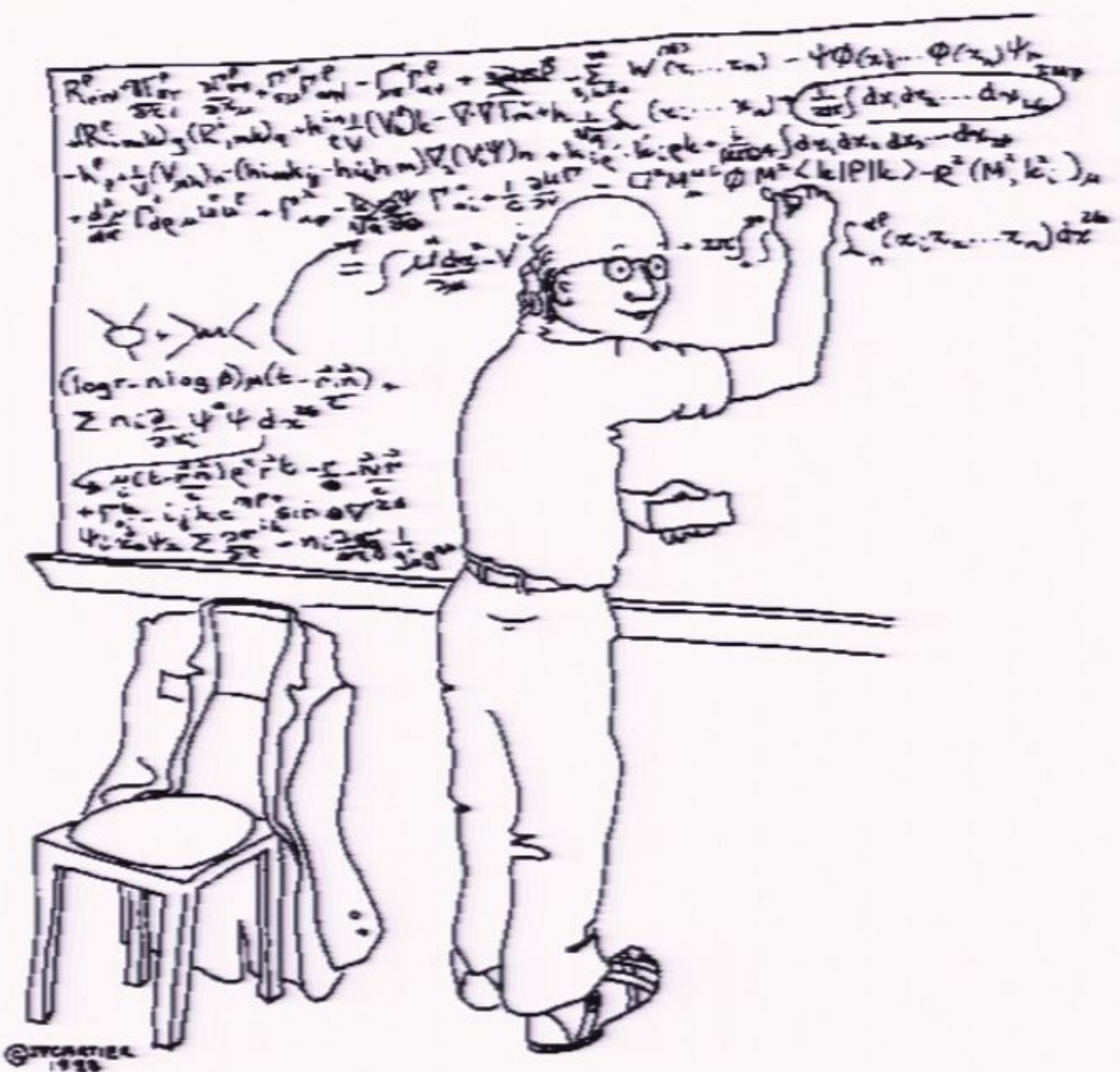


Title: The Superstring Adventure

Date: Jul 04, 2008 10:30 AM

URL: <http://pirsa.org/08070002>

Abstract: An introductory presentation on string theory.



©VICTOR 1988

"At this point we notice that this equation is beautifully simplified if we assume that space-time has 92 dimensions."

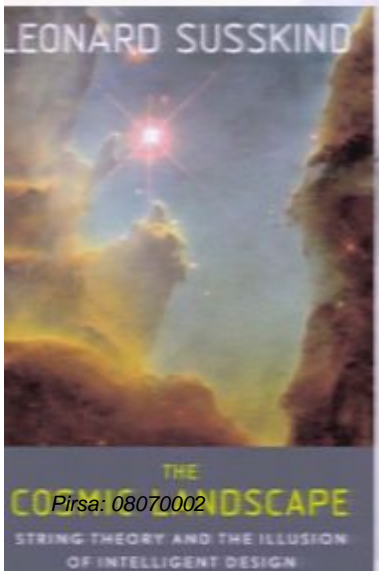
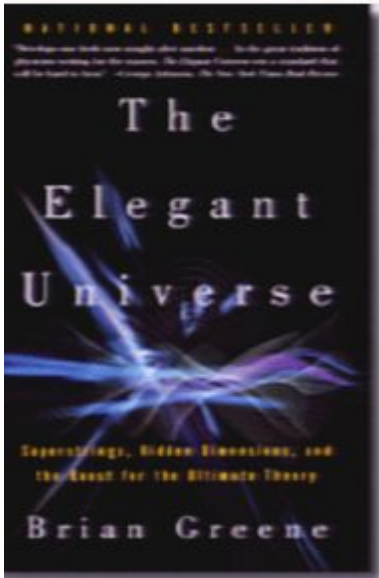


The Superstring Adventure

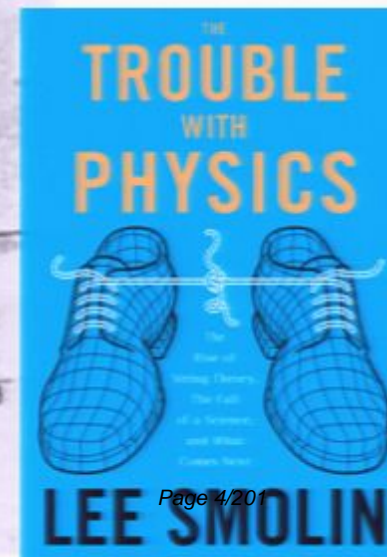
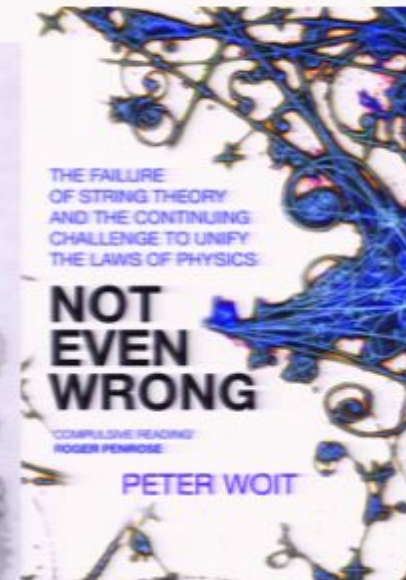
Robert Myers

(Einstein-Plus: July 4, 2008)

New Yorker magazine:

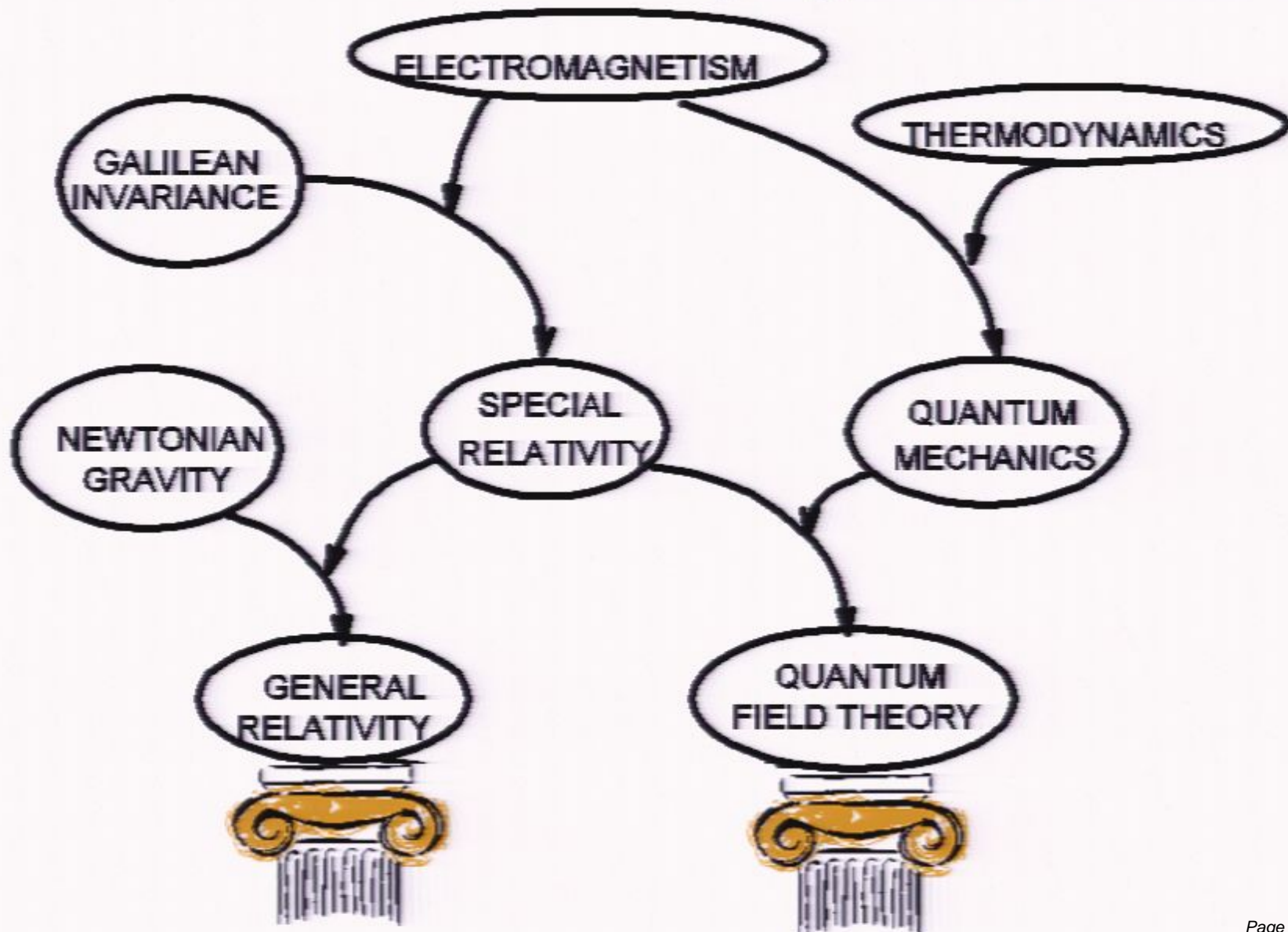


"It's all string theory to me."



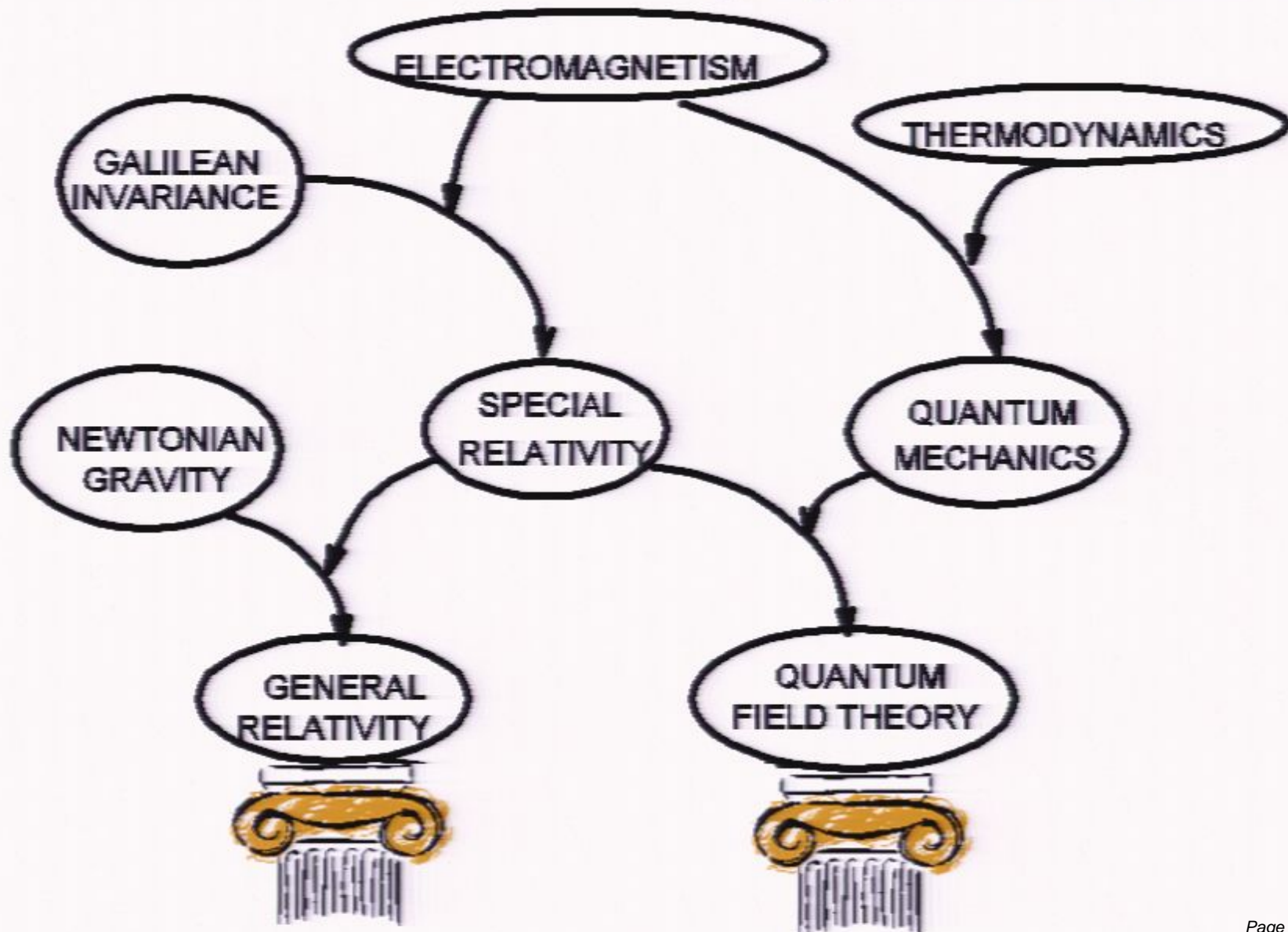
Physics of the 20th century:

A grand synthesis and progression of ideas!



