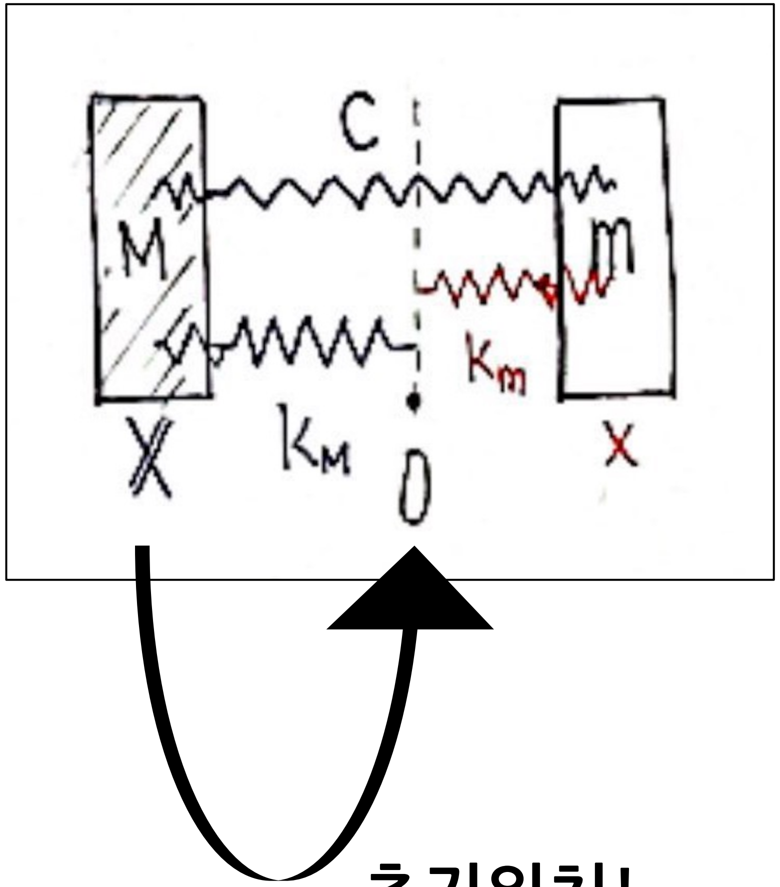
고전역학으로 이해해보자!
"용수철에 각각 매달린 두 물체가 용수철로 연결된 상황"

$$L = \frac{1}{2}M\dot{X}^2 - \frac{1}{2}K_M X^2 + \frac{1}{2}m\dot{x}^2 - \frac{1}{2}K_m x^2 - \frac{1}{2}C(X-x)^2$$

$$\rightarrow \quad L_{eff} = -\frac{1}{2}K_M X^2 + \frac{1}{2}m\dot{x}^2 - \frac{1}{2}K_m x^2 - \frac{1}{2}C(X-x)^2$$

$$S_{eff} = \int dt L_{eff}$$

<u>단, X(0)=0</u> / 잠자는 M을 깨울 수 있을까?



$$\delta X \ : \ K_M X + C(X-x) = 0, \quad X = \frac{C}{K_M + C}x, \quad x - X = \frac{K_M}{K_M + C}x$$

$$\delta x \ : \ m\ddot{x} + K_m x^2 - C(X-x) = 0$$

극한을 잘 이해해야 한다!

$$\frac{1}{2}M\dot{X}^2 - \frac{1}{2}K_M X^2 \leftrightarrow \frac{1}{2}\dot{\tilde{X}}^2 - \frac{1}{2}\frac{K_M}{M}\tilde{X}^2 \quad (\tilde{X} \equiv \sqrt{M}X) \text{ VS } \frac{1}{2}\dot{\phi}^2 - \frac{1}{2}m^2\frac{c^4}{\hbar^2}\phi^2$$

$$\rightarrow \frac{K_M}{M} \sim m^2 \times (\text{Const.})$$

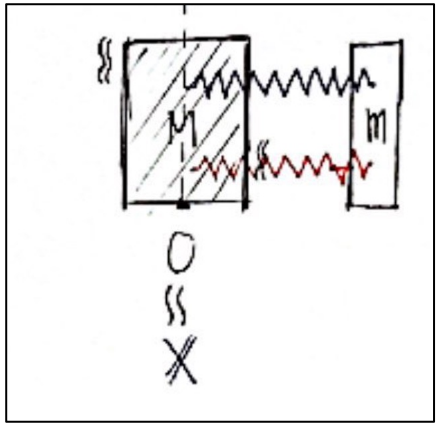
즉, 무거운 입자의 Dynamics를 무시해도 좋다

$\sim \frac{K_M}{M}$이 클 때, M의 Dynamics를 무시해도 좋다 (‘무엇보다?’는 곧!)