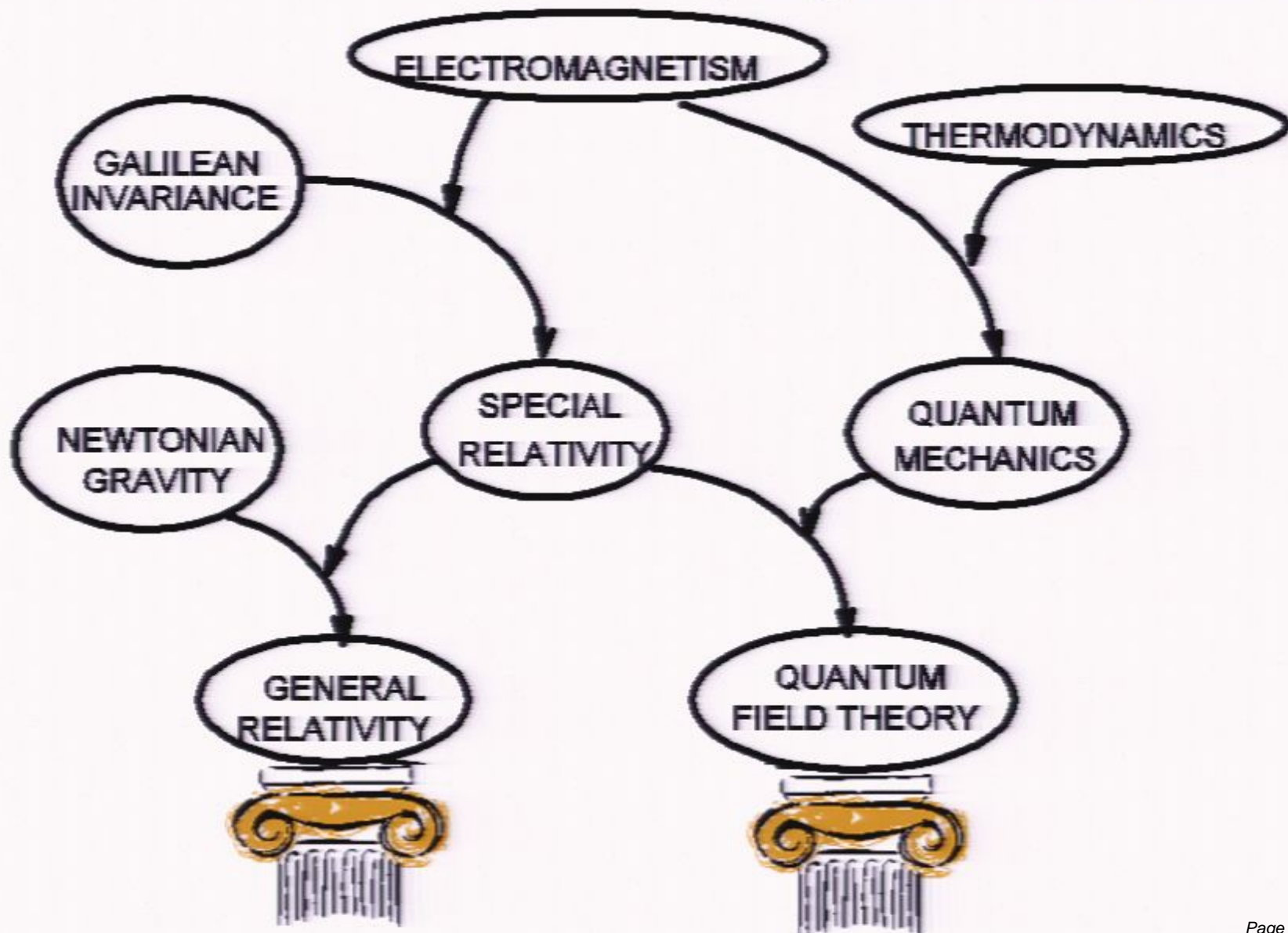
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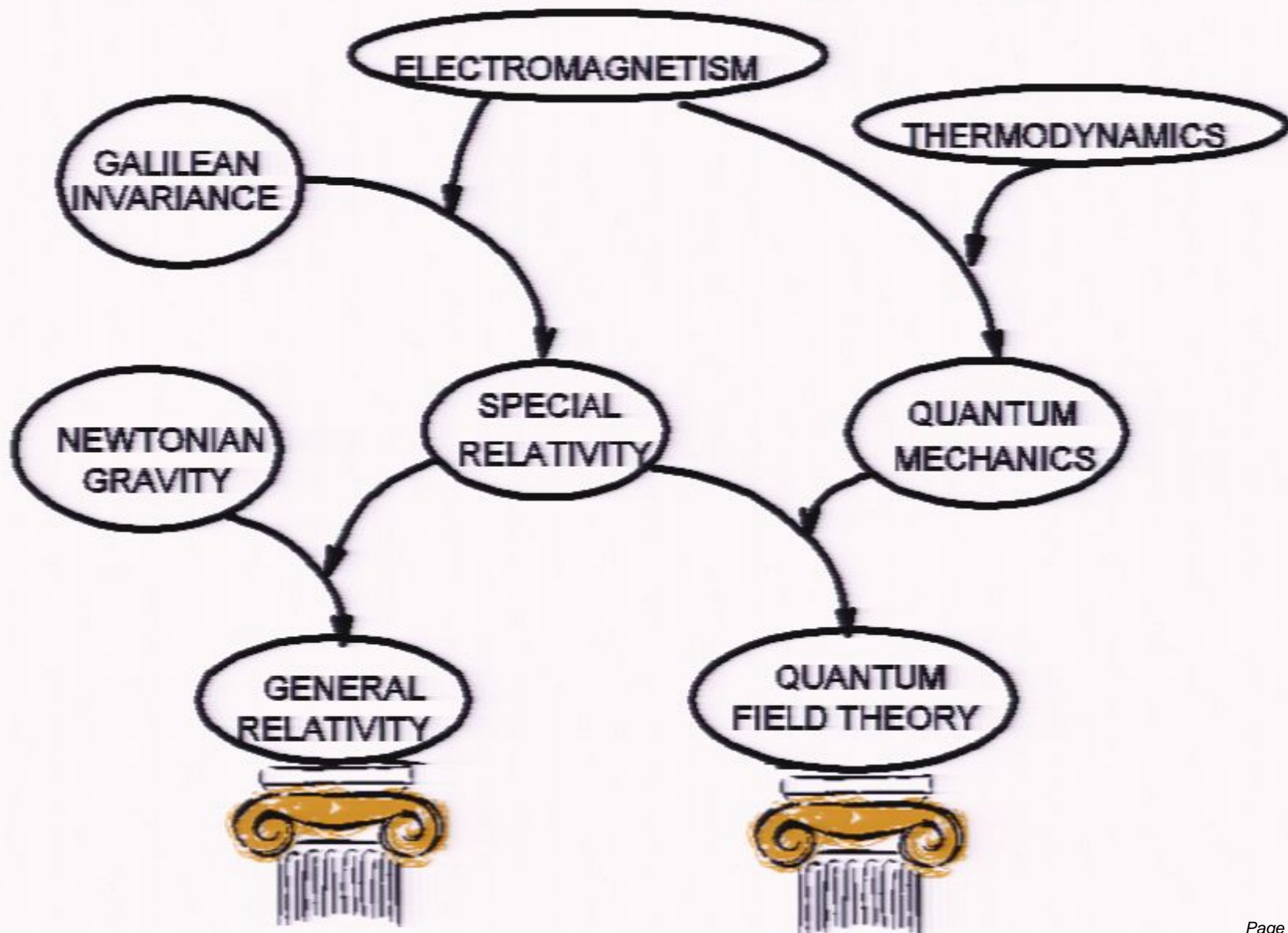
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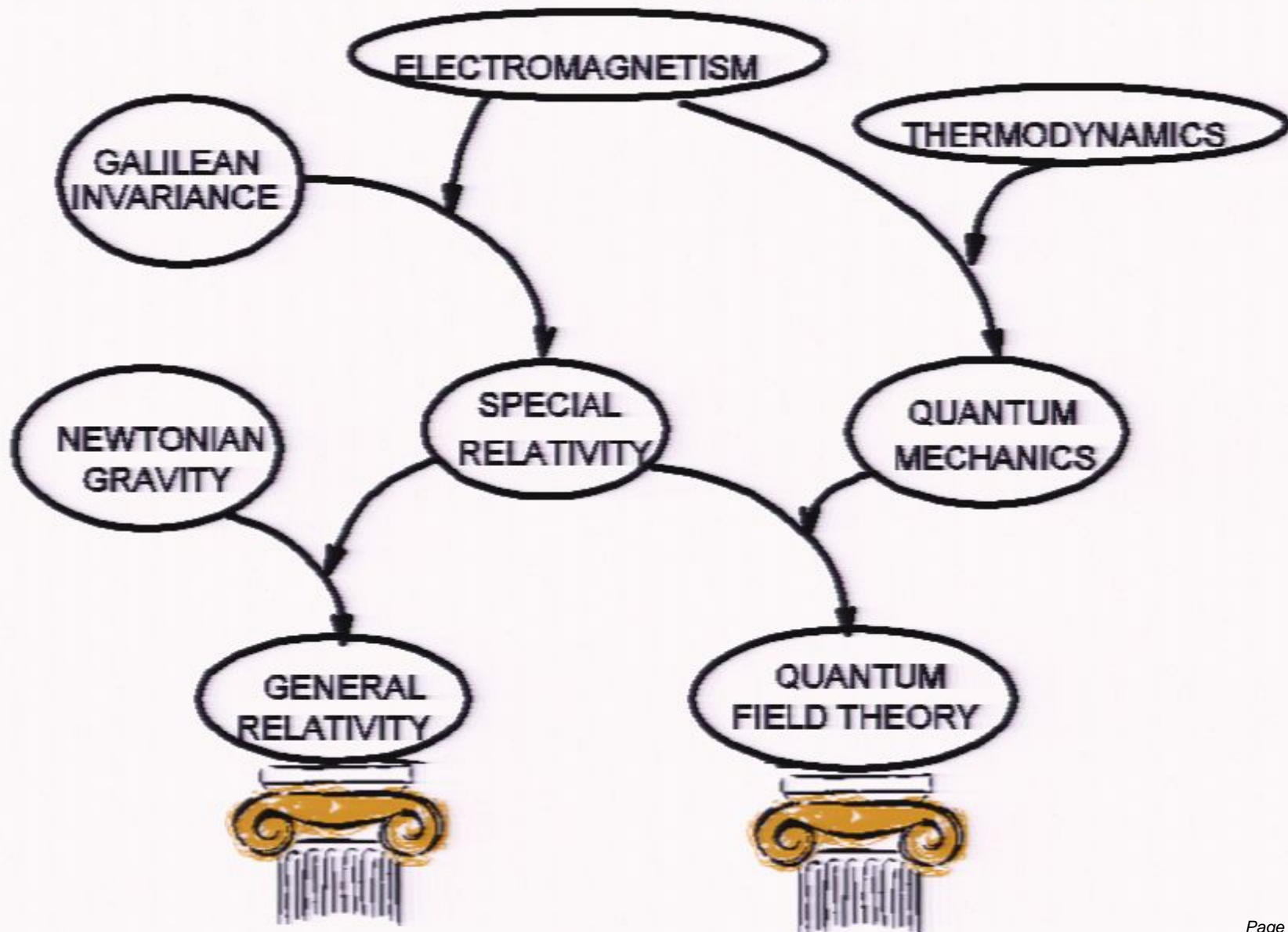
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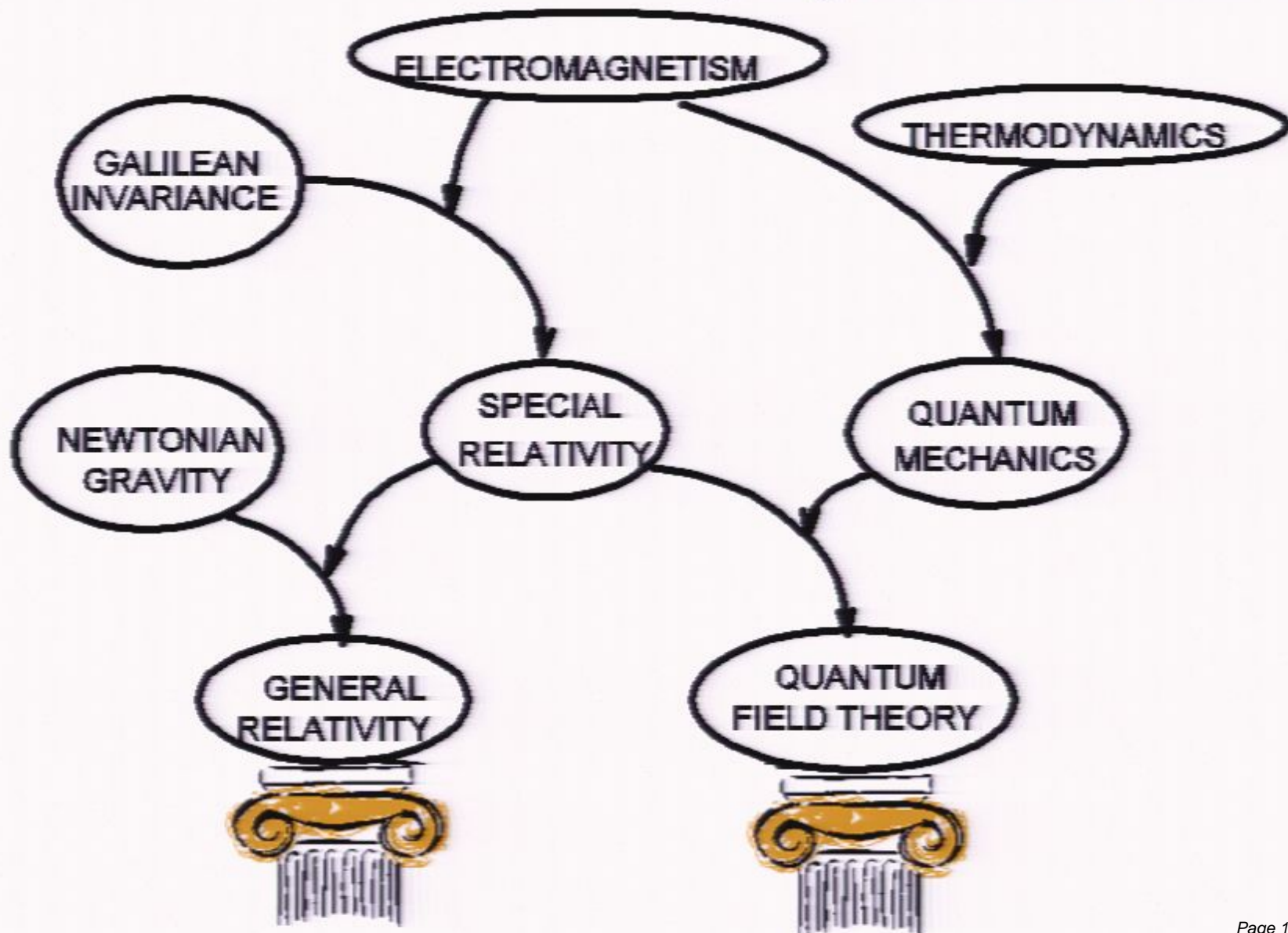
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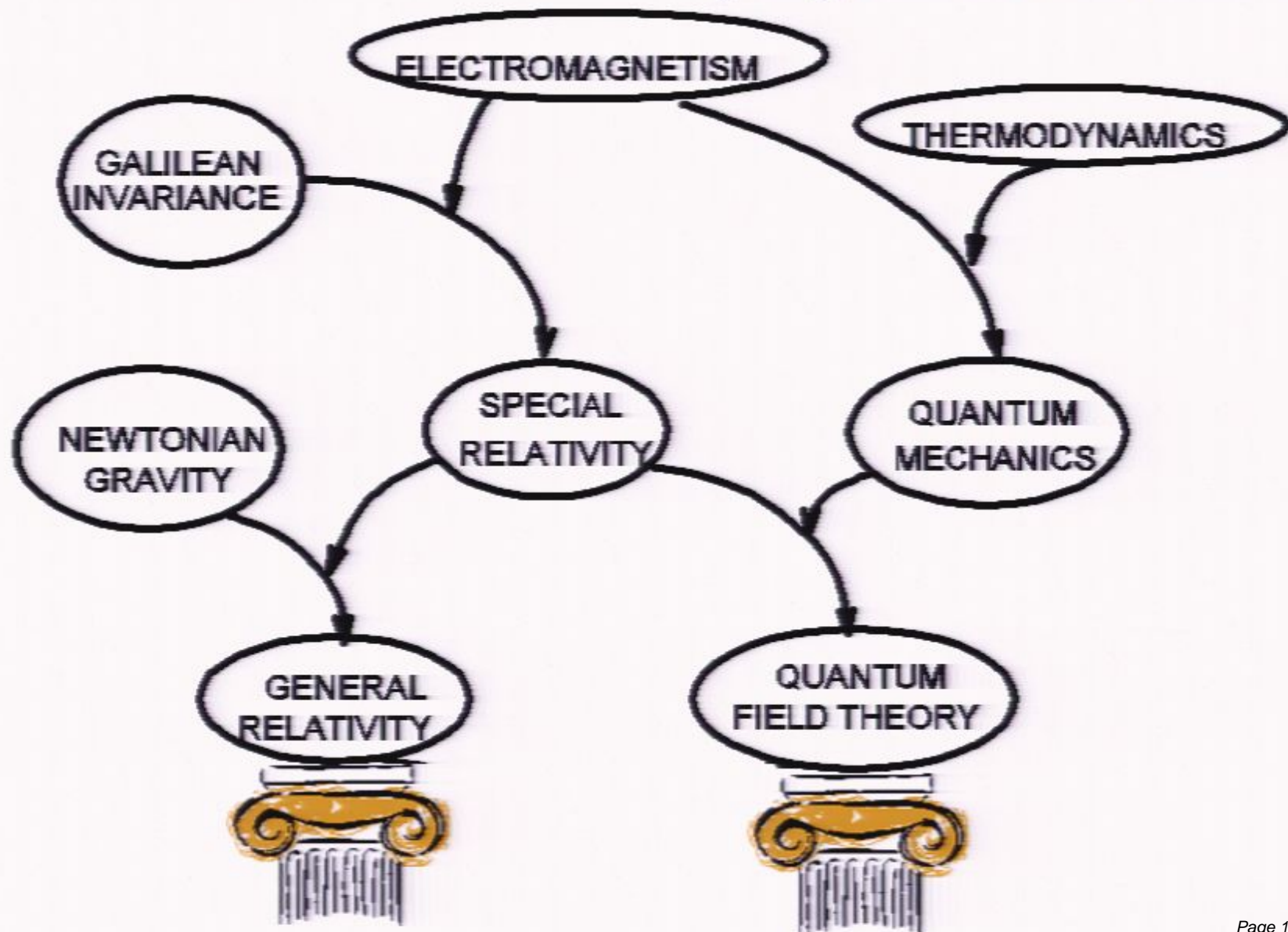
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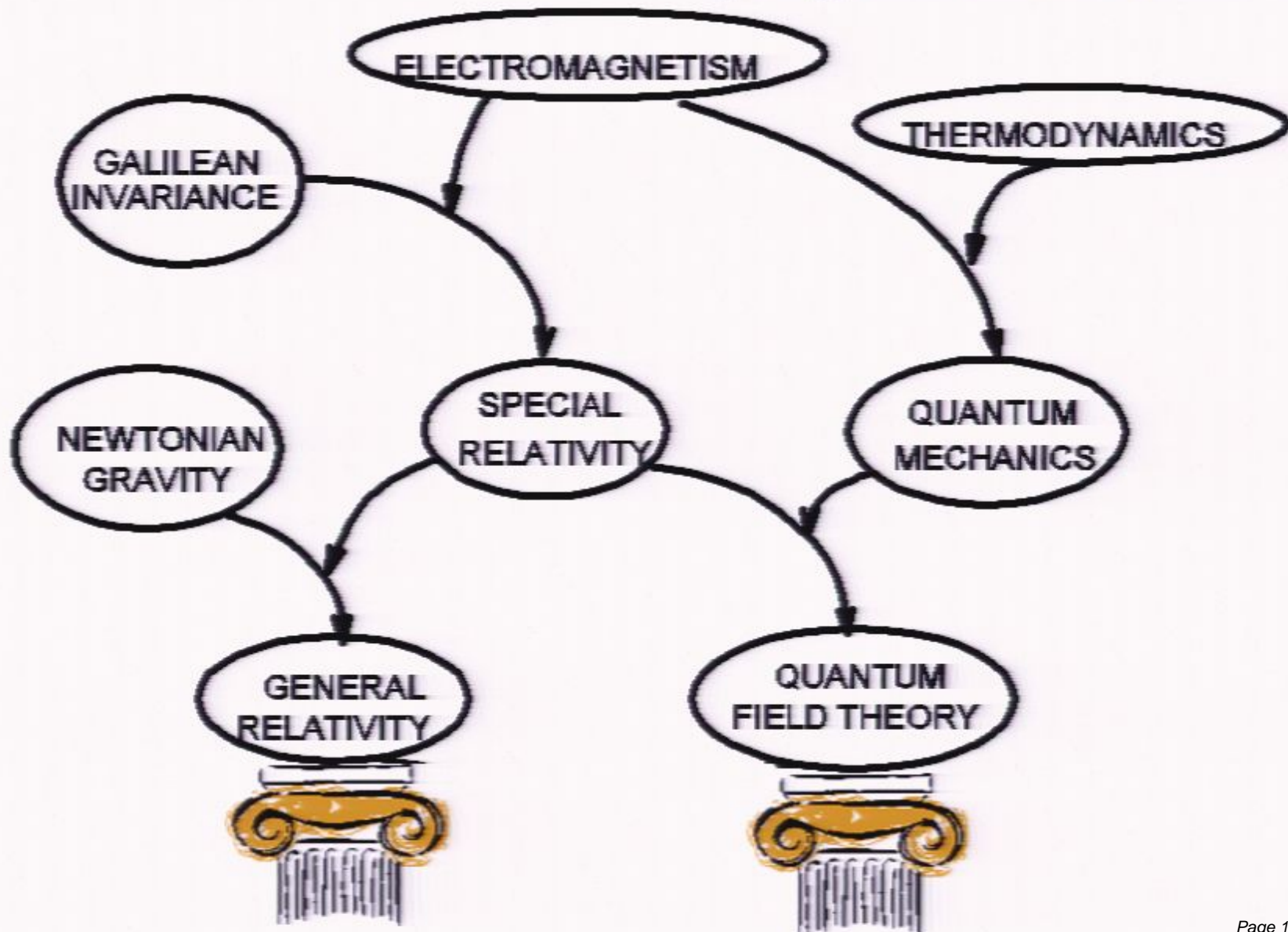
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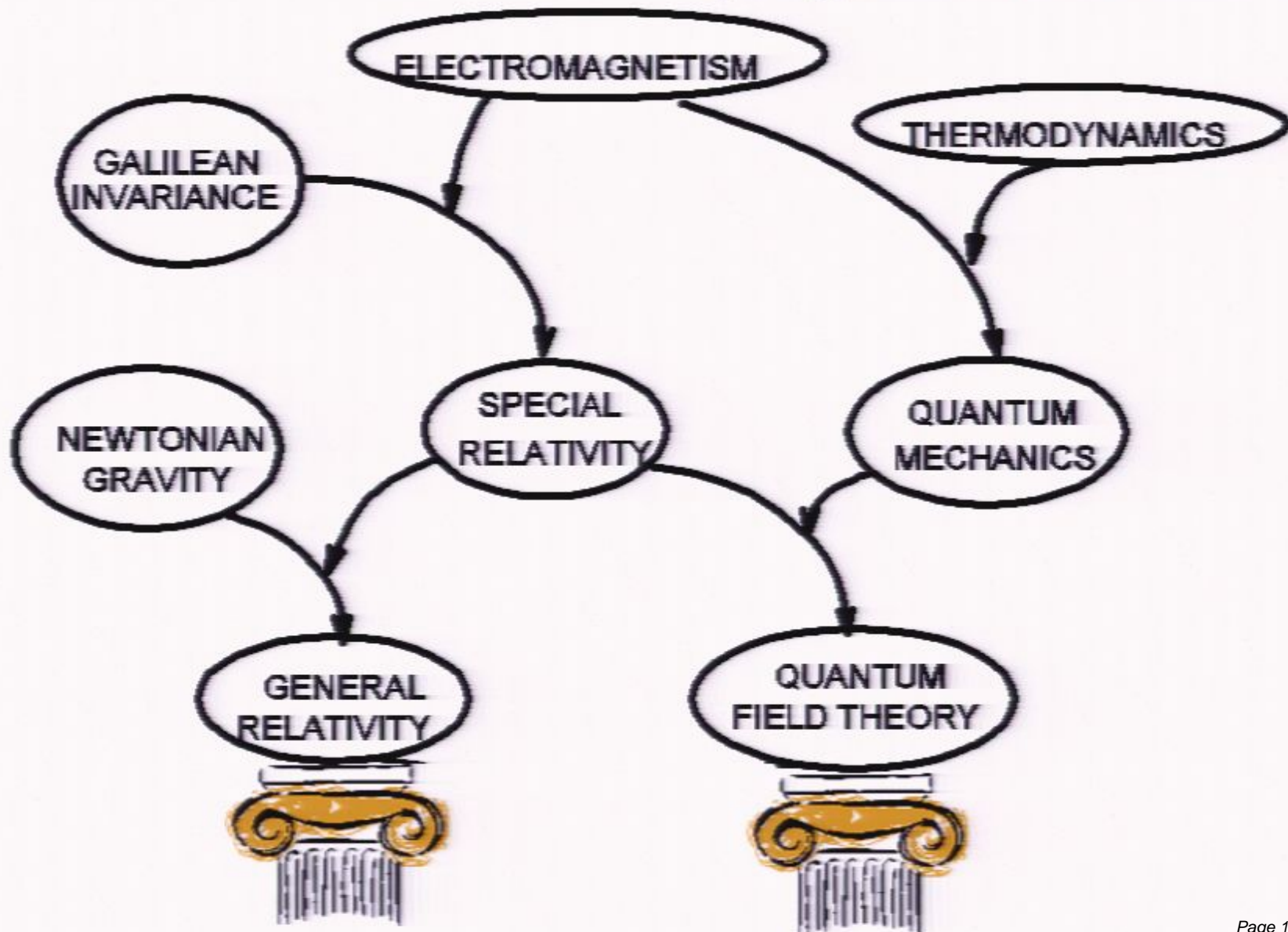
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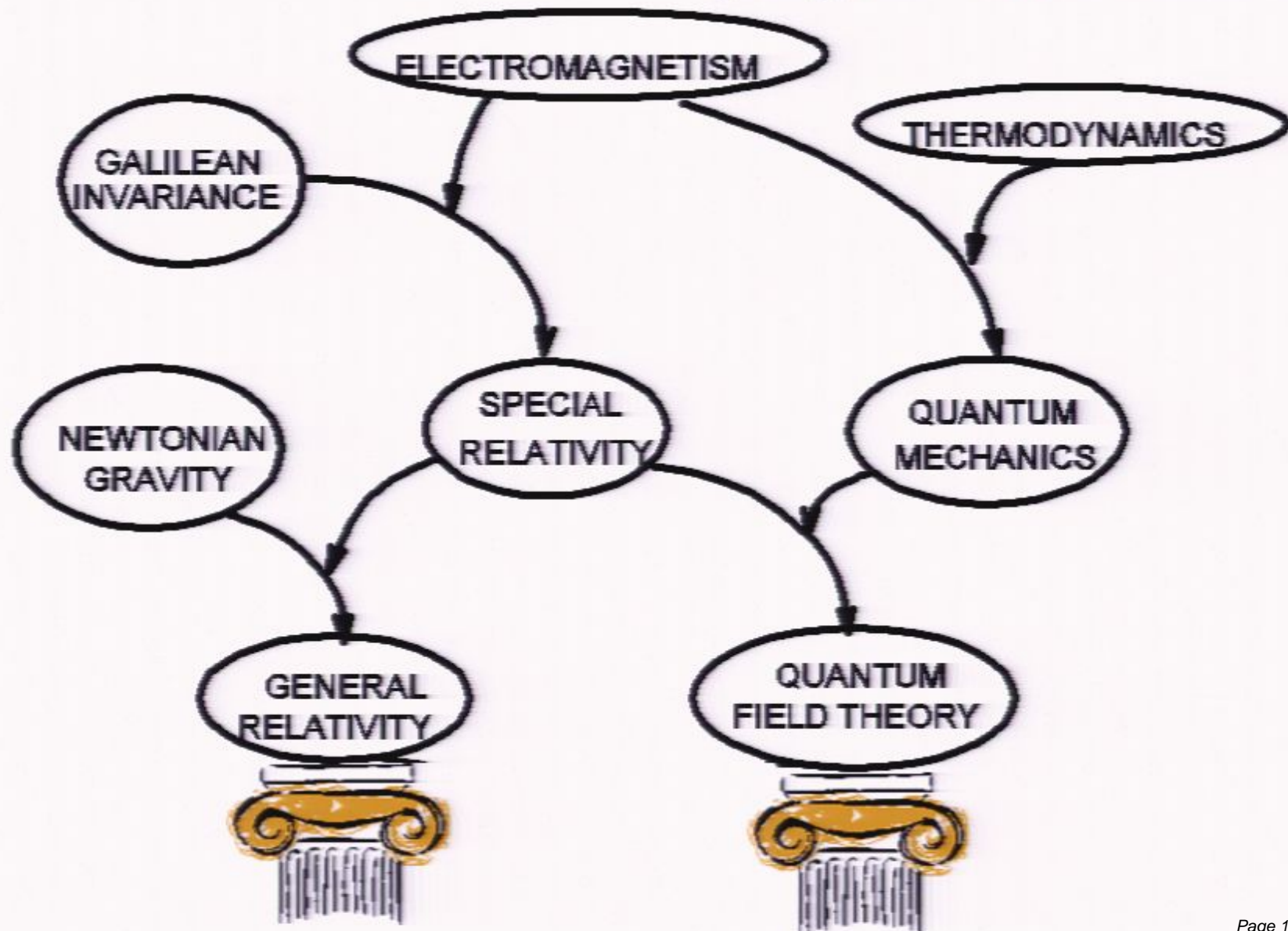
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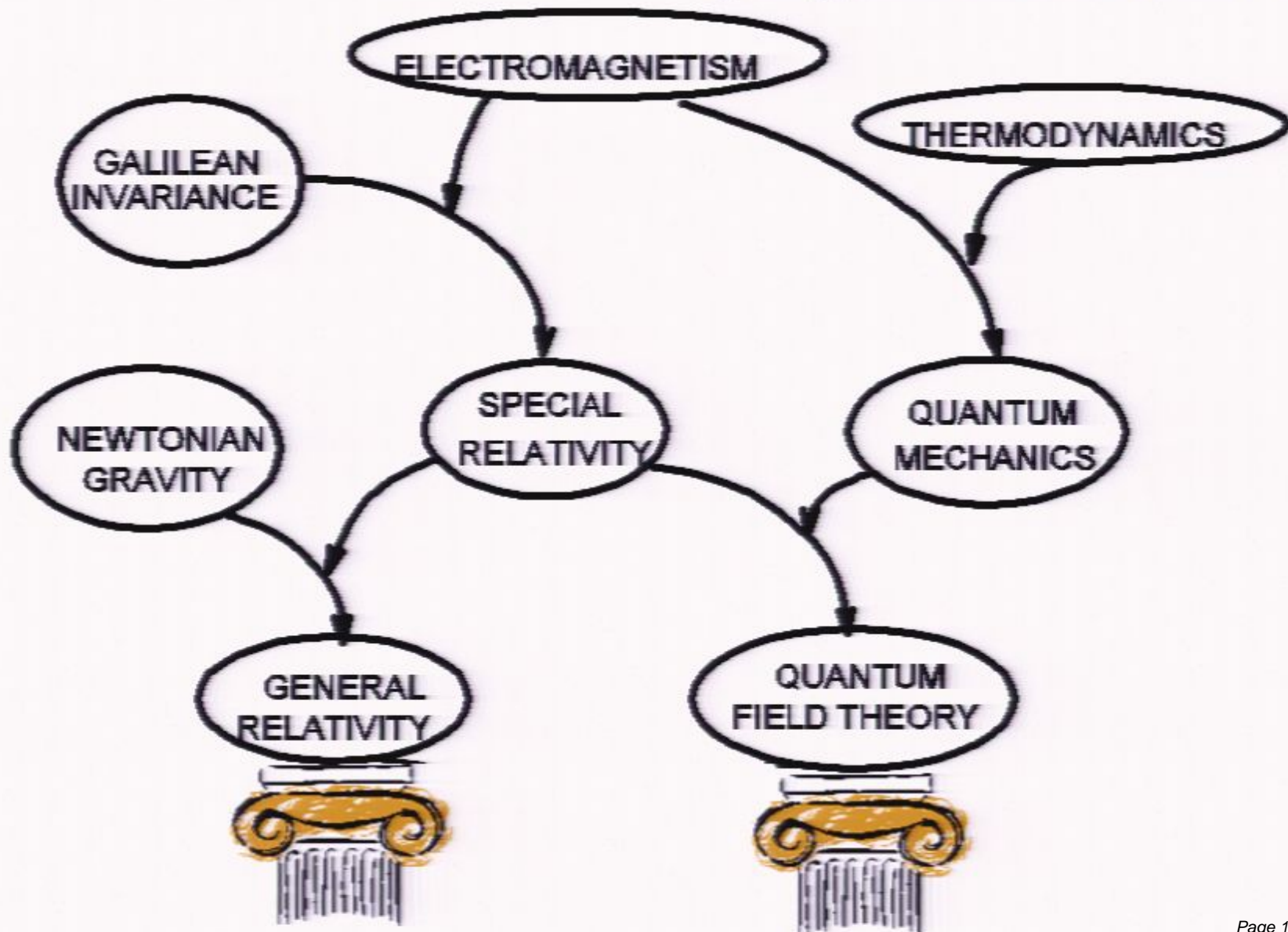
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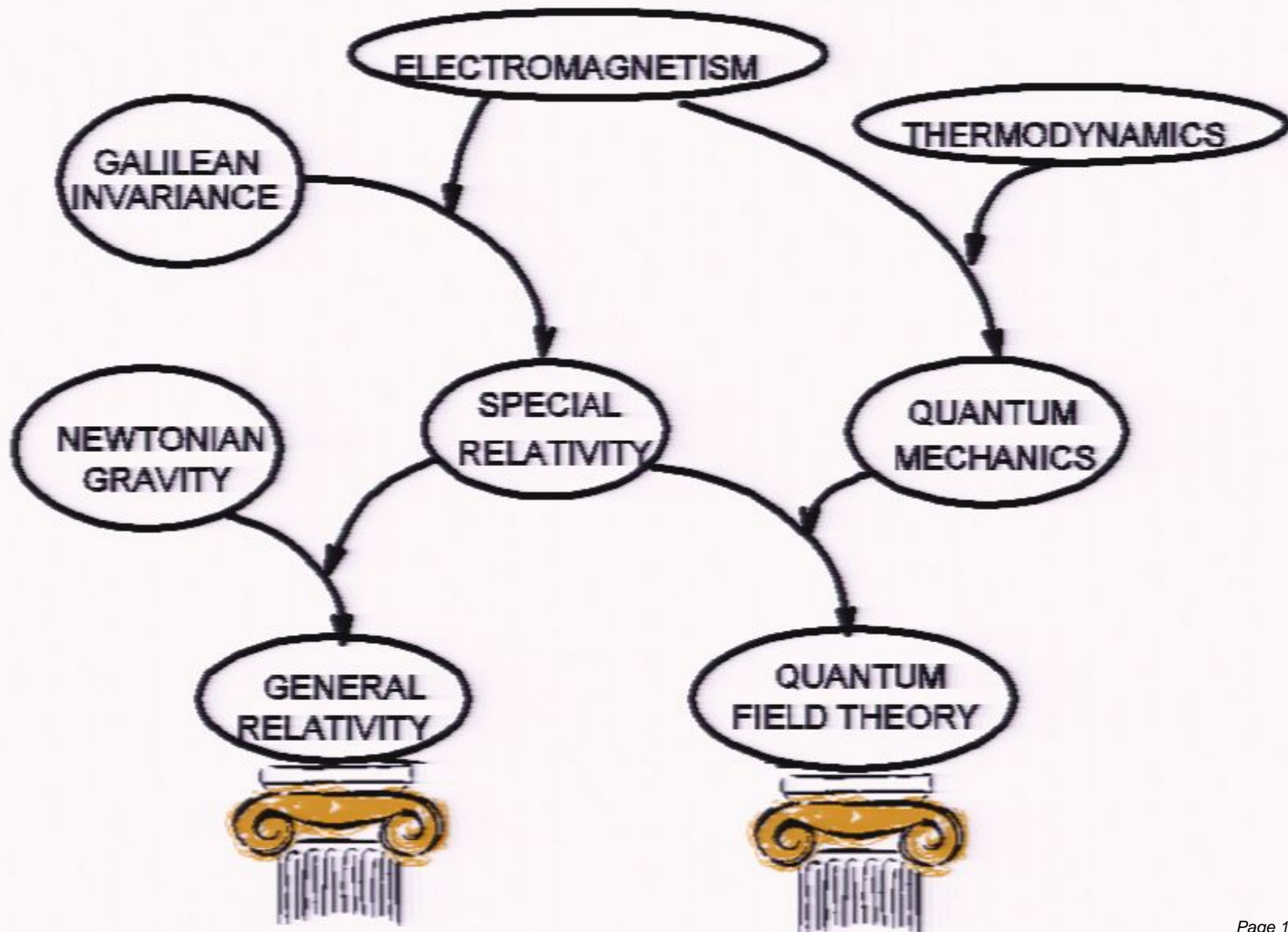
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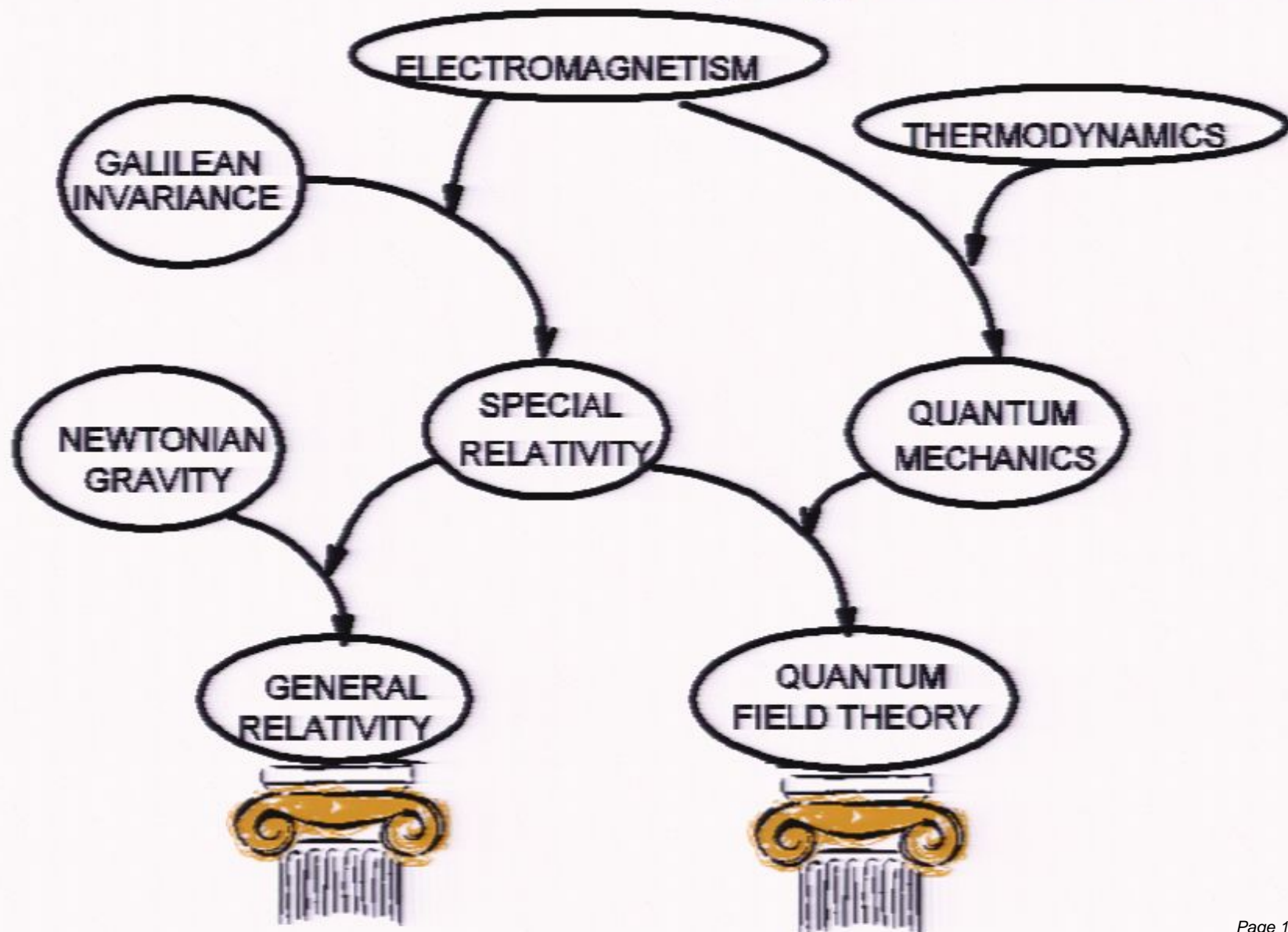
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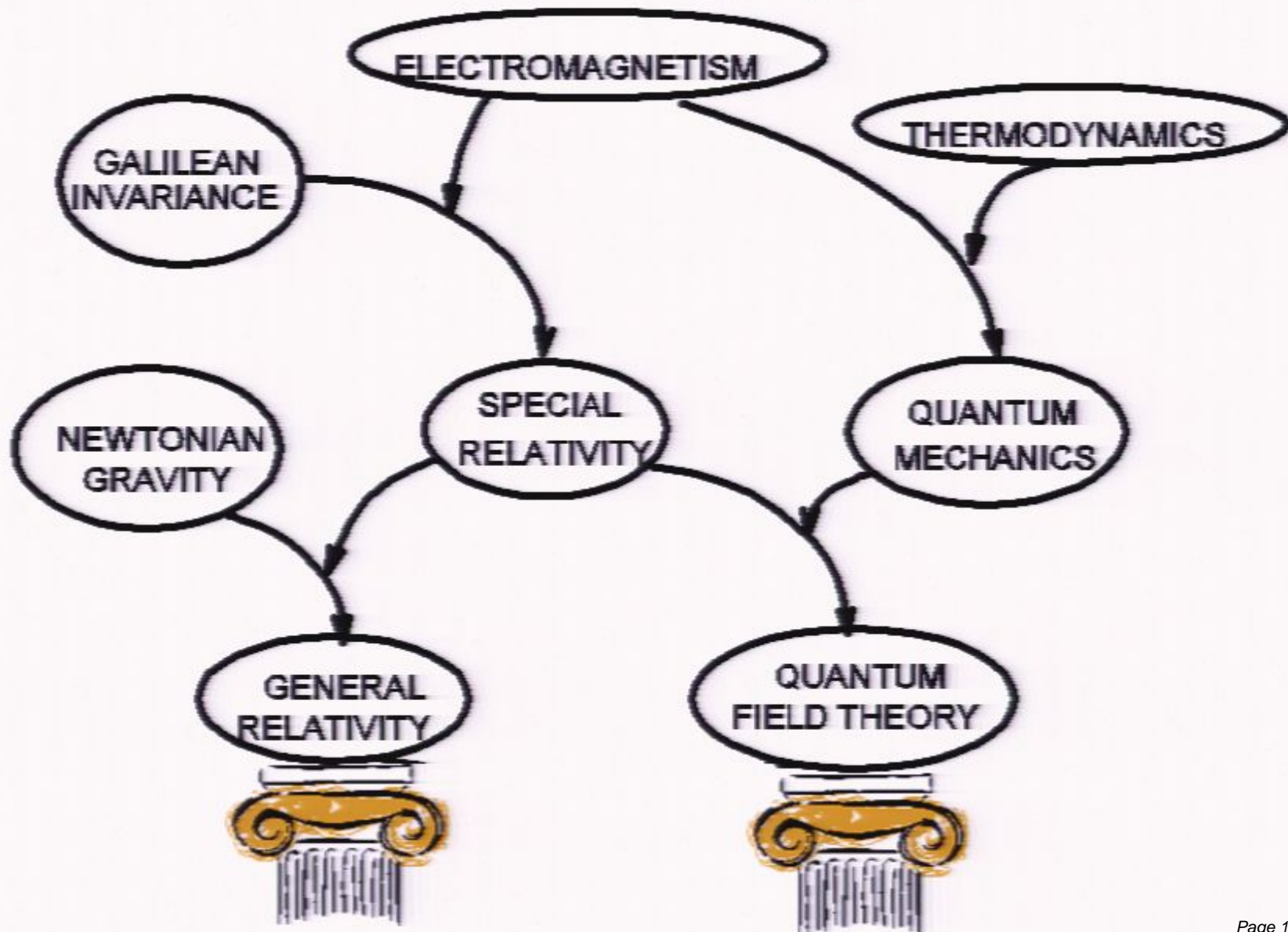
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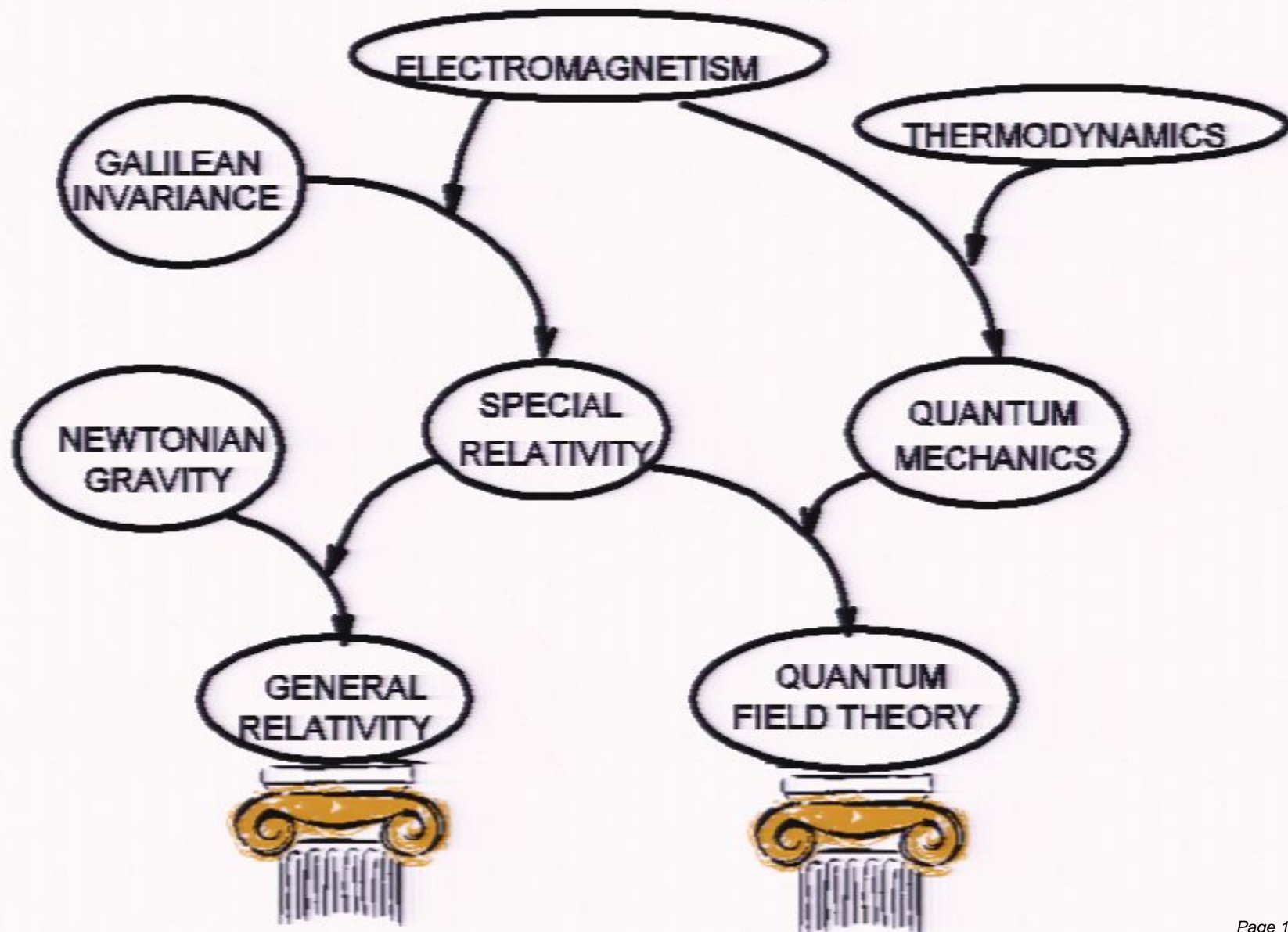
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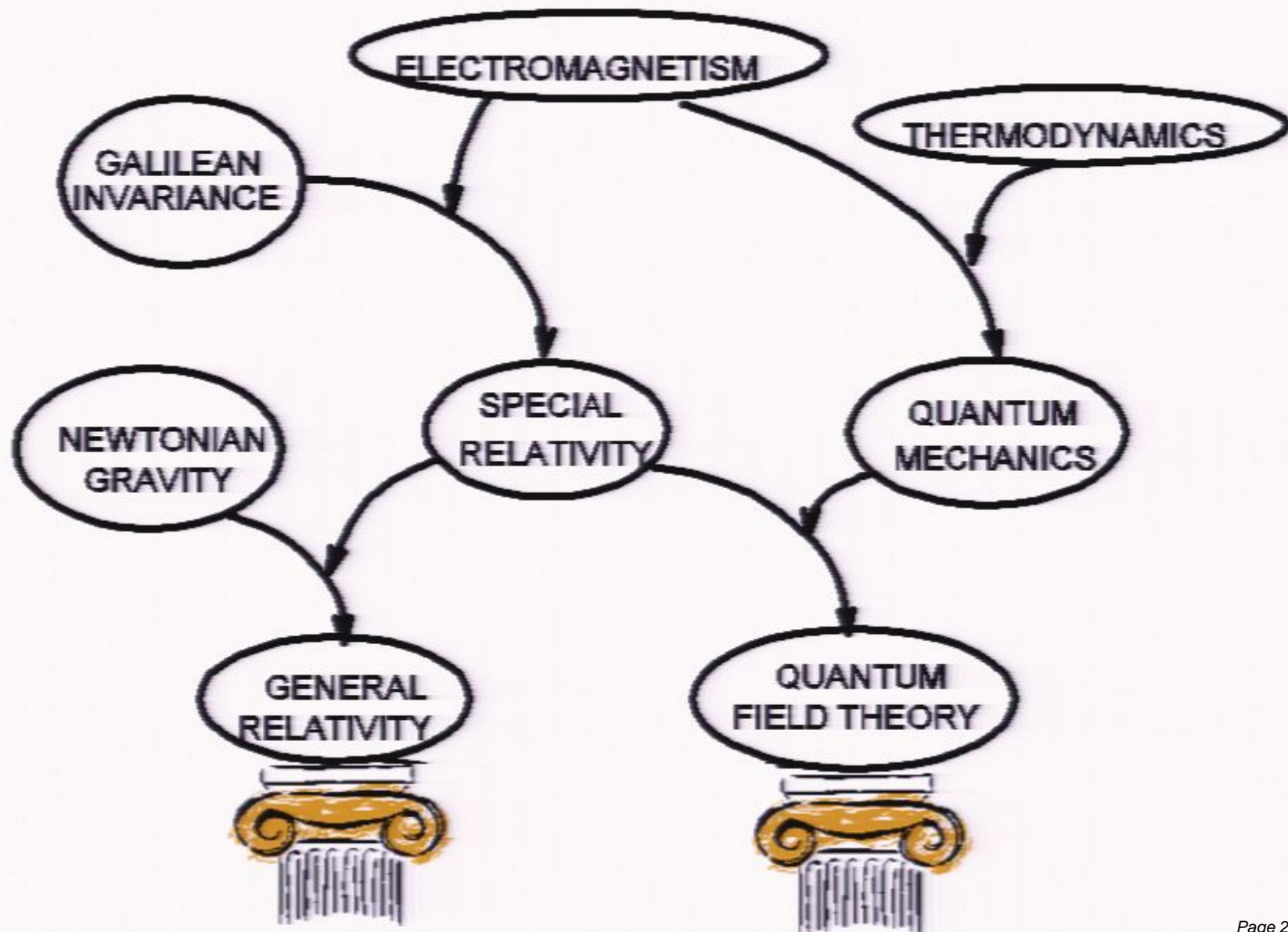
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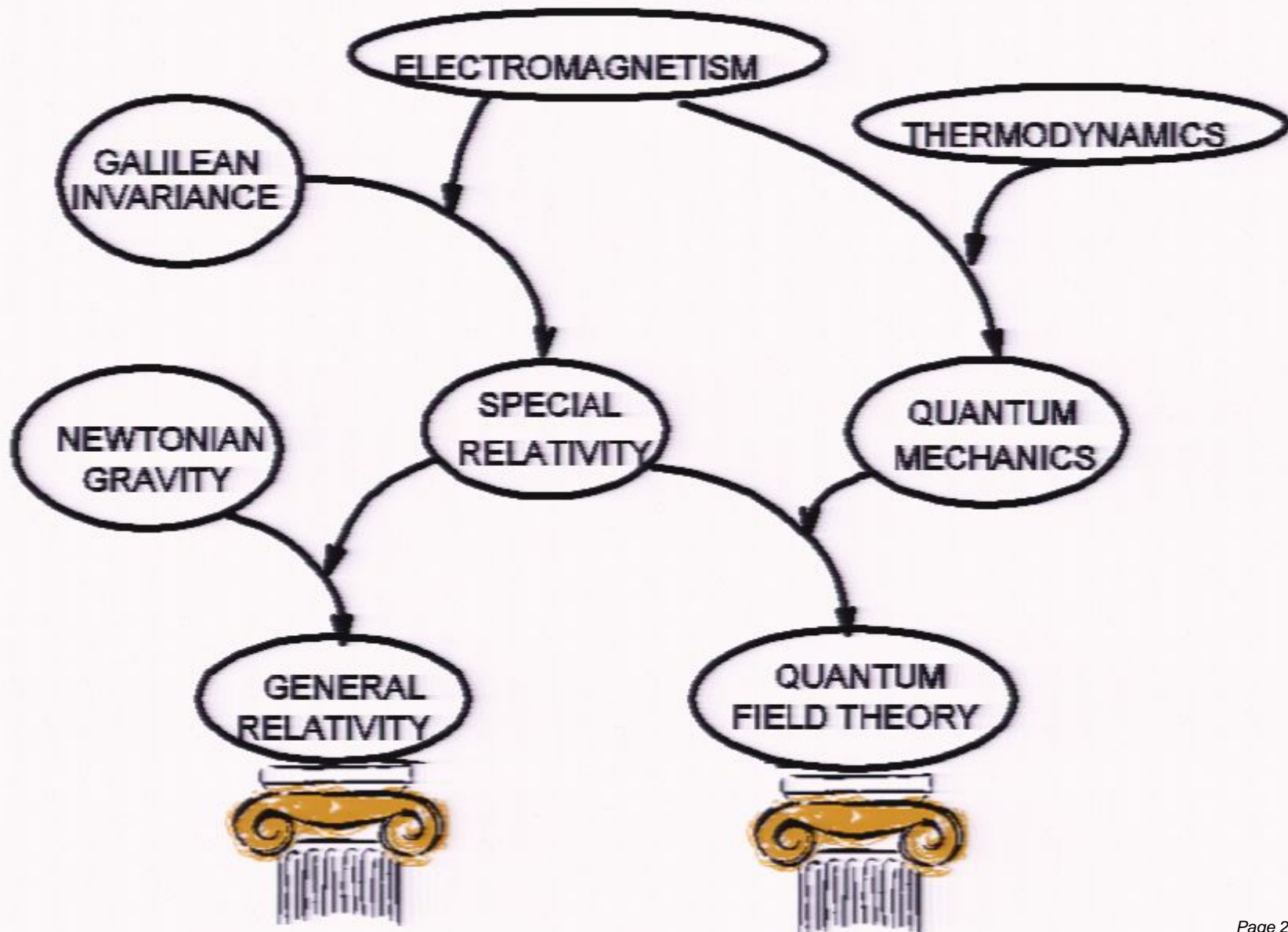
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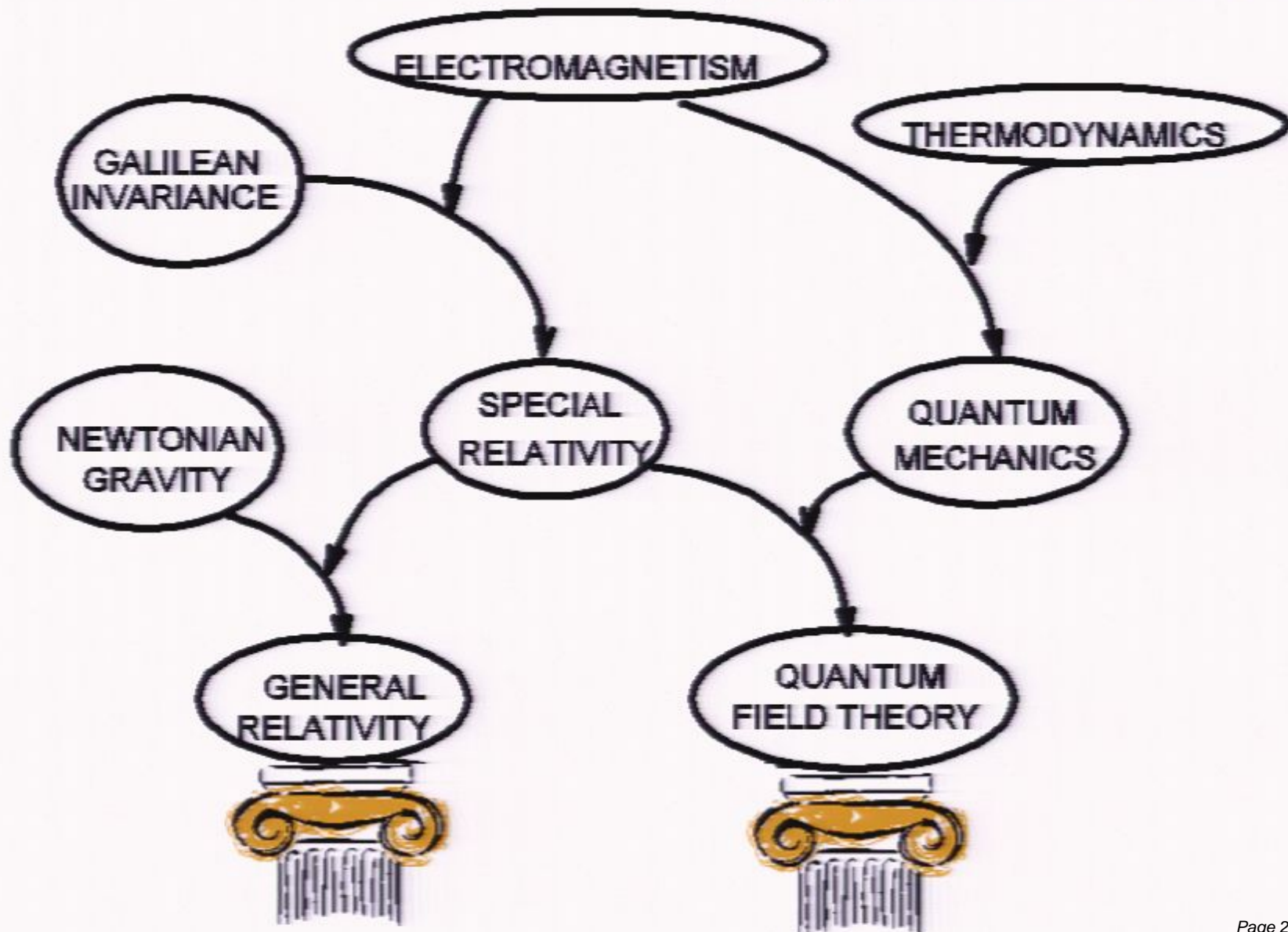