무시할 수 있다?
- (A) Dynamics가 없다
- (B) Dynamics가 미치는 영향이 미미하다

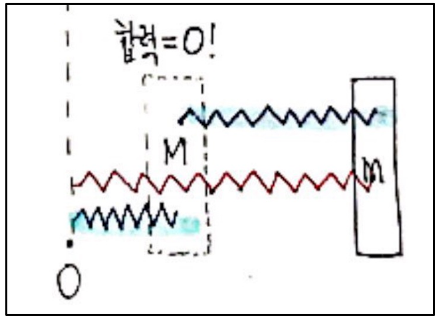
$$\delta X\ :\ K_M X + C(X - x) = 0,\ \ X = \frac{C}{K_M + C}x,\ \ x - X = \frac{K_M}{K_M + C}x$$

$$\delta x\ :\ m\ddot{x} + K_m x\ - C(X - x) = 0$$



(A) $x - X \approx x$ $(K_M \gg C)$ 조건을 적용하면

$$\rightarrow\ m\ddot{x} + (K_m + C)x = 0$$



(B) $x - X = \frac{K_M}{K_M + C}x$ 를 그대로 사용하면

$$\rightarrow\ m\ddot{x} + \left(K_m + \frac{CK_M}{K_M + C}\right)x = 0$$

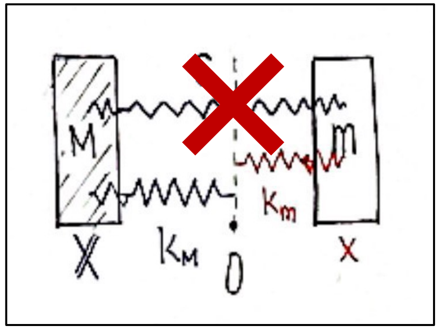
$d_1 + d_2 = x\ \ \&\ \ -K_M d_1 + C d_2 = 0$

$\rightarrow\ d_2 = \frac{K_M}{K_M + C}x,\ \ Cd_2!$

한 가지 상황이 더 있다!

$$\delta X \ : \ K_M X + C(X - x) = 0, \ \ X = \frac{C}{K_M + C}x, \ \ x - X = \frac{K_M}{K_M + C}x$$

$$\delta x \ : \ m\ddot{x} + K_m x \ - C(X - x) = 0$$



(C) $x - X \approx x \ \ (C \ll K_M)$ 조건을 적용하면

$$\rightarrow \ m\ddot{x} + (K_m + C)x = 0$$

원래 문제와 비교해보자!

상호작용의 크기가 Gauge boson의 mass보다 충분히 작다면
Gauge boson의 Dynamics를 무시할 수 있다

VS

C 가 K_M 보다 충분히 작다면
M 의 Dynamics를 무시할 수 있다

(A), (C)를 돌이켜보자! NICE!

앞으로 할 일과 요즘 하는 생각

1. (A)와 (B)의 구분에 양자적 대응성이 있는지 확인!
2. 사실 한 가지 상황이 더 있다…(또!!)

$\rightarrow M \gg m$

3. 정확한 해와 섬세하게 비교하기!

$$\frac{d^2}{dt^2}\begin{pmatrix} X \\ x \end{pmatrix} = \begin{pmatrix} \frac{K_M + C}{M} & -\frac{C}{M} \\ -\frac{C}{m} & \frac{K_m + C}{m} \end{pmatrix}\begin{pmatrix} X \\ x \end{pmatrix}$$

4. Fermi theory로 계산 해보기!

UV - IR 대응성? (NOT SURE X100)

(1) Resurgence Theory

$$y \sim \zeta e^{\frac{2}{3}x^{\frac{3}{2}}} x^{-\frac{1}{4}} \sum C_n (x^{-\frac{3}{2}})^n \quad (x \to \infty)$$

$$C_n = (\frac{3}{4})^n \frac{1}{n!} \Gamma(n + \frac{5}{6}) \Gamma(n + \frac{1}{6})$$

$$C_1 = \frac{5}{48}, \quad C_2 = \frac{385}{4608}, \quad C_3 = \frac{85085}{663552}, \quad \cdots$$

$$\frac{1}{n!}\Gamma(n + \frac{5}{6})\Gamma(n + \frac{1}{6}) \sim (n-1)!(1 - \frac{5}{36n} + \frac{25}{2592n^2} + \frac{775}{279936n^3} + \cdots) \quad (n \to \infty)$$

$$\sim (n-1)!(1 - \frac{A_1}{n-1} + \frac{A_2}{(n-1)(n-2)} - \frac{A_3}{(n-1)(n-2)(n-3)} + \cdots)$$

$$\frac{3}{4}A_1 = C_1, \quad (\frac{3}{4})^2 A_2 = C_2, \quad (\frac{3}{4})^3 A_3 = C_3, \quad \cdots$$

(2) IR divergence VS Wilsonian picture

행복했어요 감사합니다(하트)