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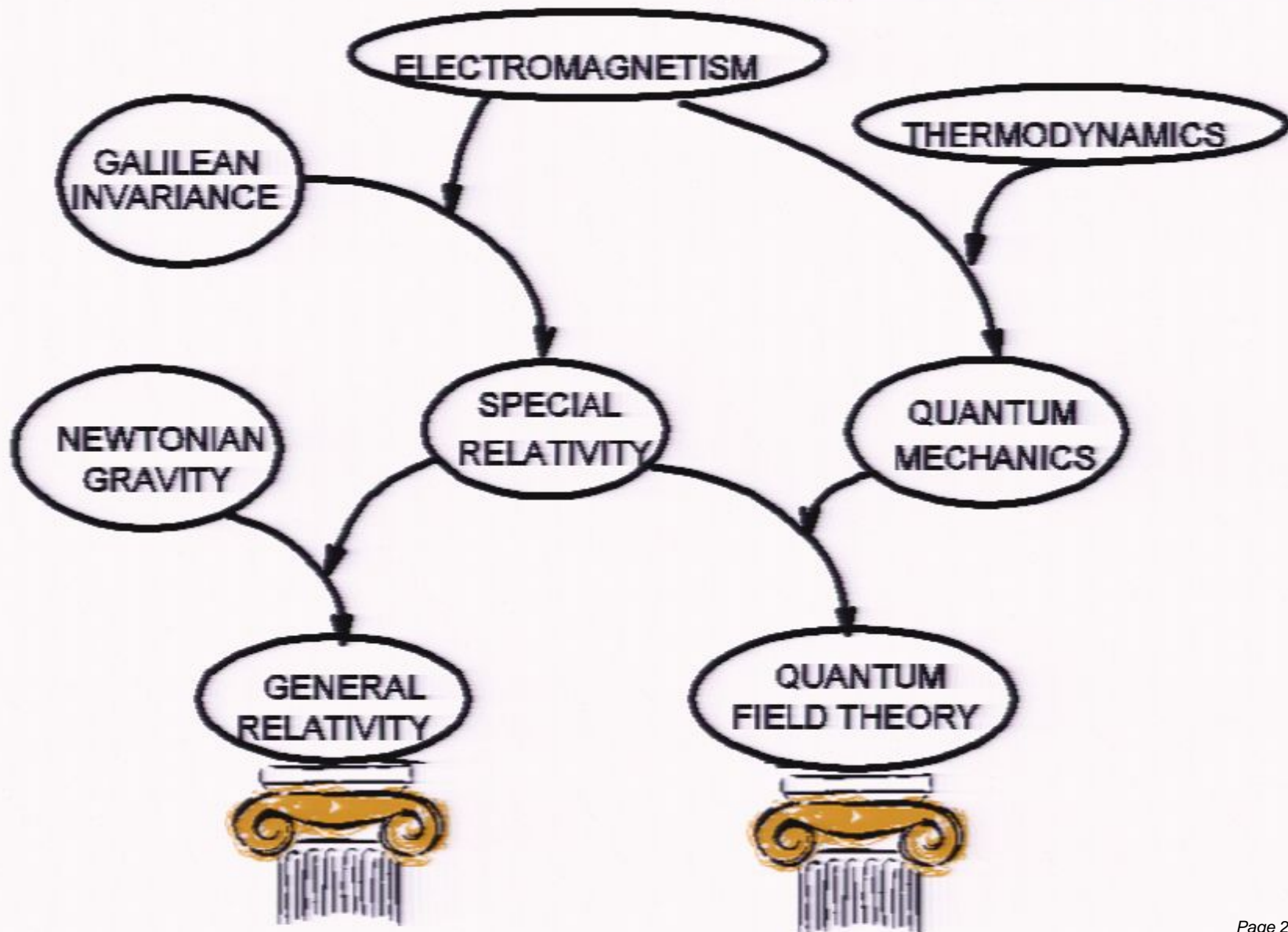
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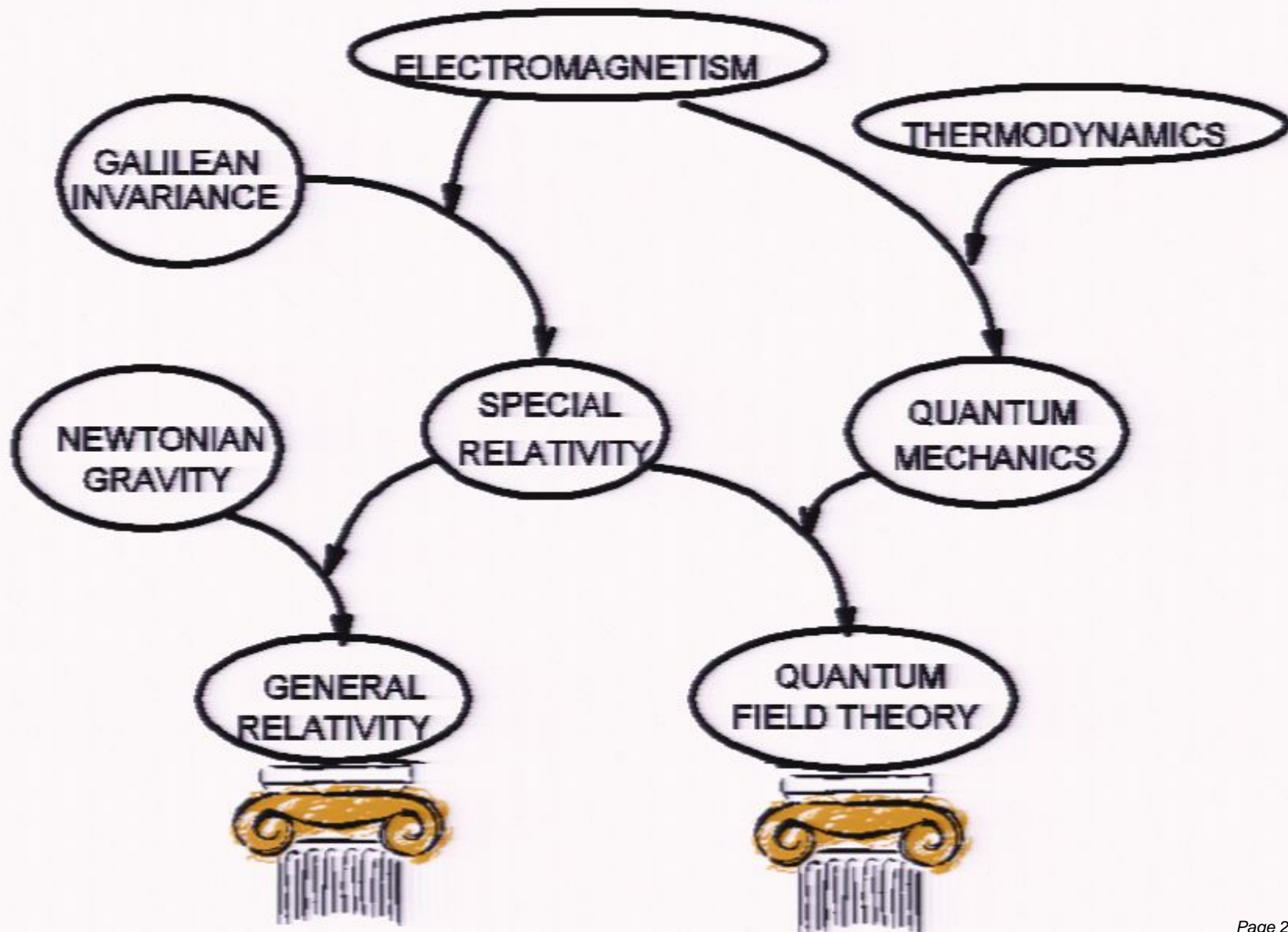
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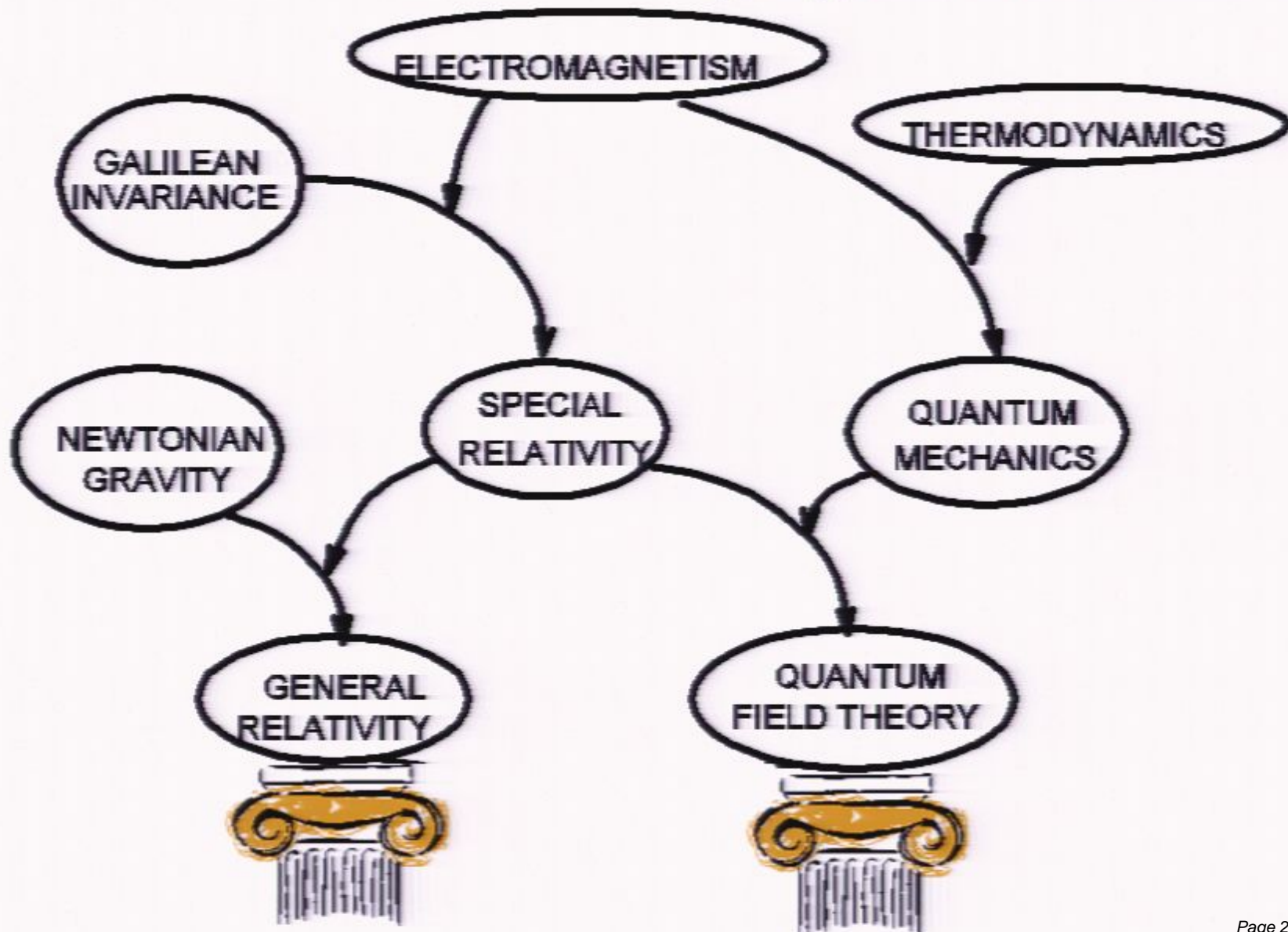
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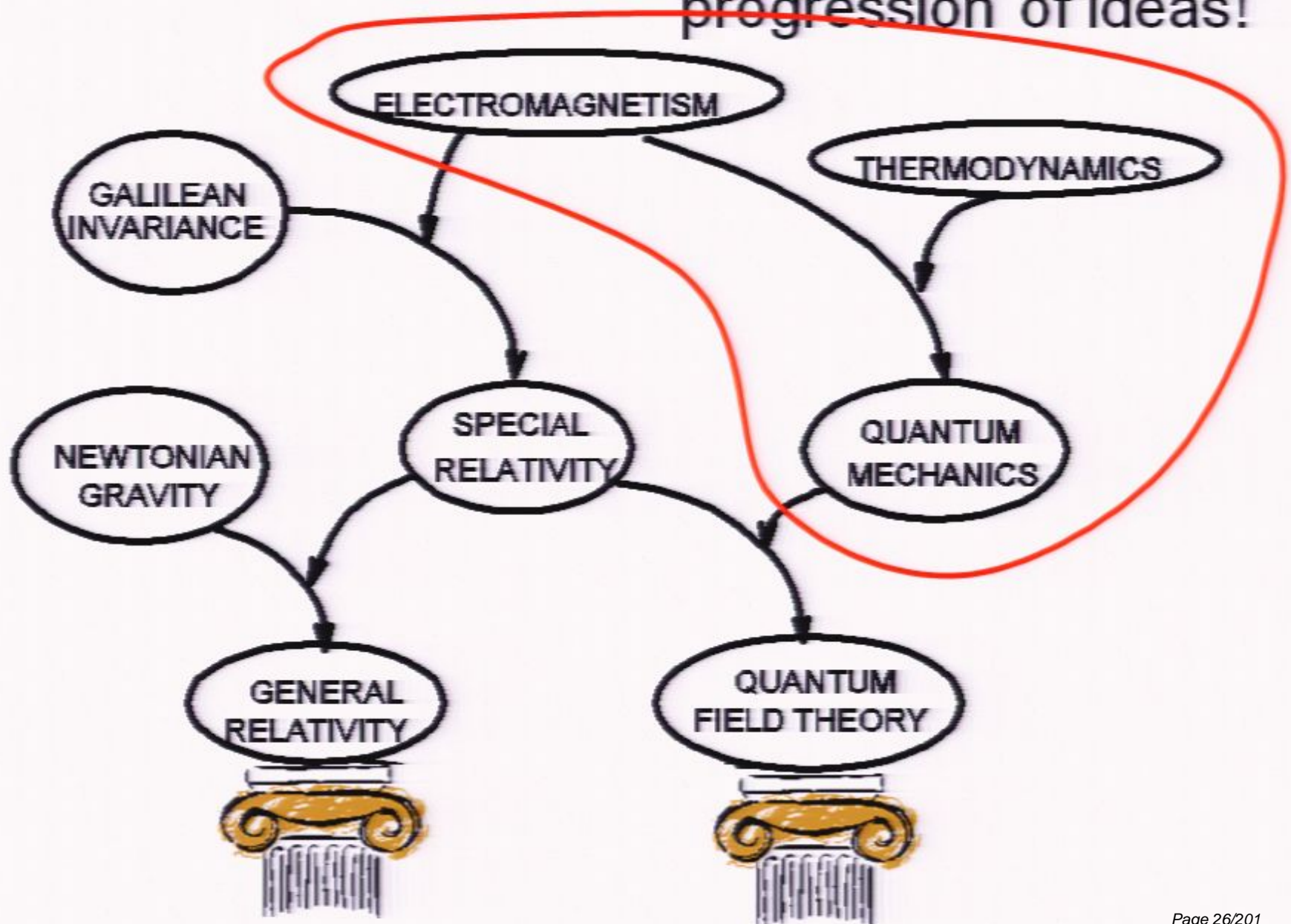
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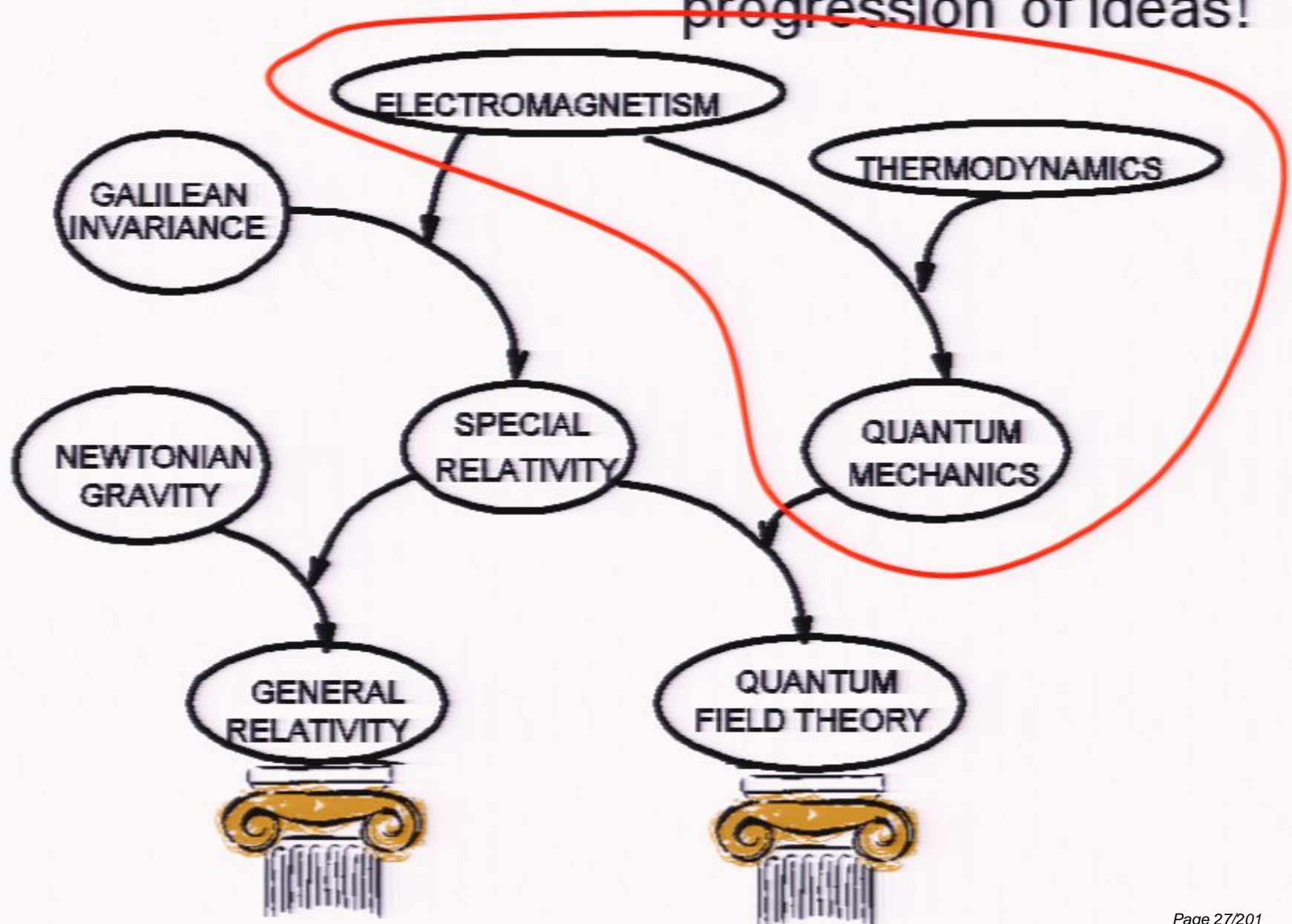
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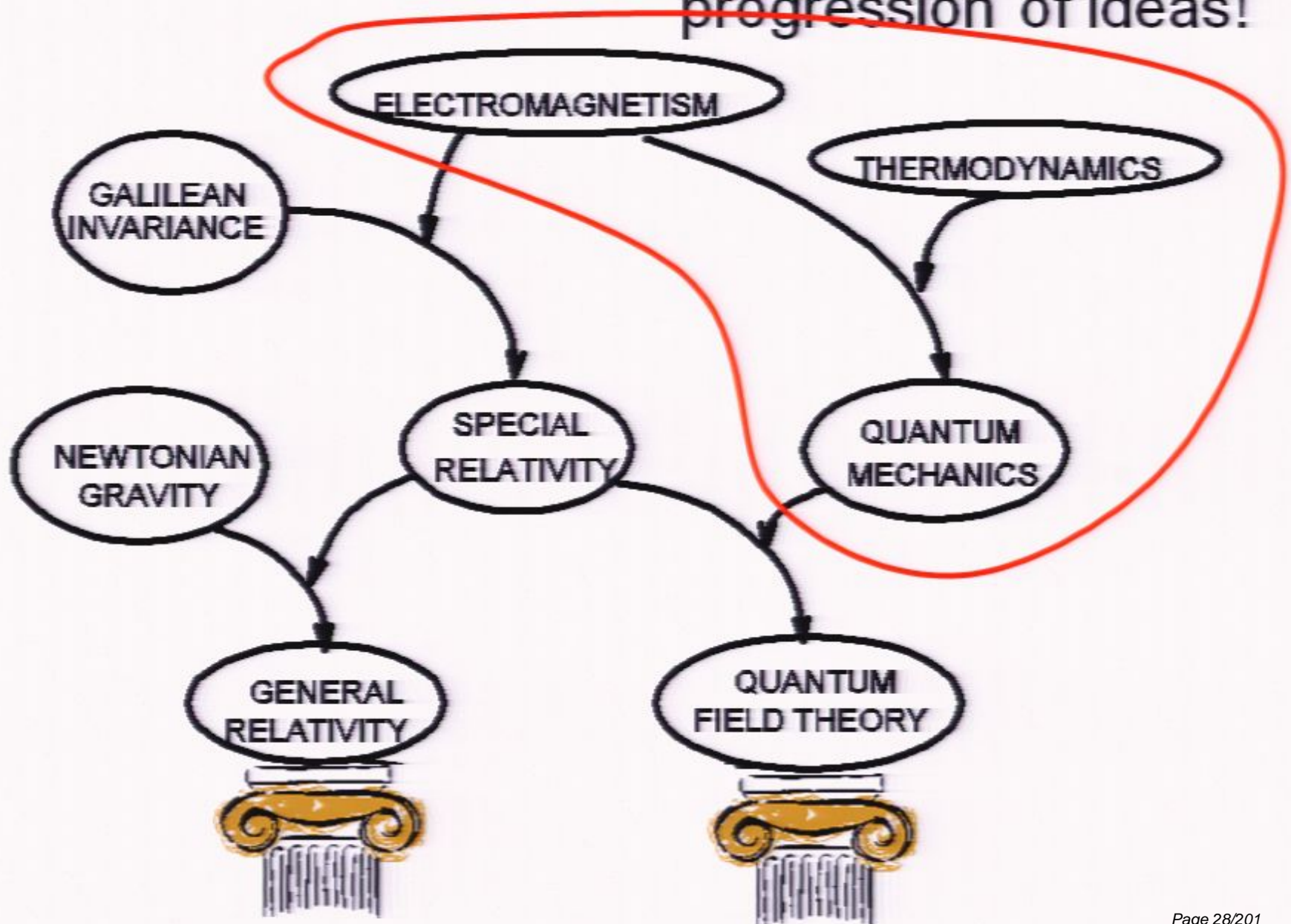
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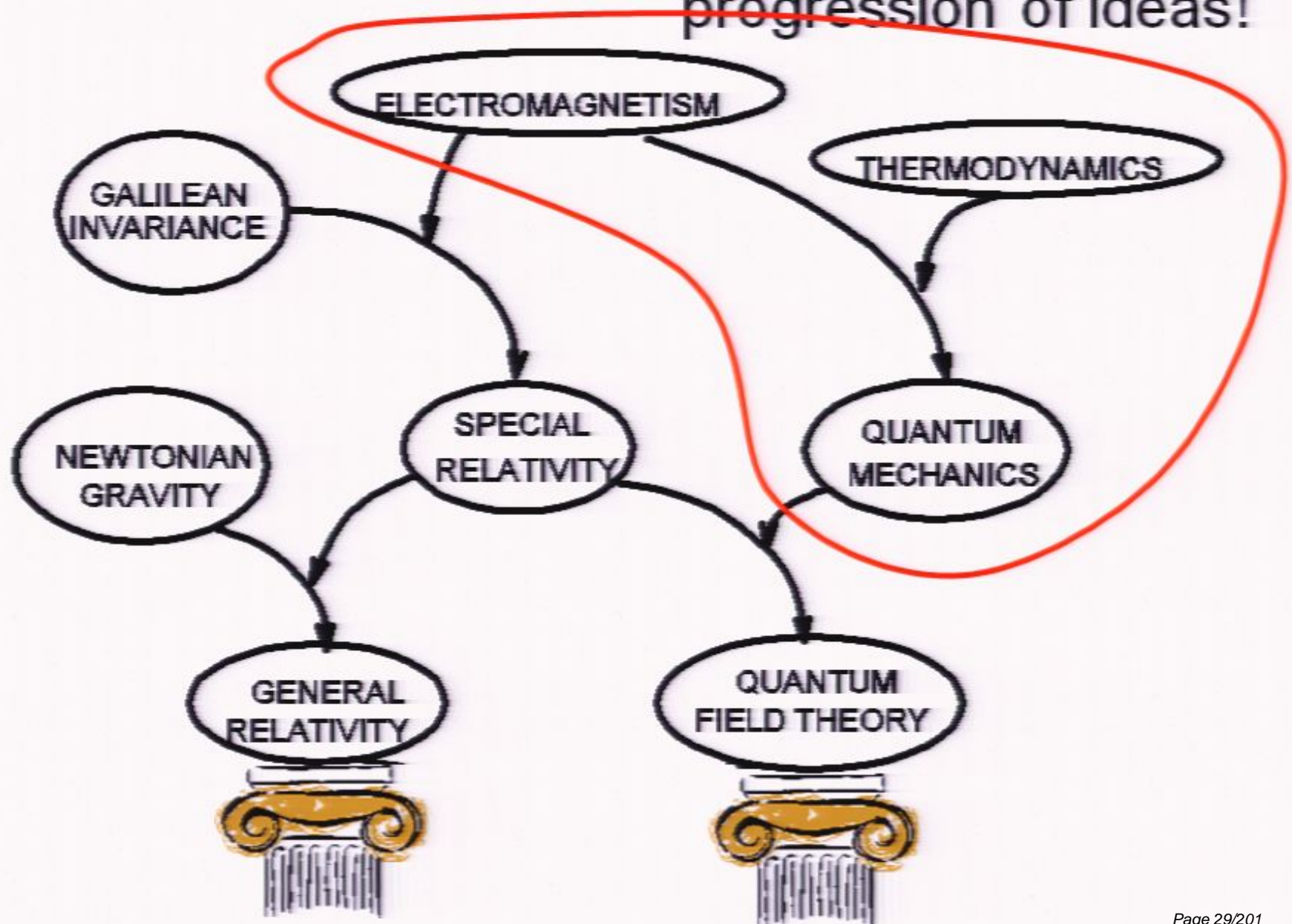
Physics of the 20th century:

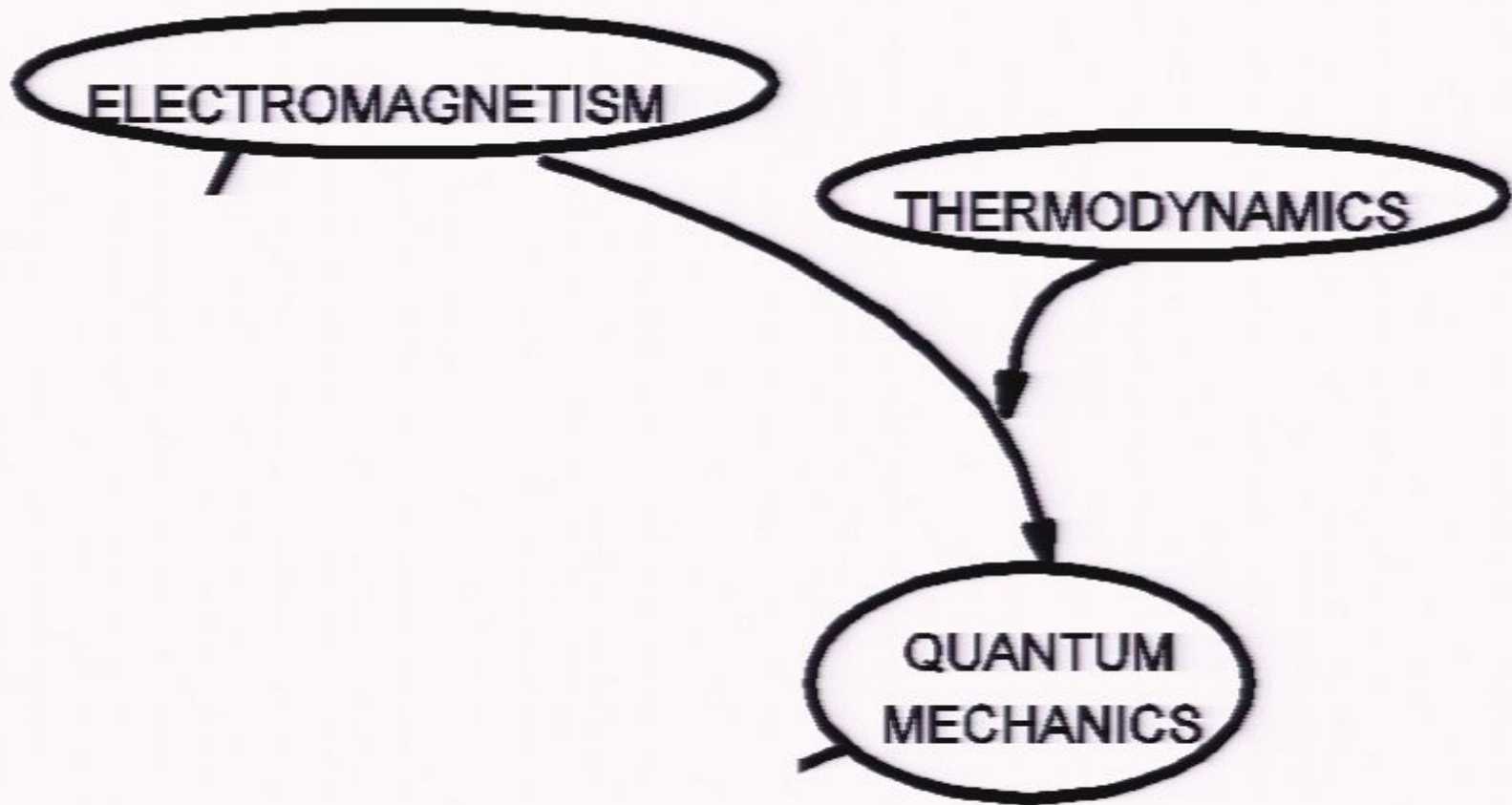
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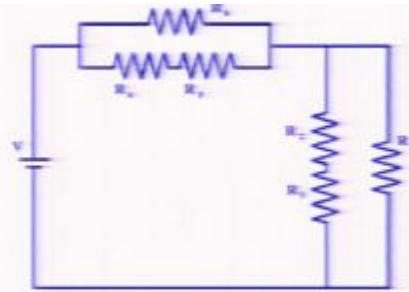


ELECTROMAGNETISM

THERMODYNAMICS

QUANTUM MECHANICS



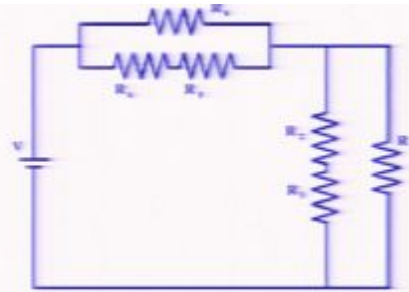


ELECTROMAGNETISM

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**QUANTUM
MECHANICS**



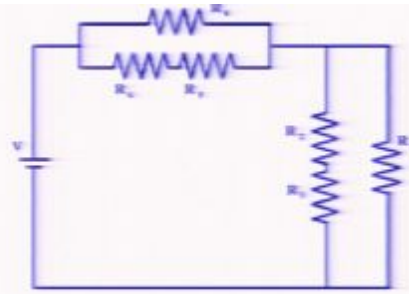


ELECTROMAGNETISM

THERMODYNAMICS



**QUANTUM
MECHANICS**



ELECTROMAGNETISM

THERMODYNAMICS

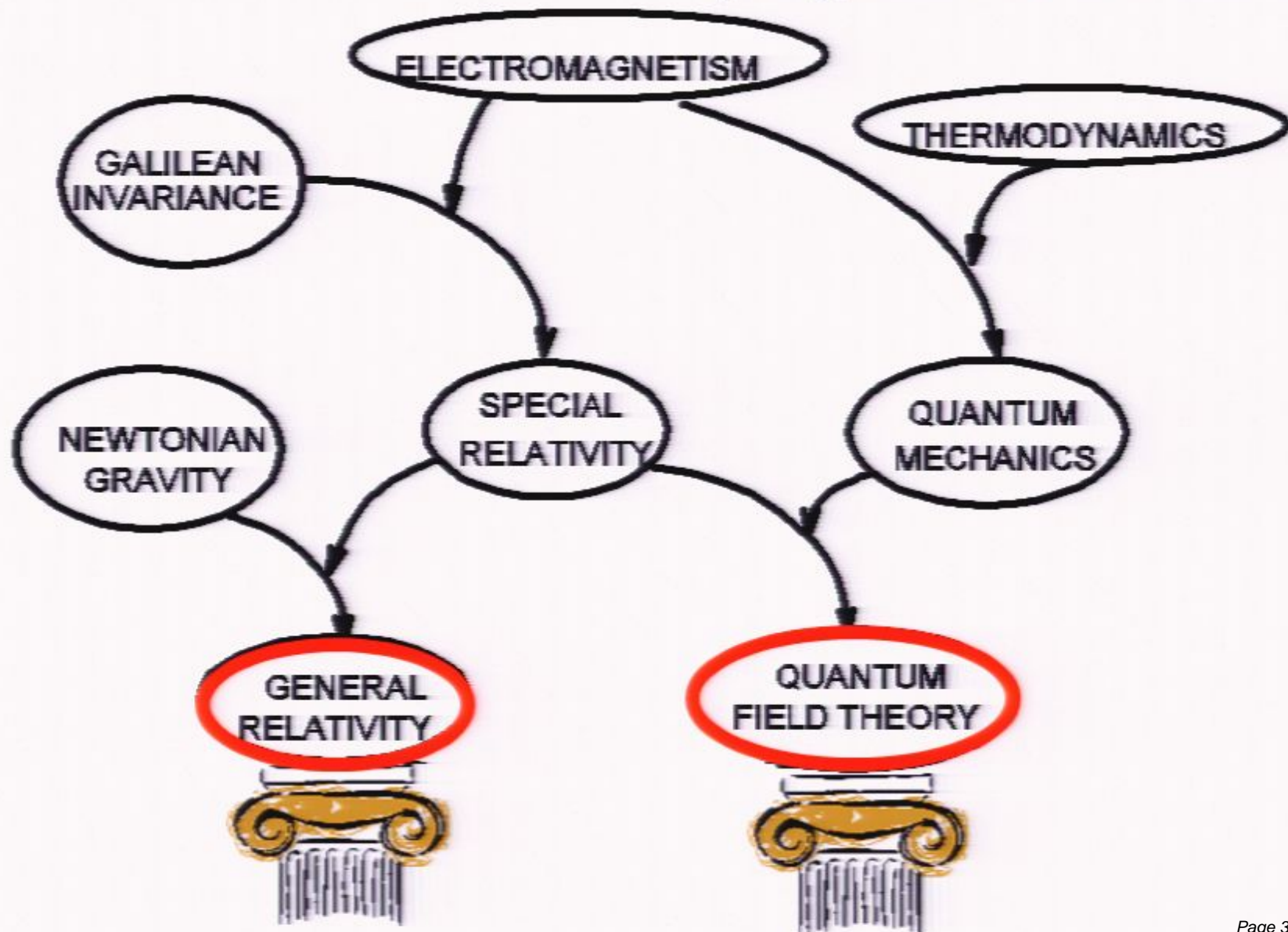


QUANTUM MECHANICS



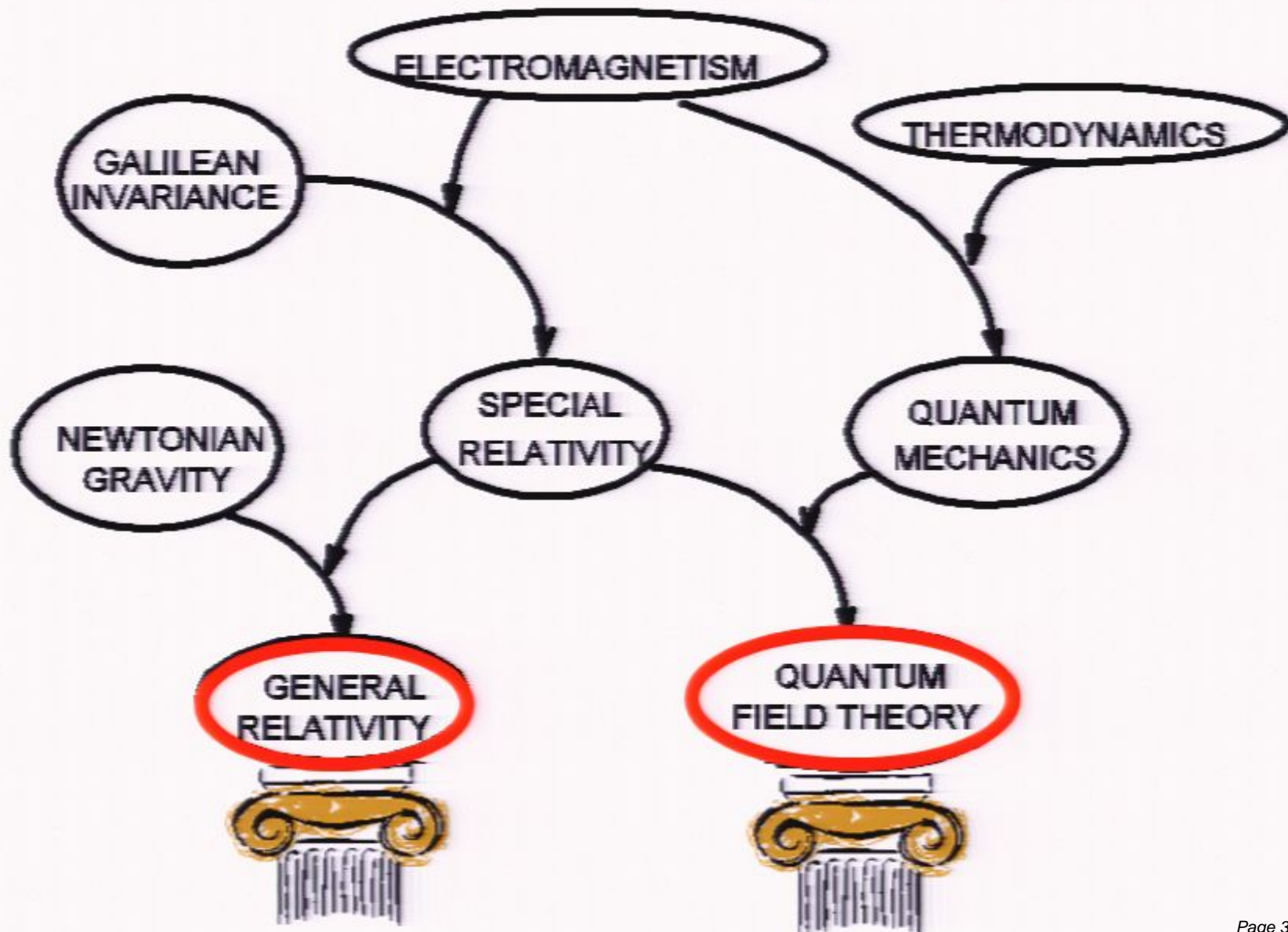
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A grand synthesis and progression of ideas!



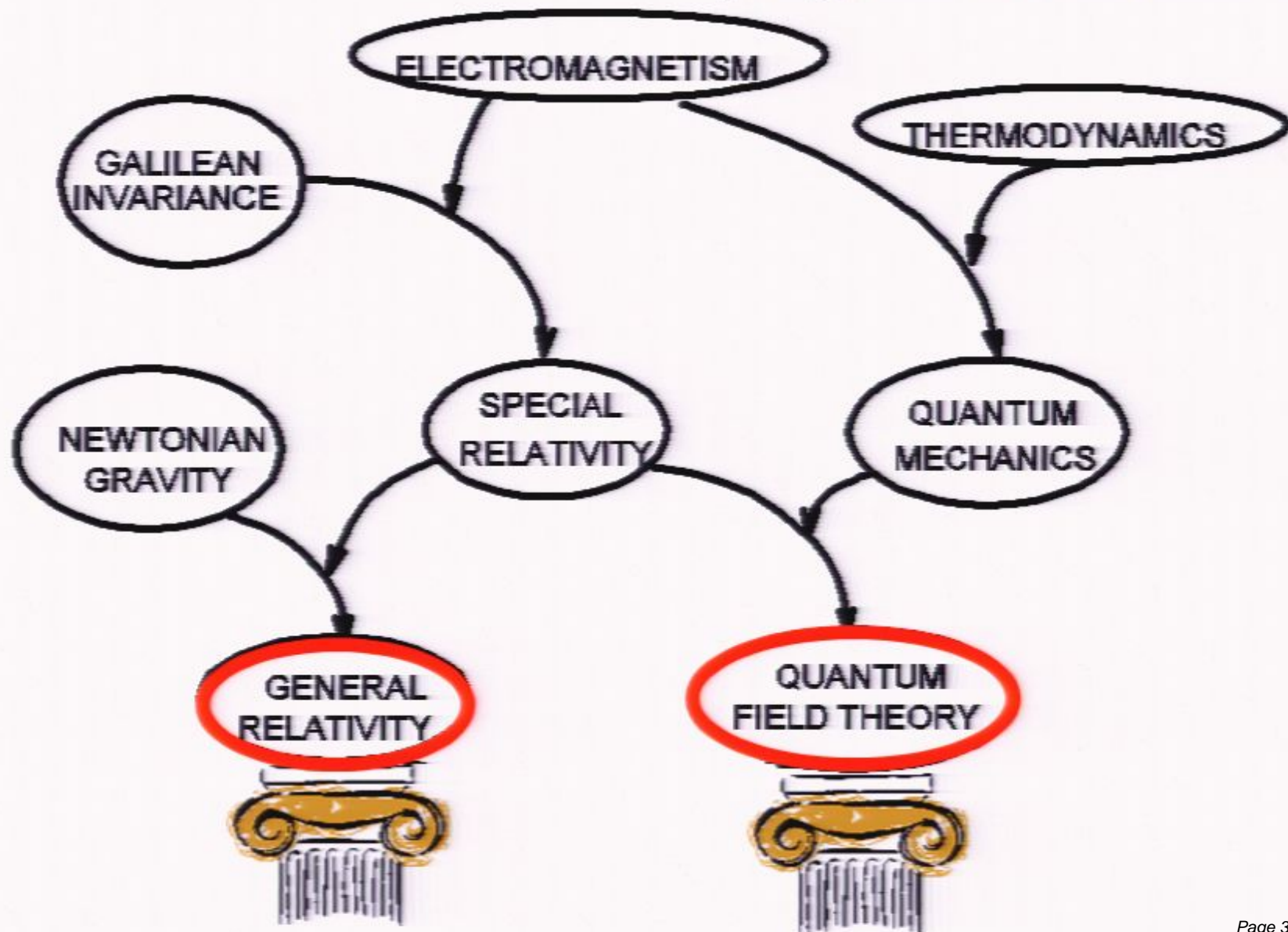
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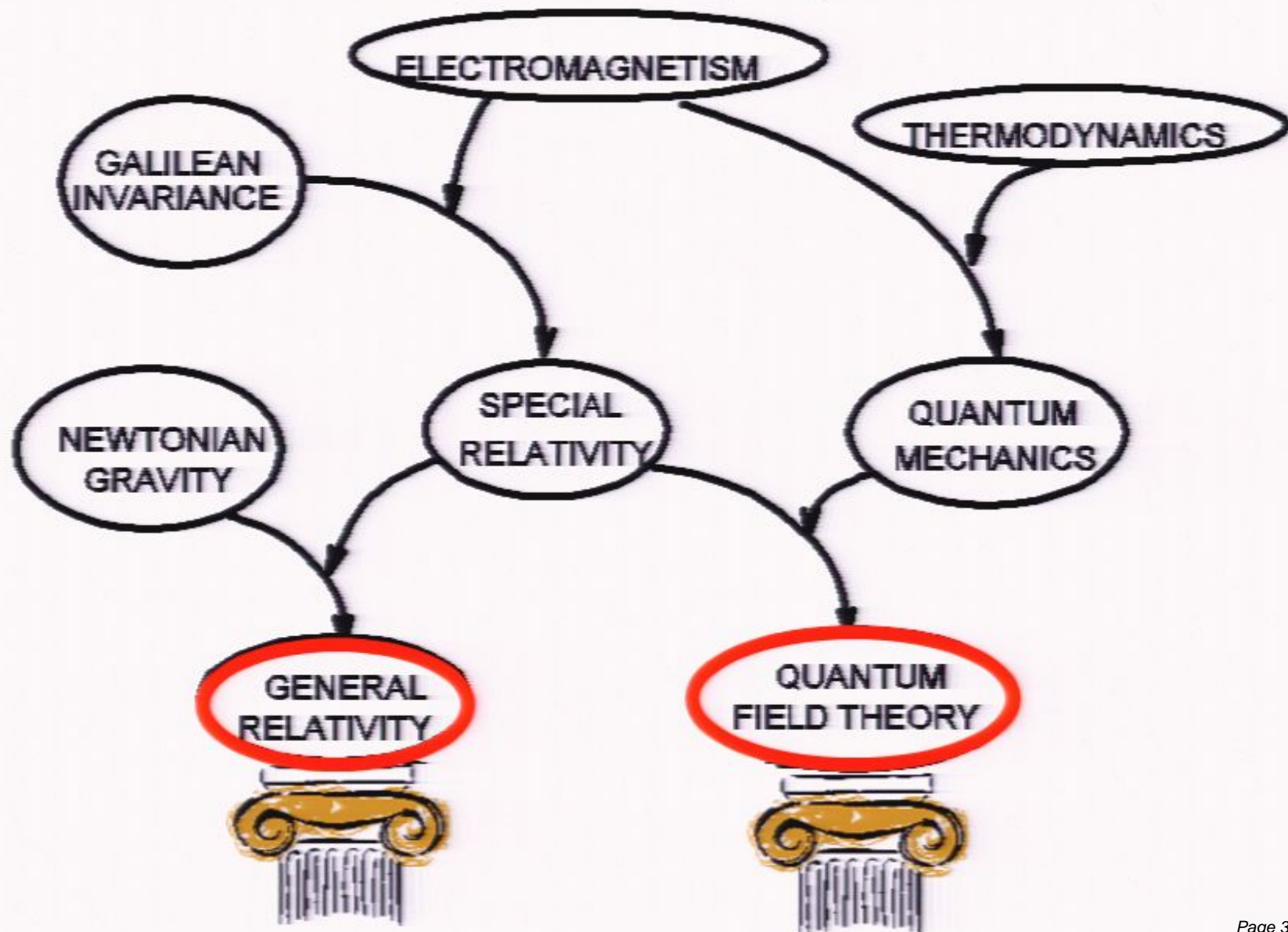
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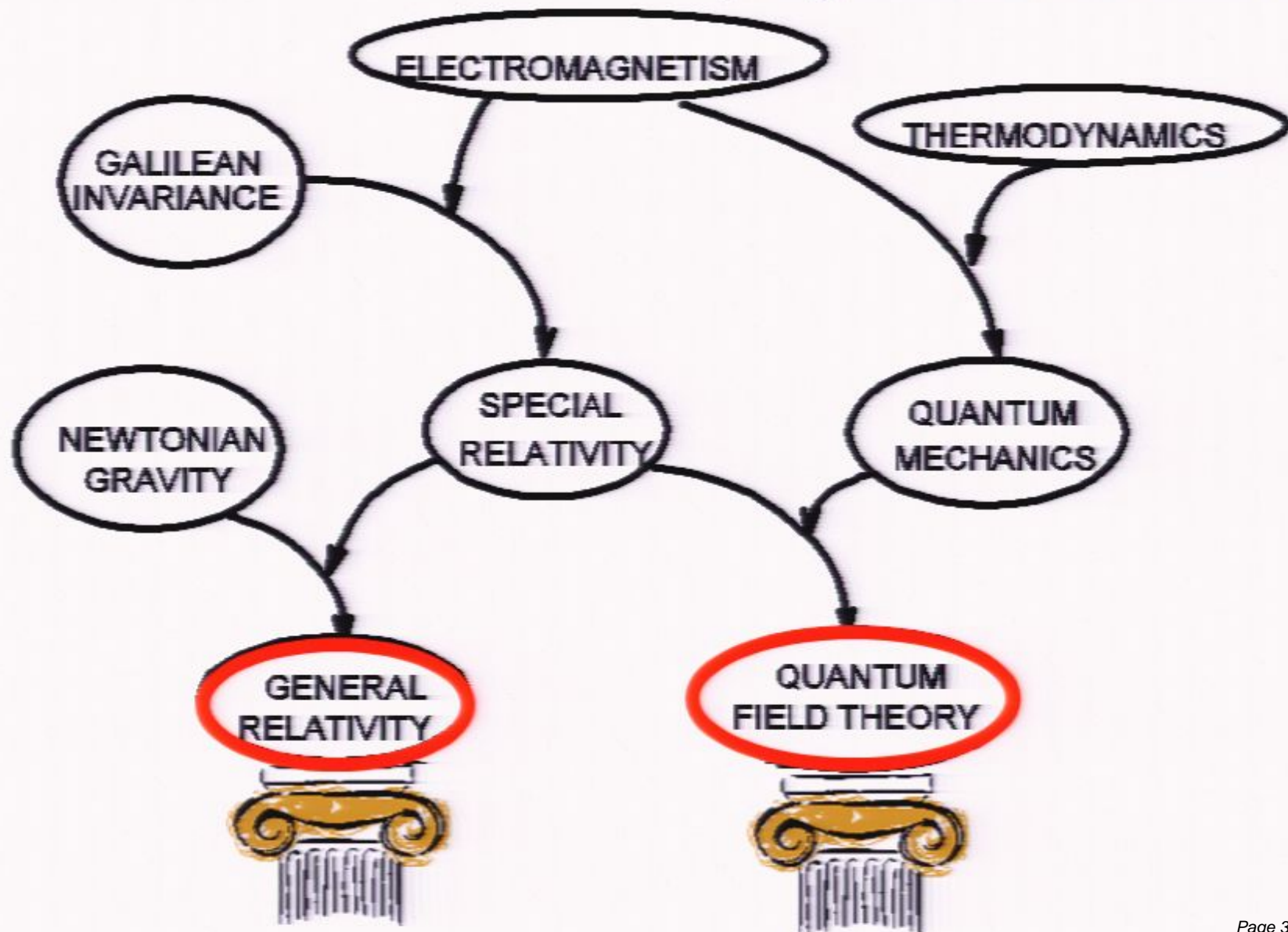
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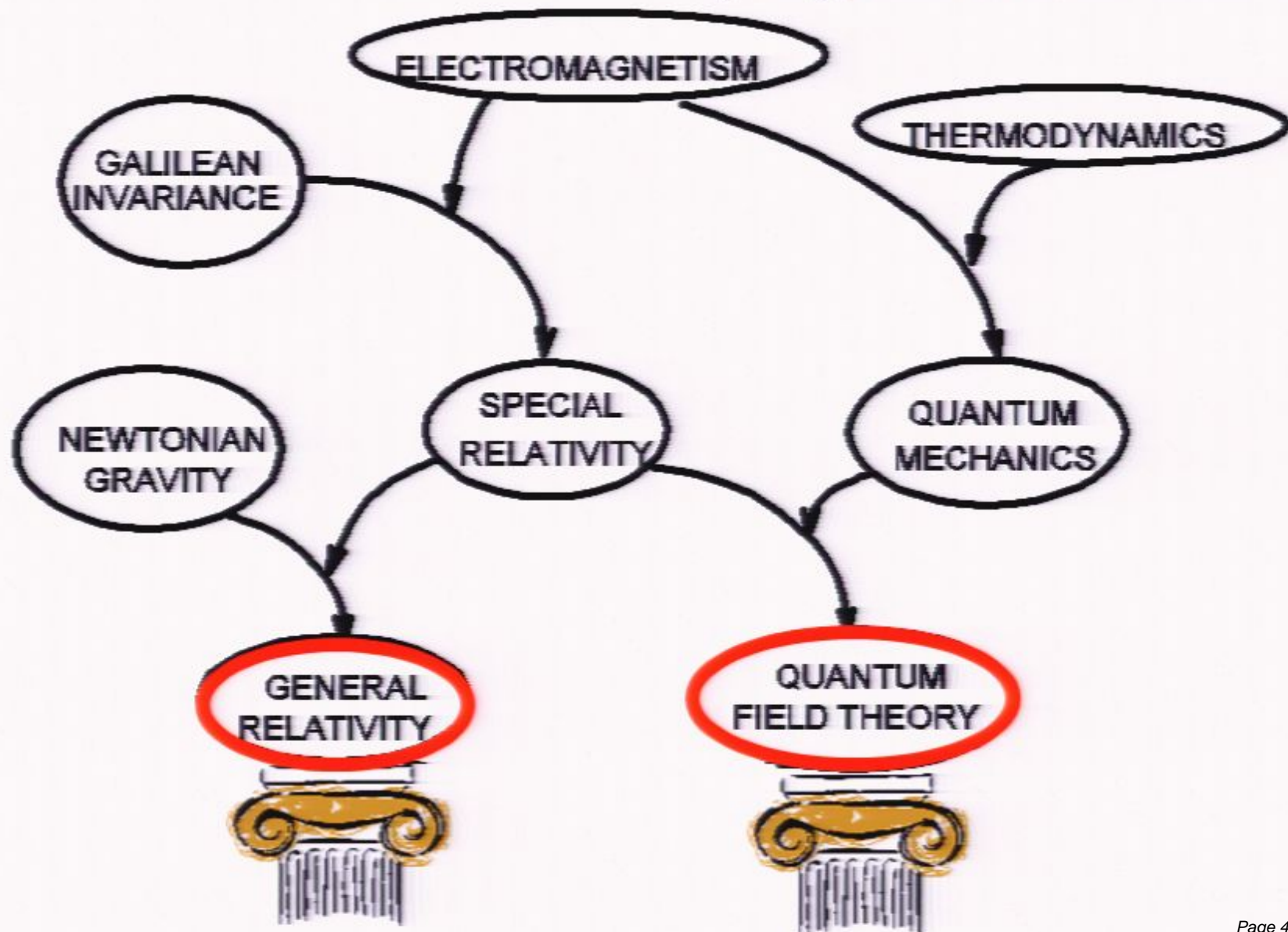
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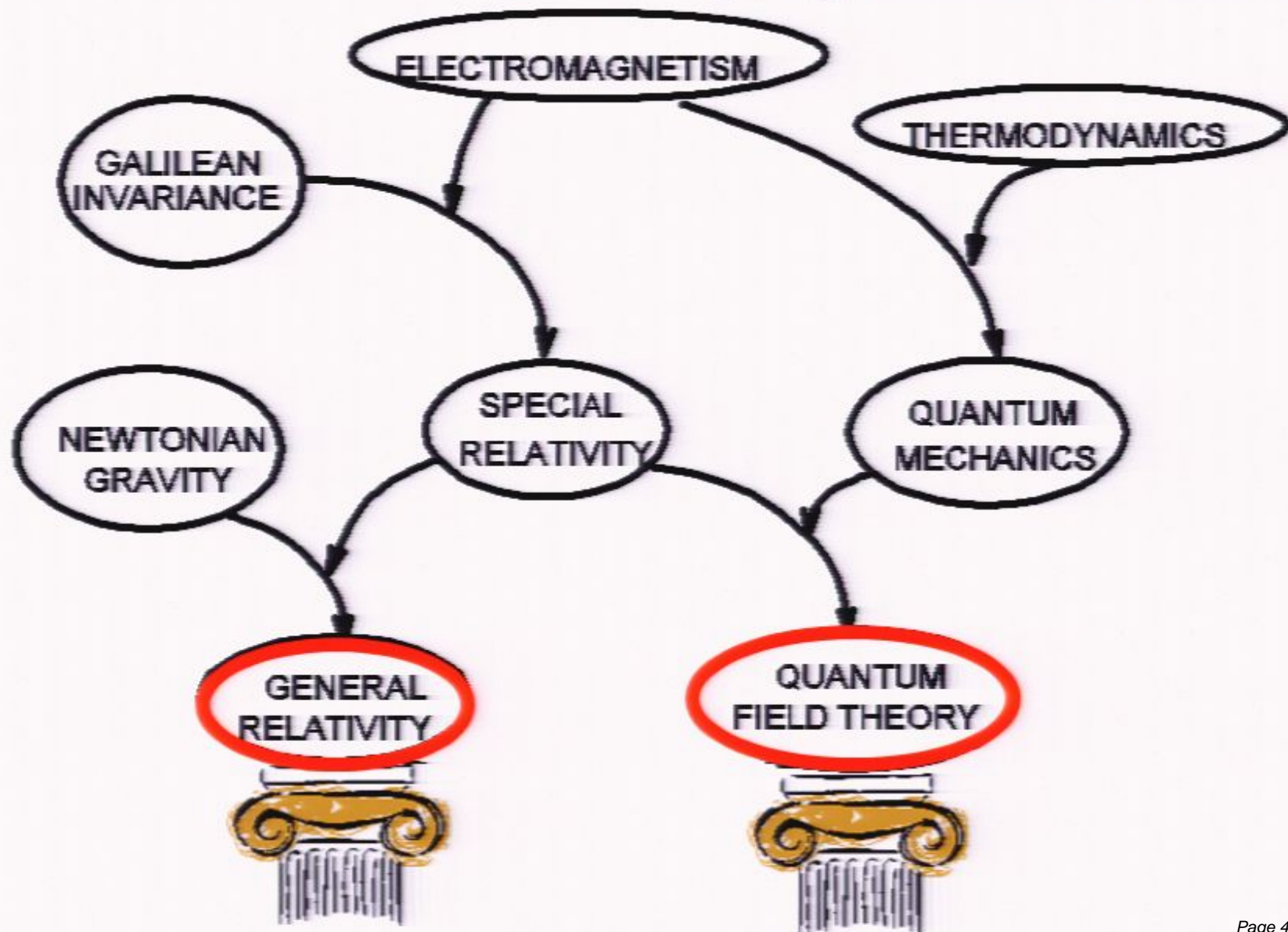
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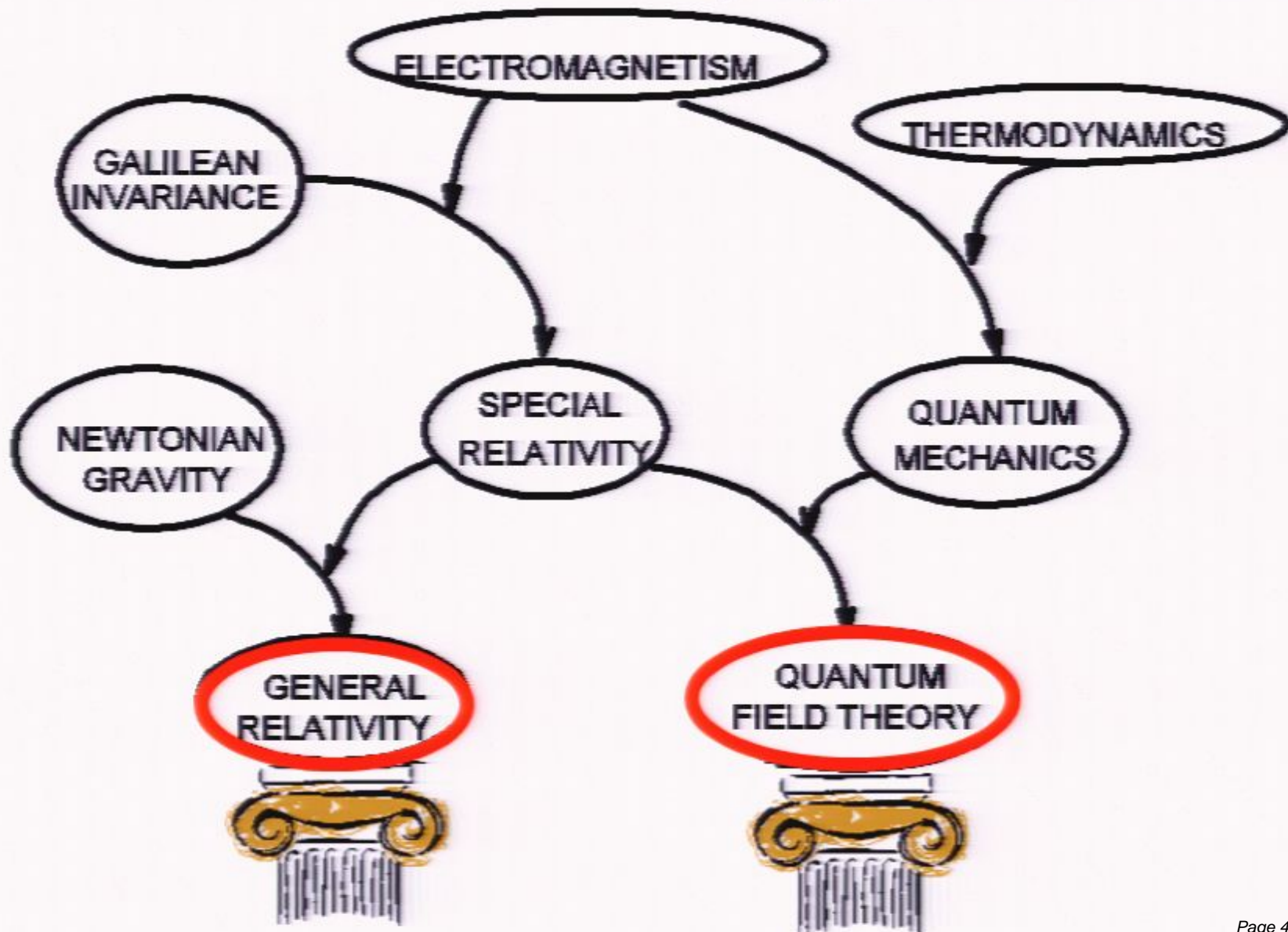
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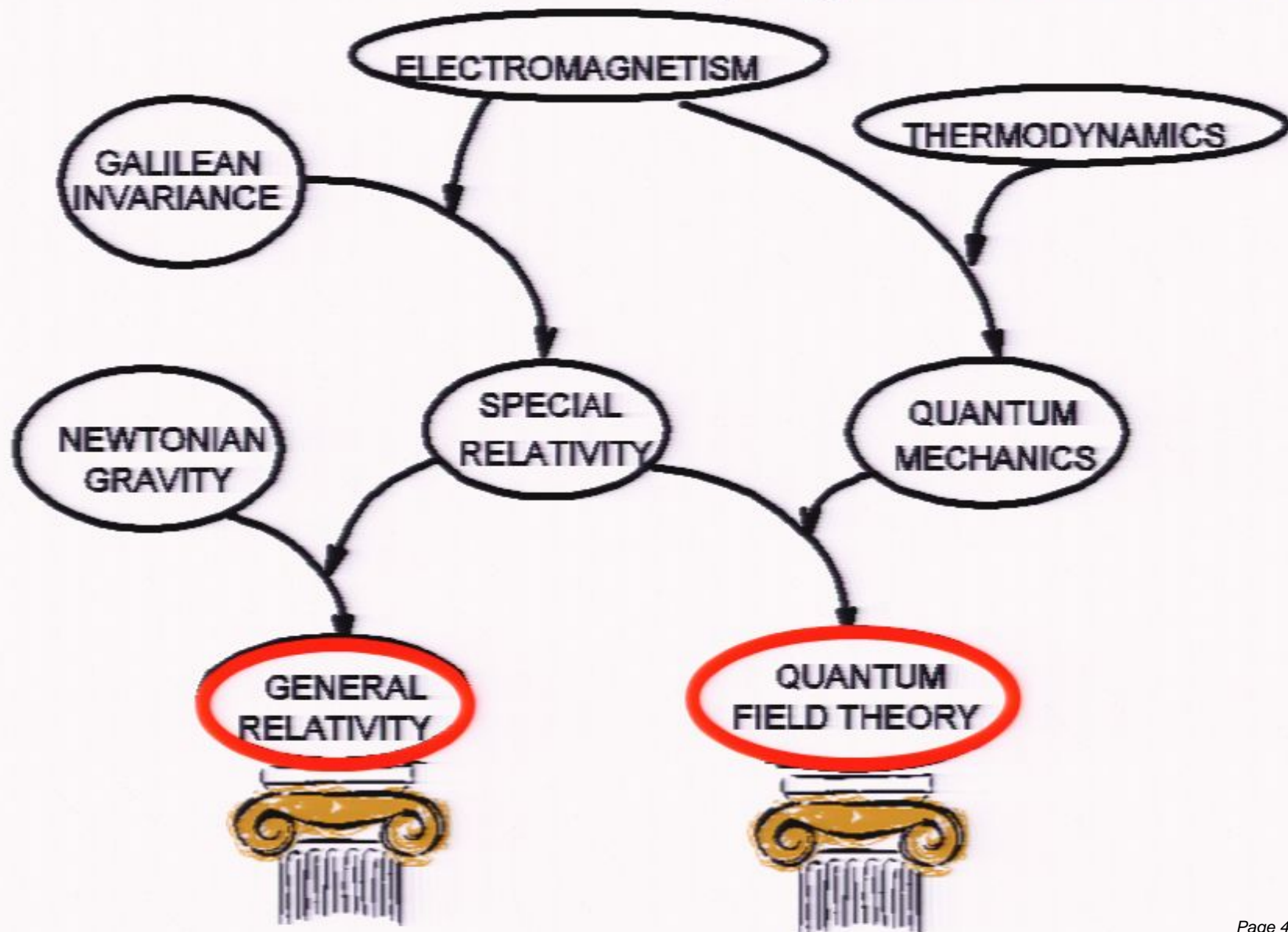
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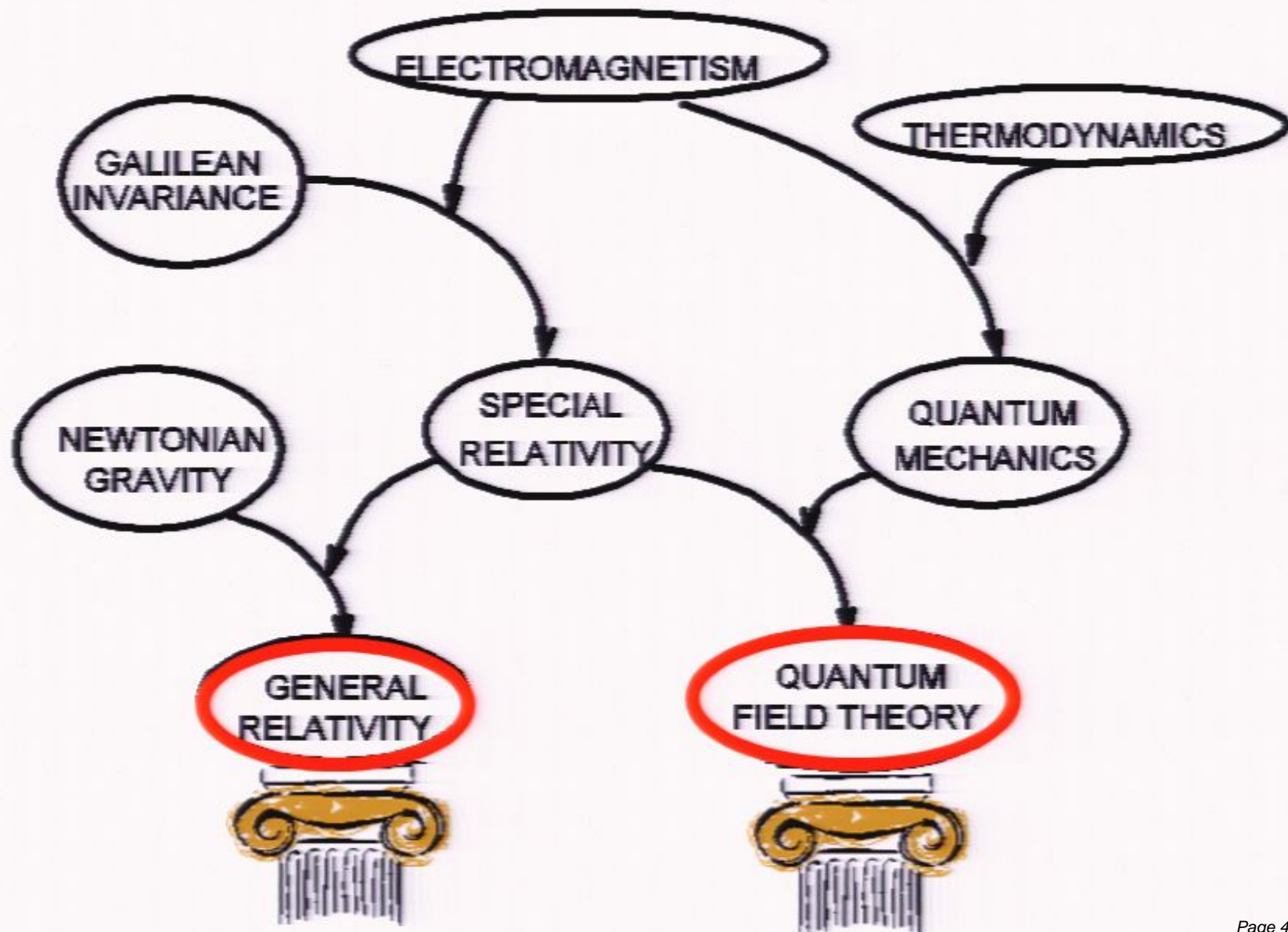
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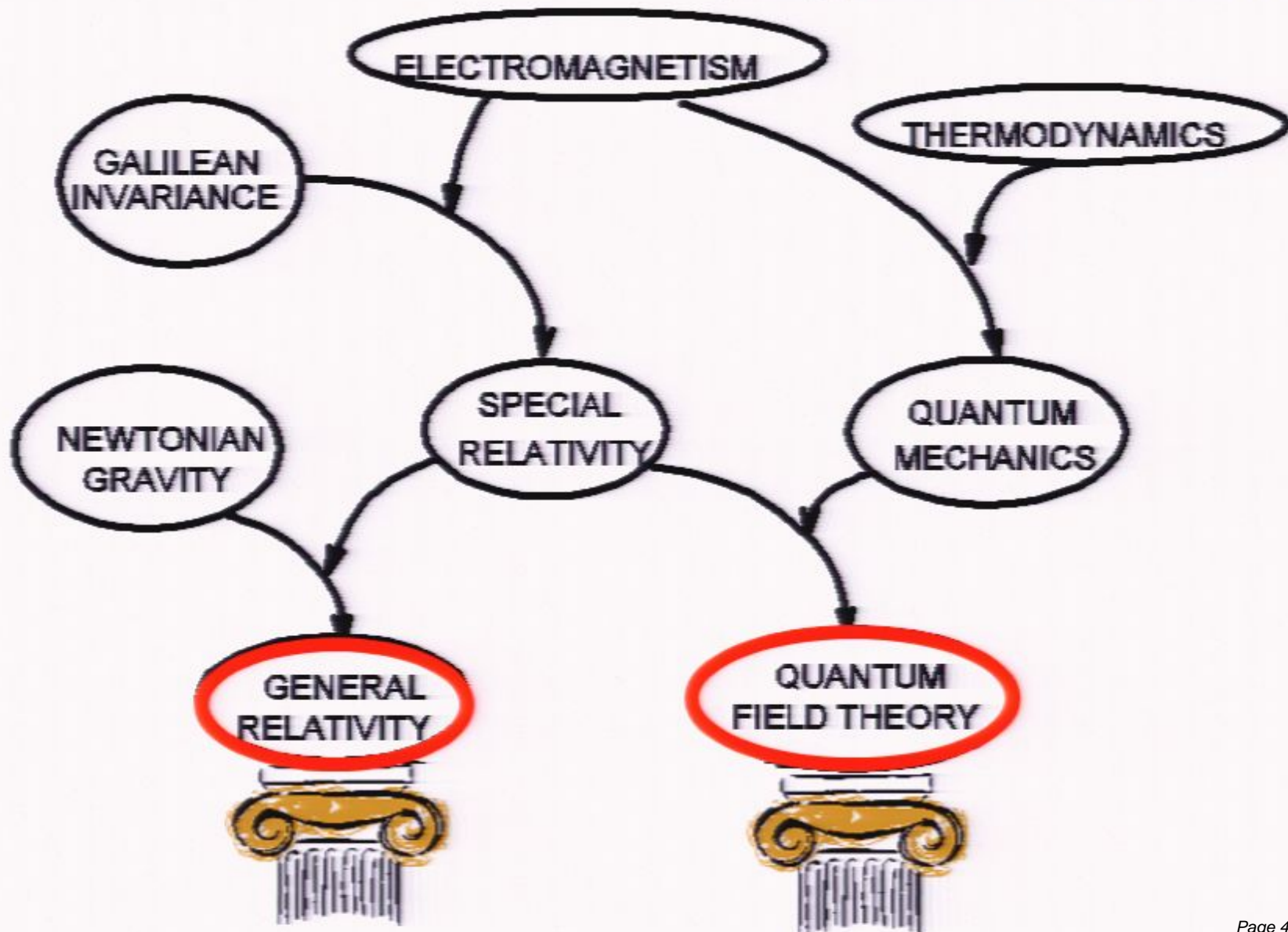
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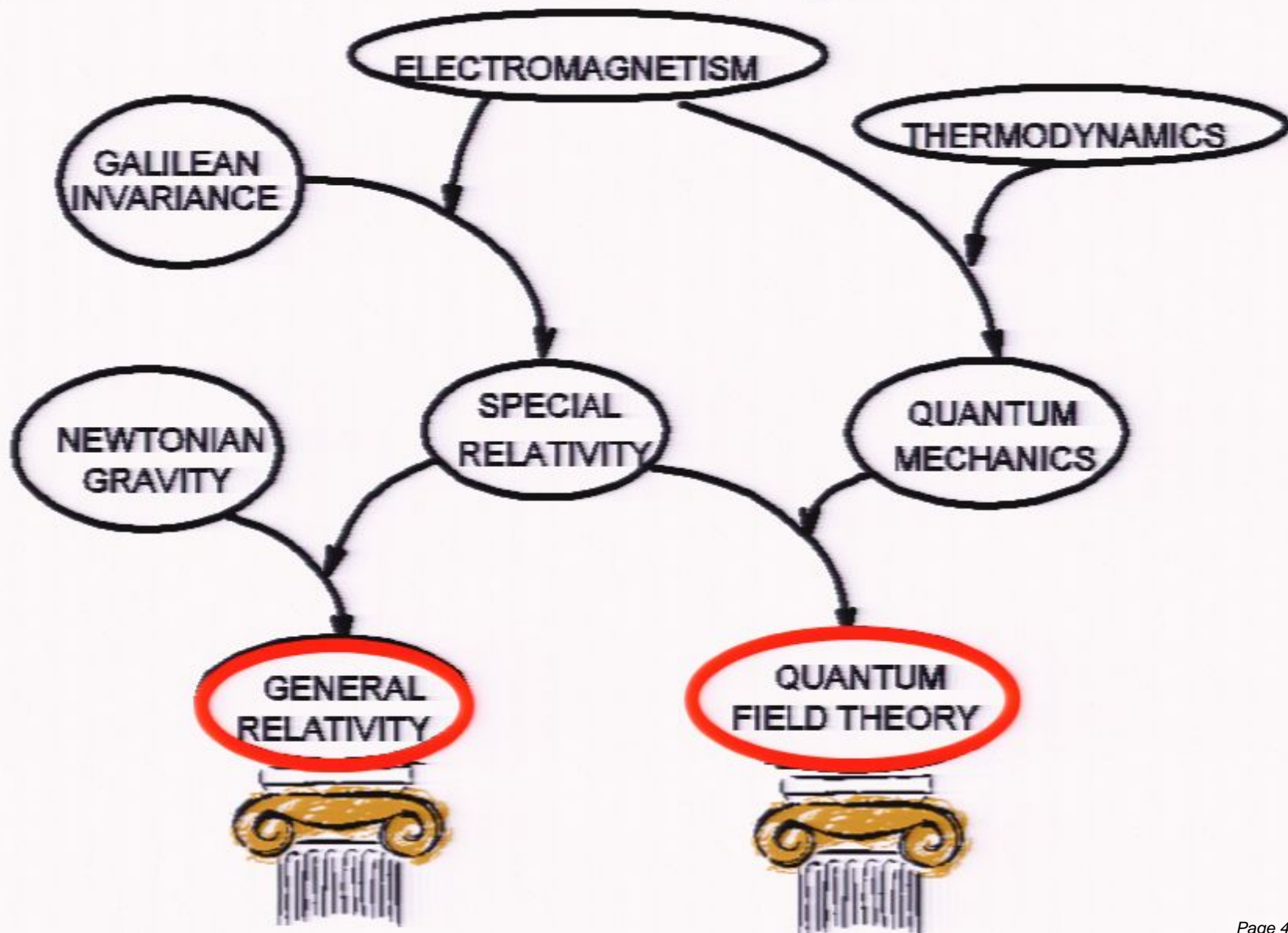
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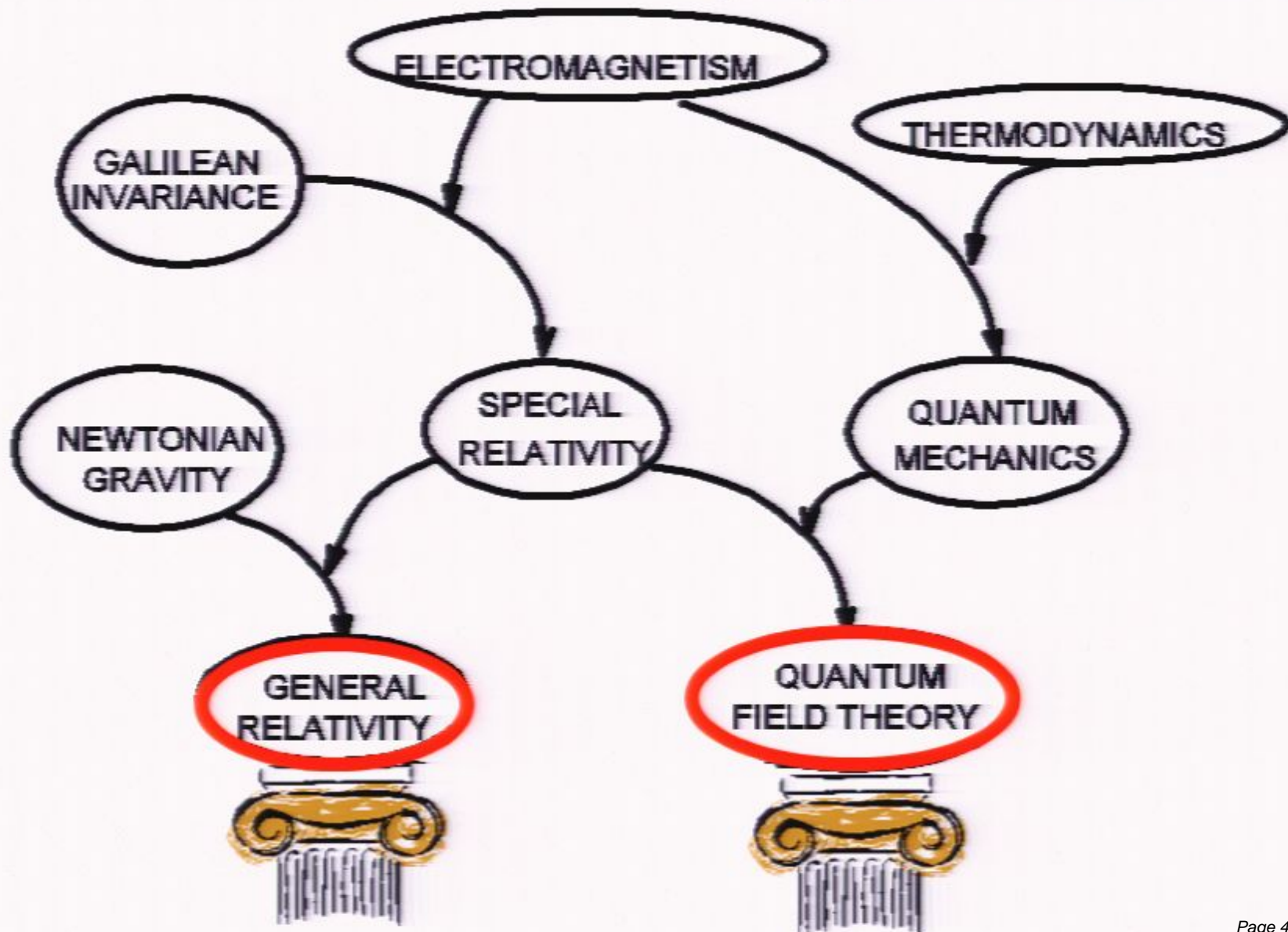
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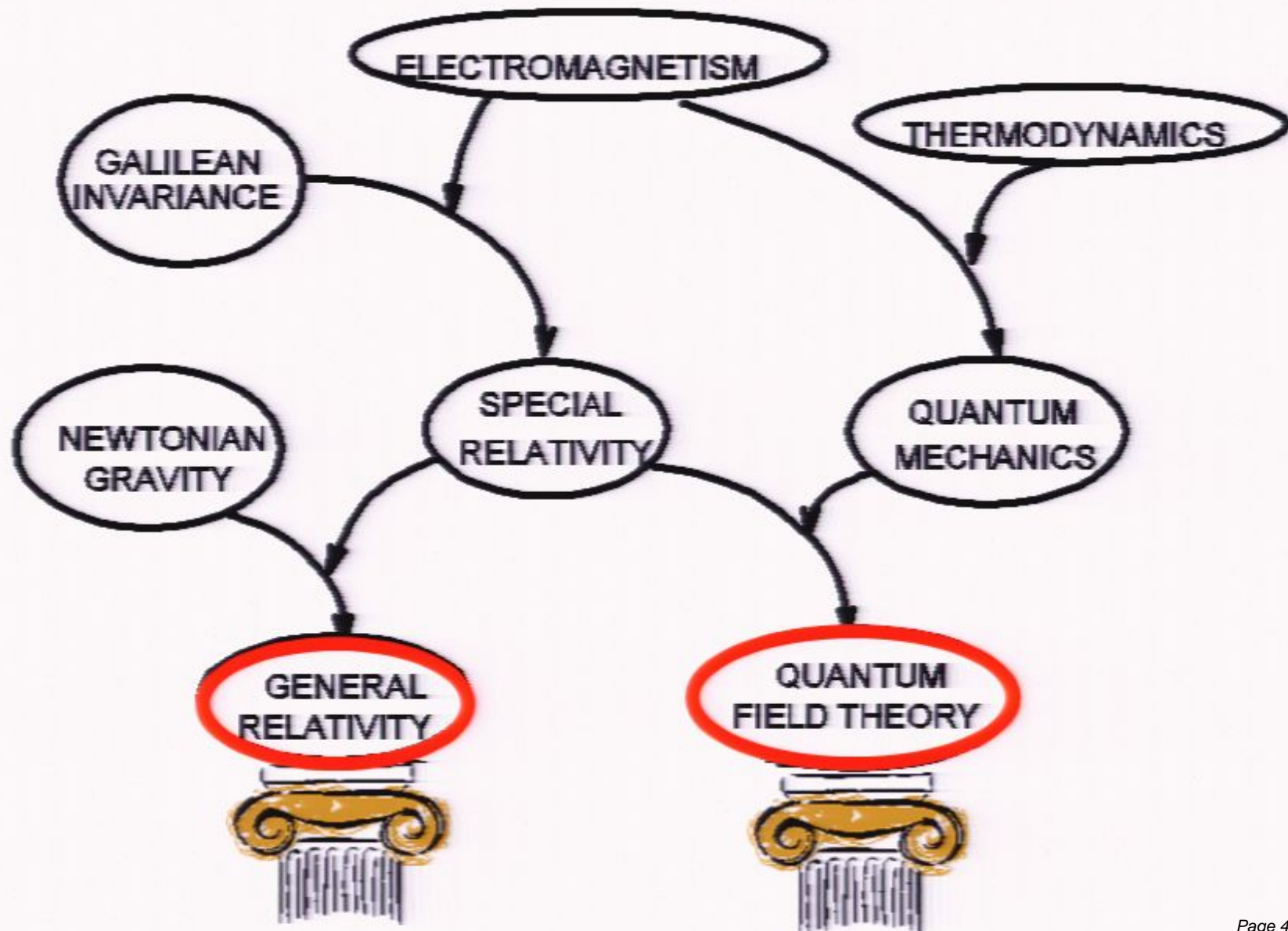
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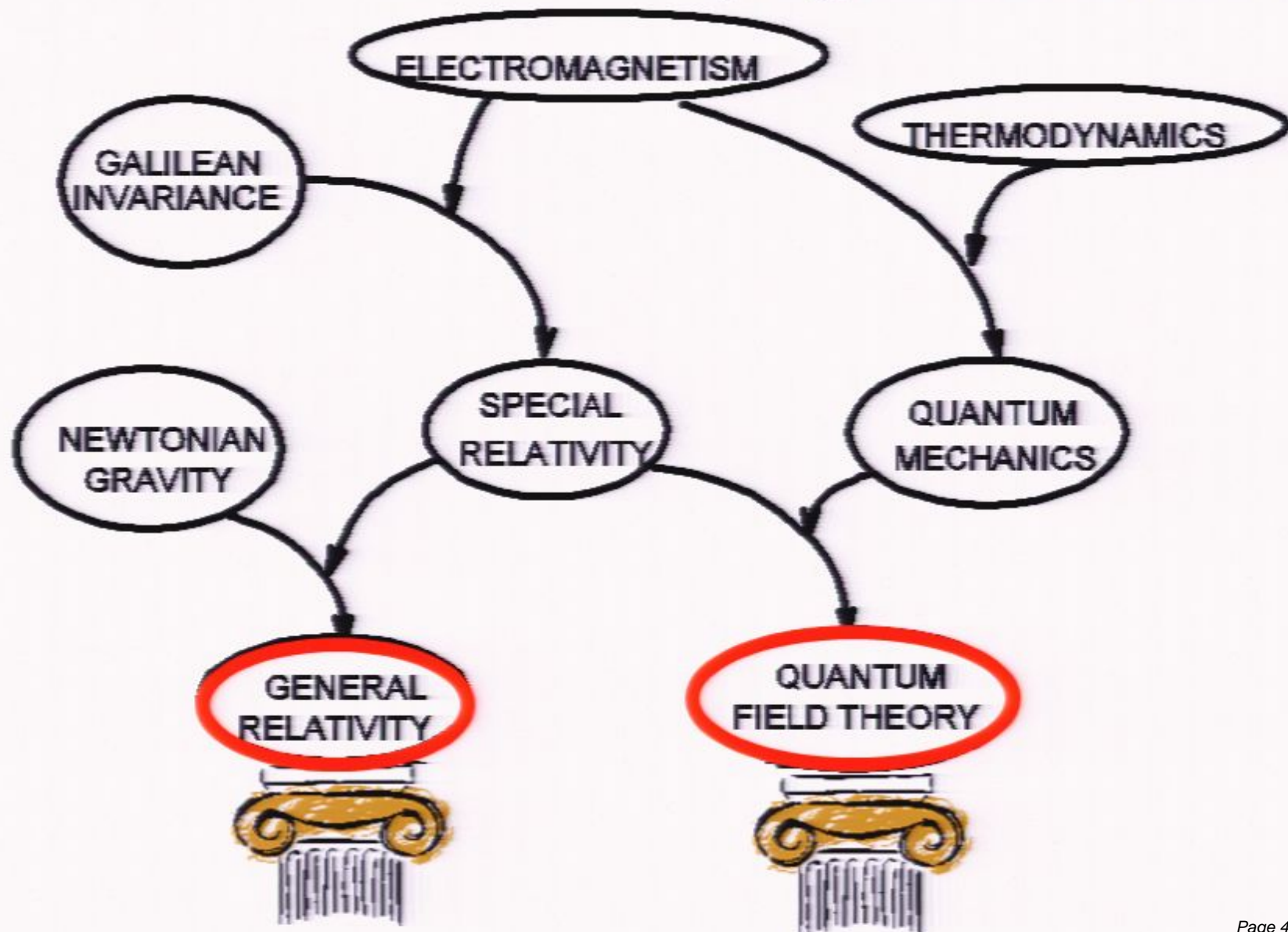
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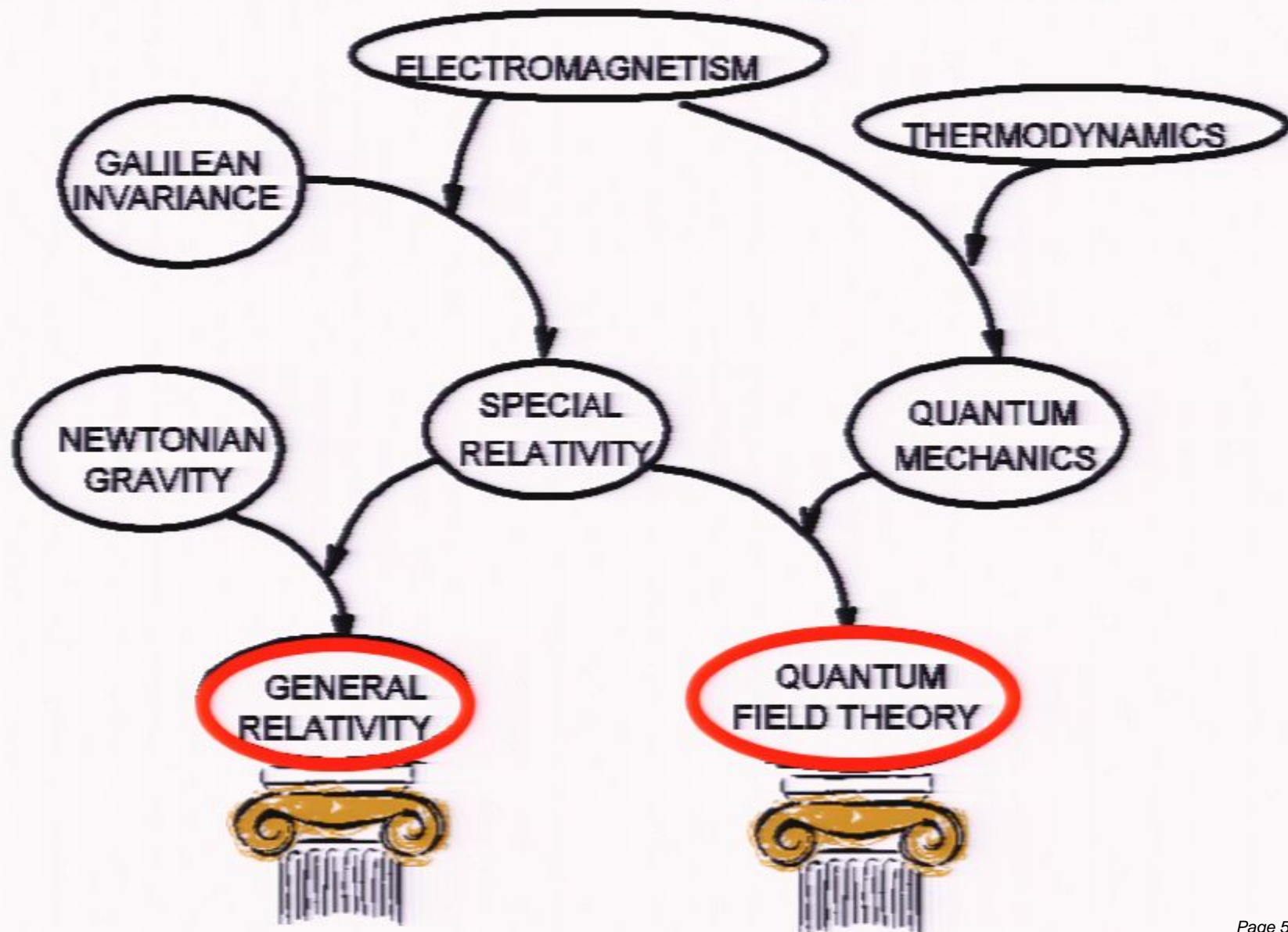
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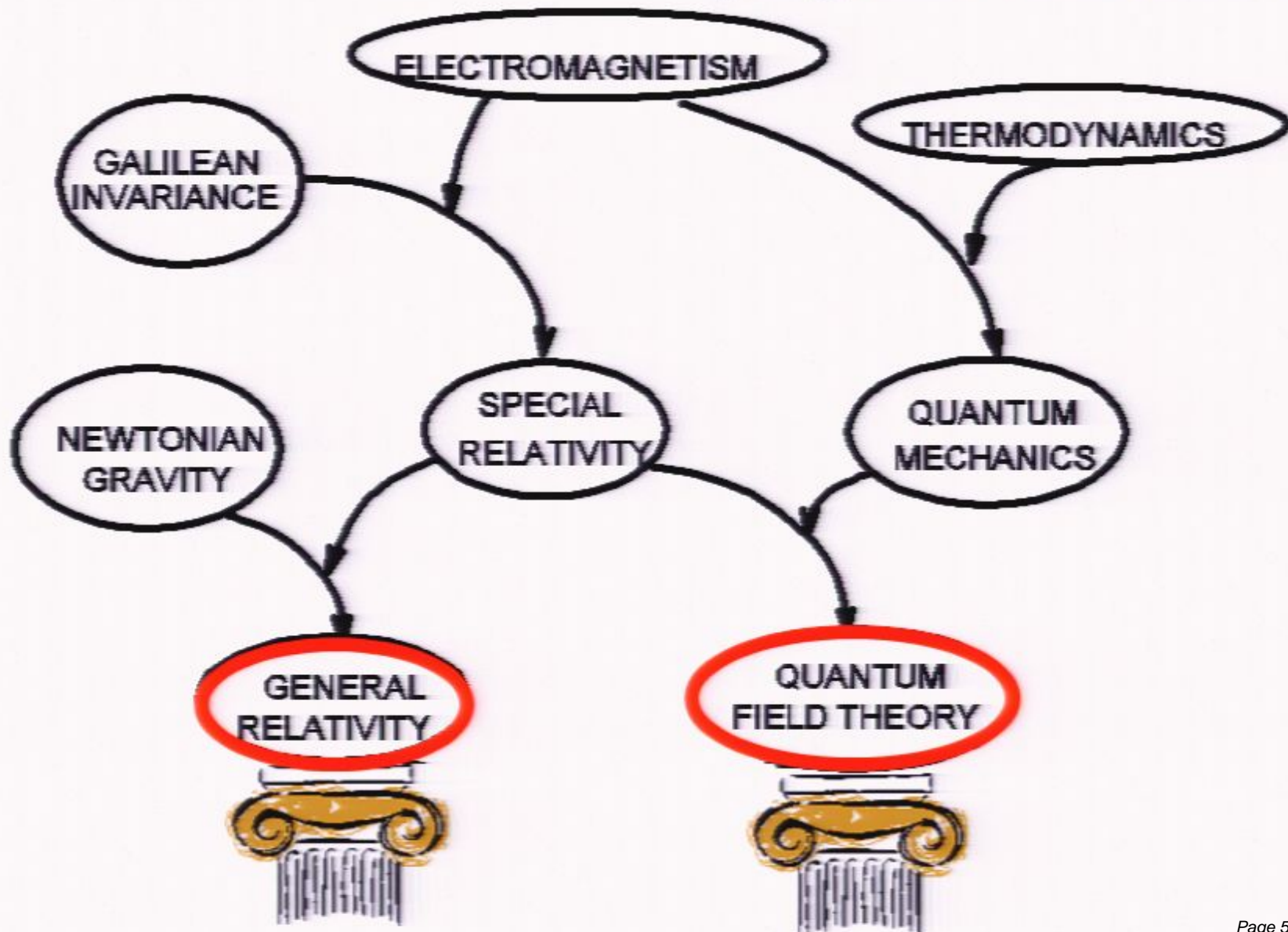
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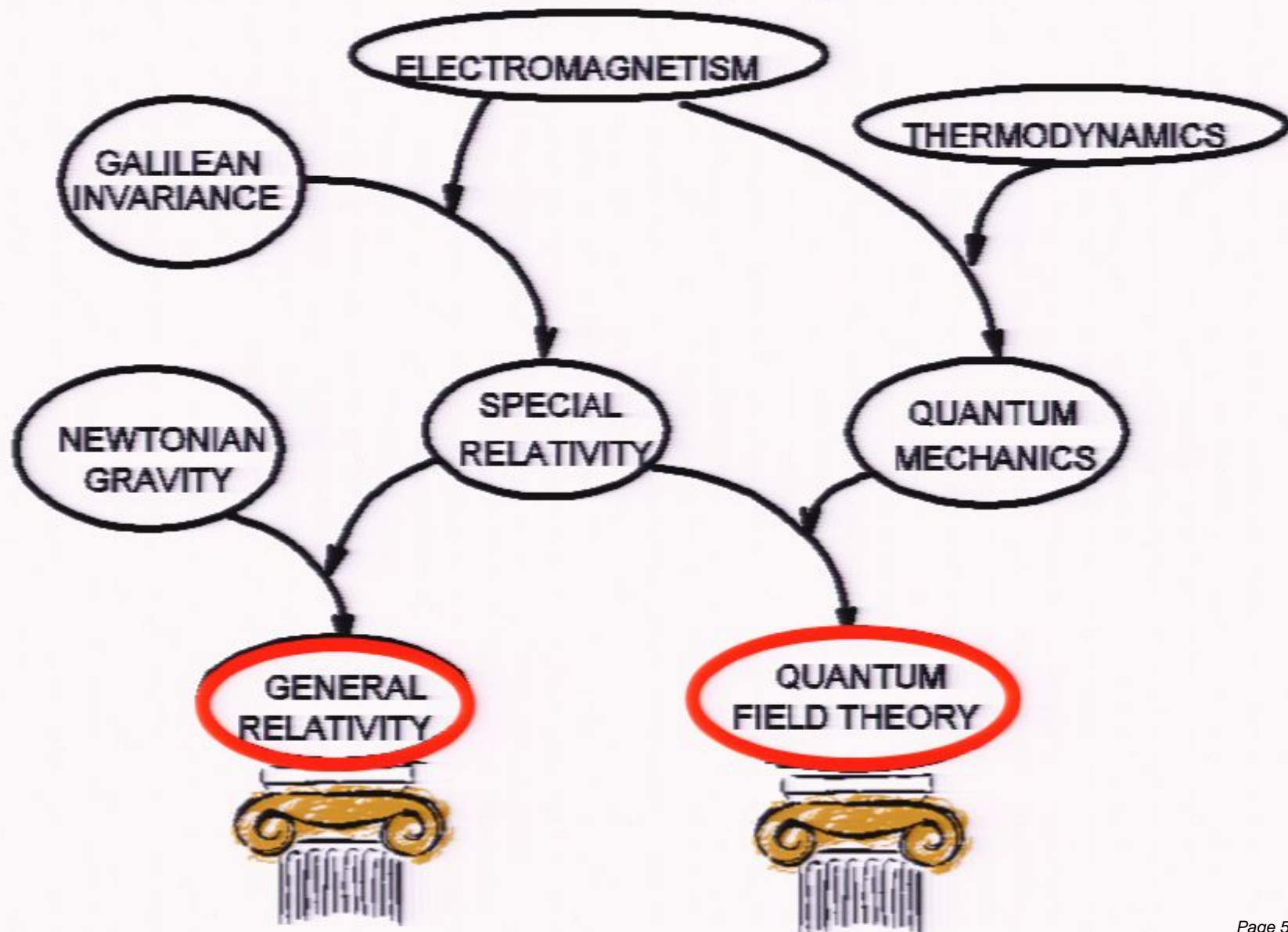
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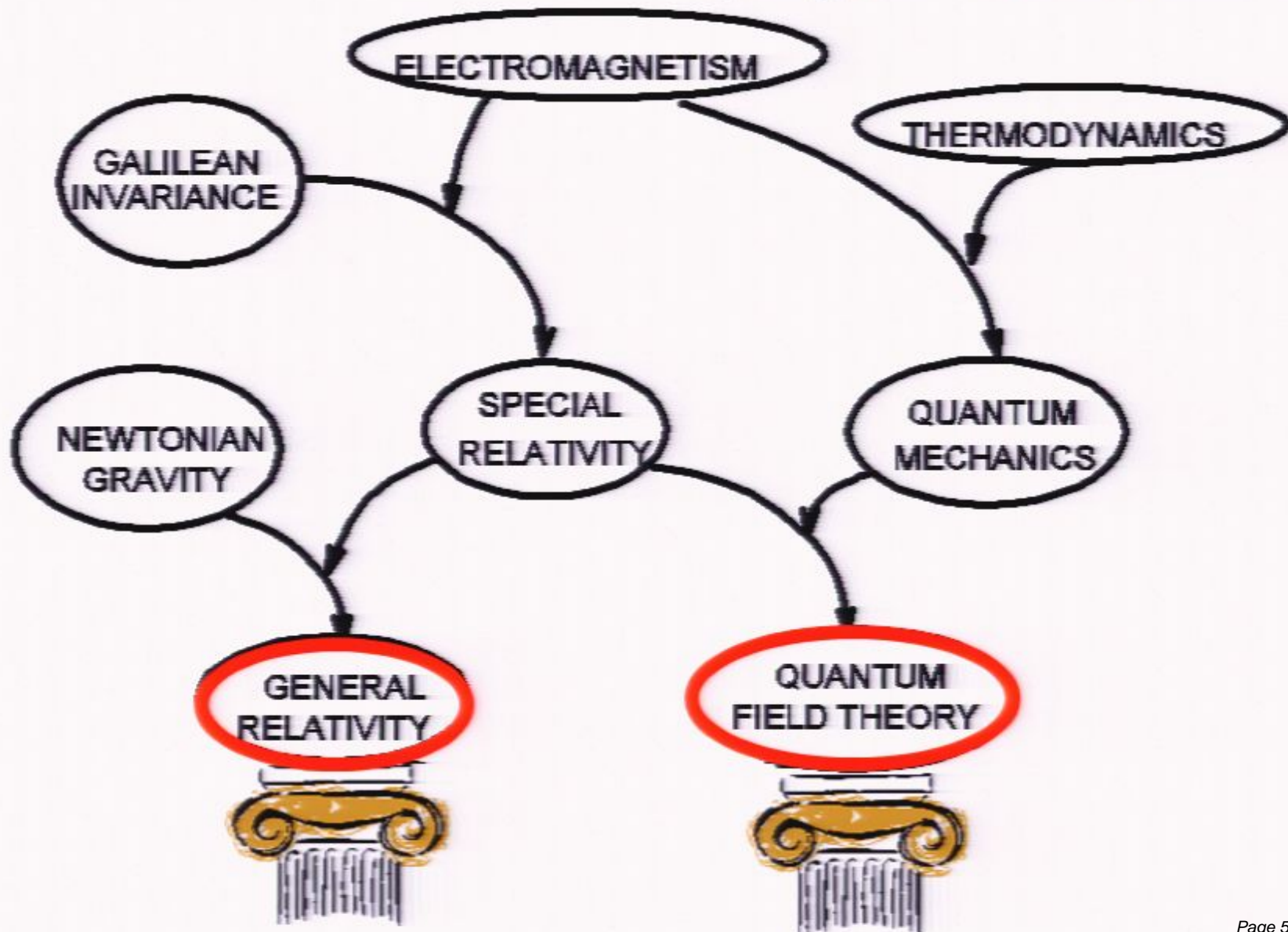
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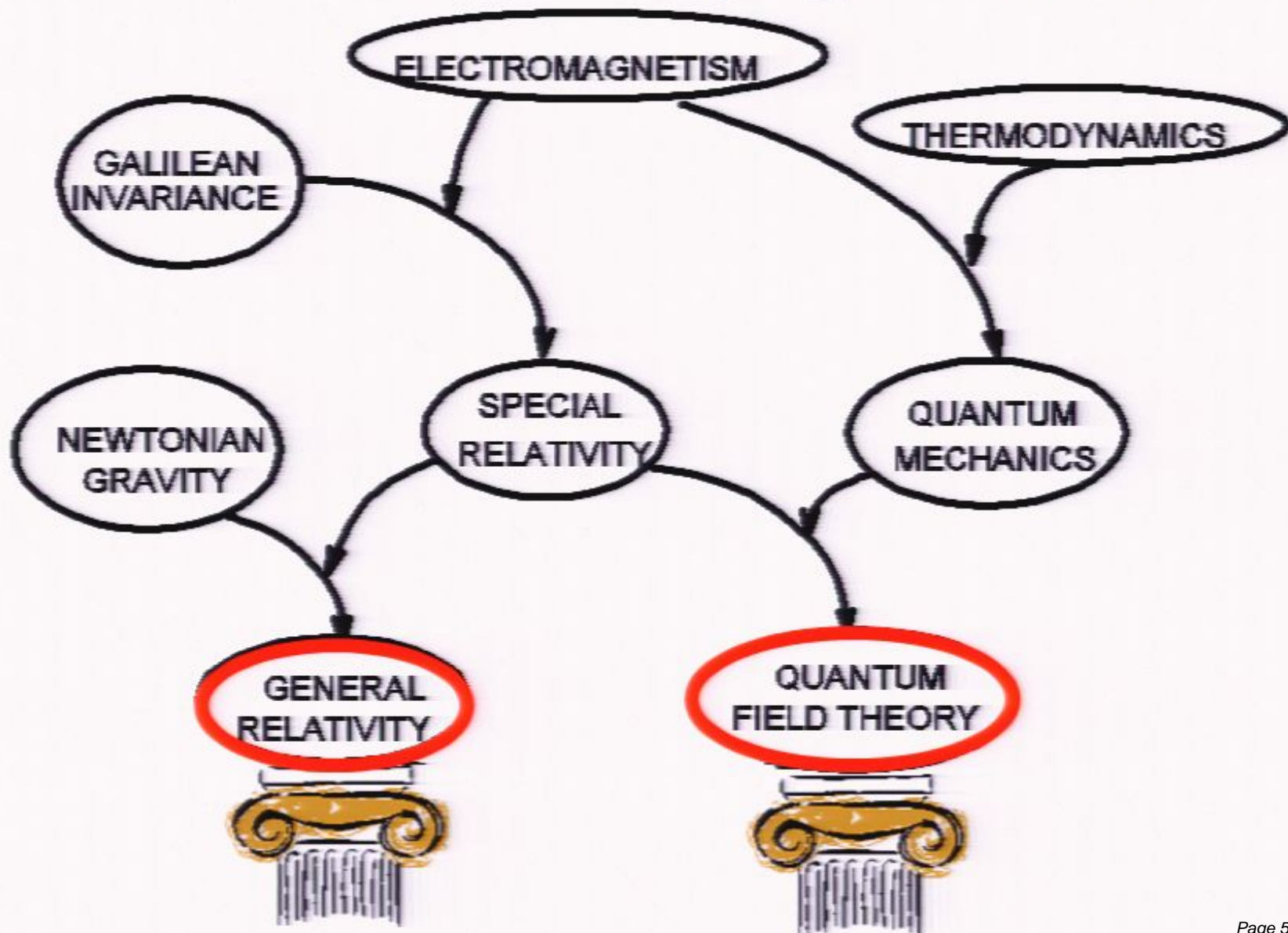
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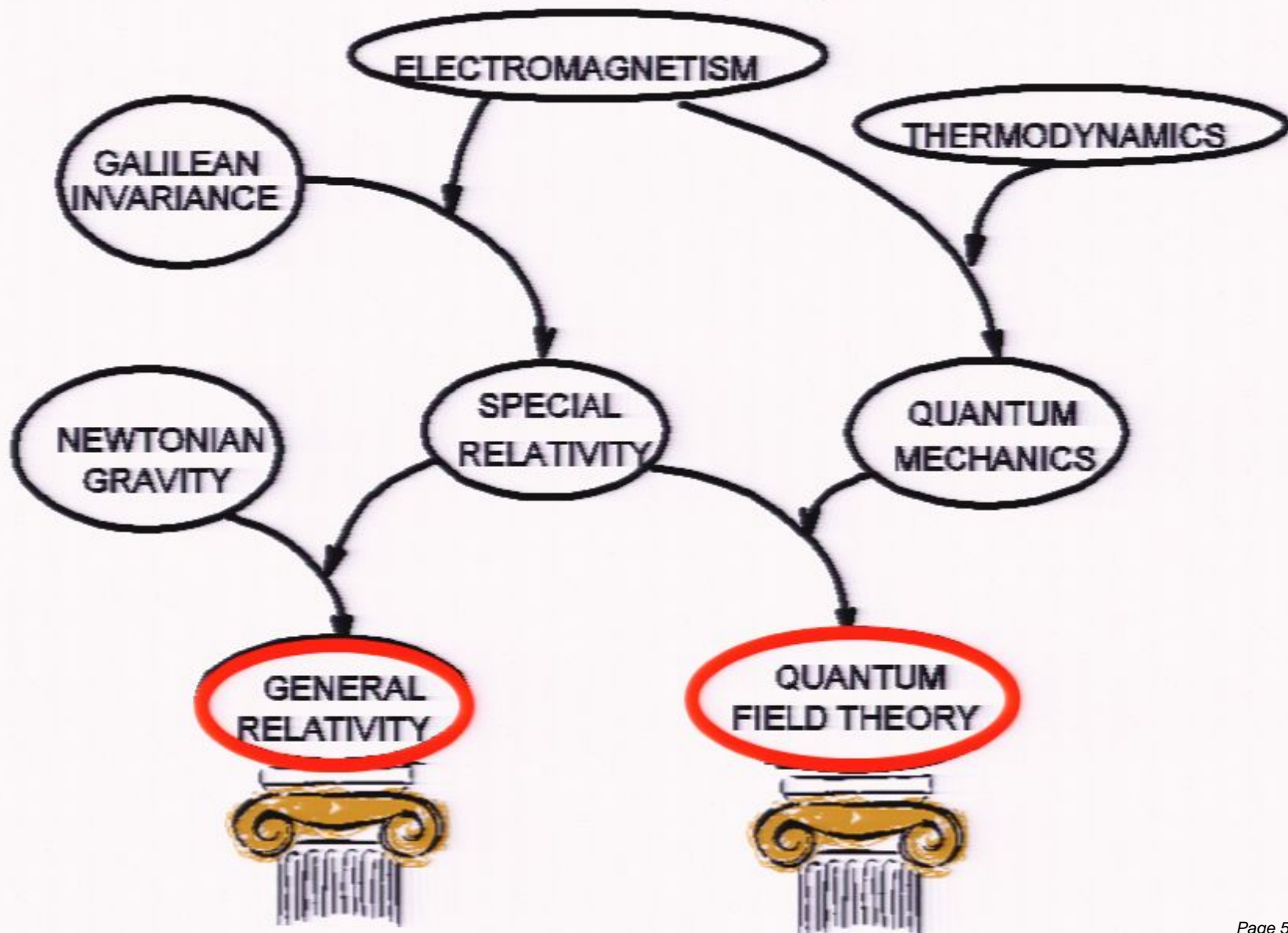
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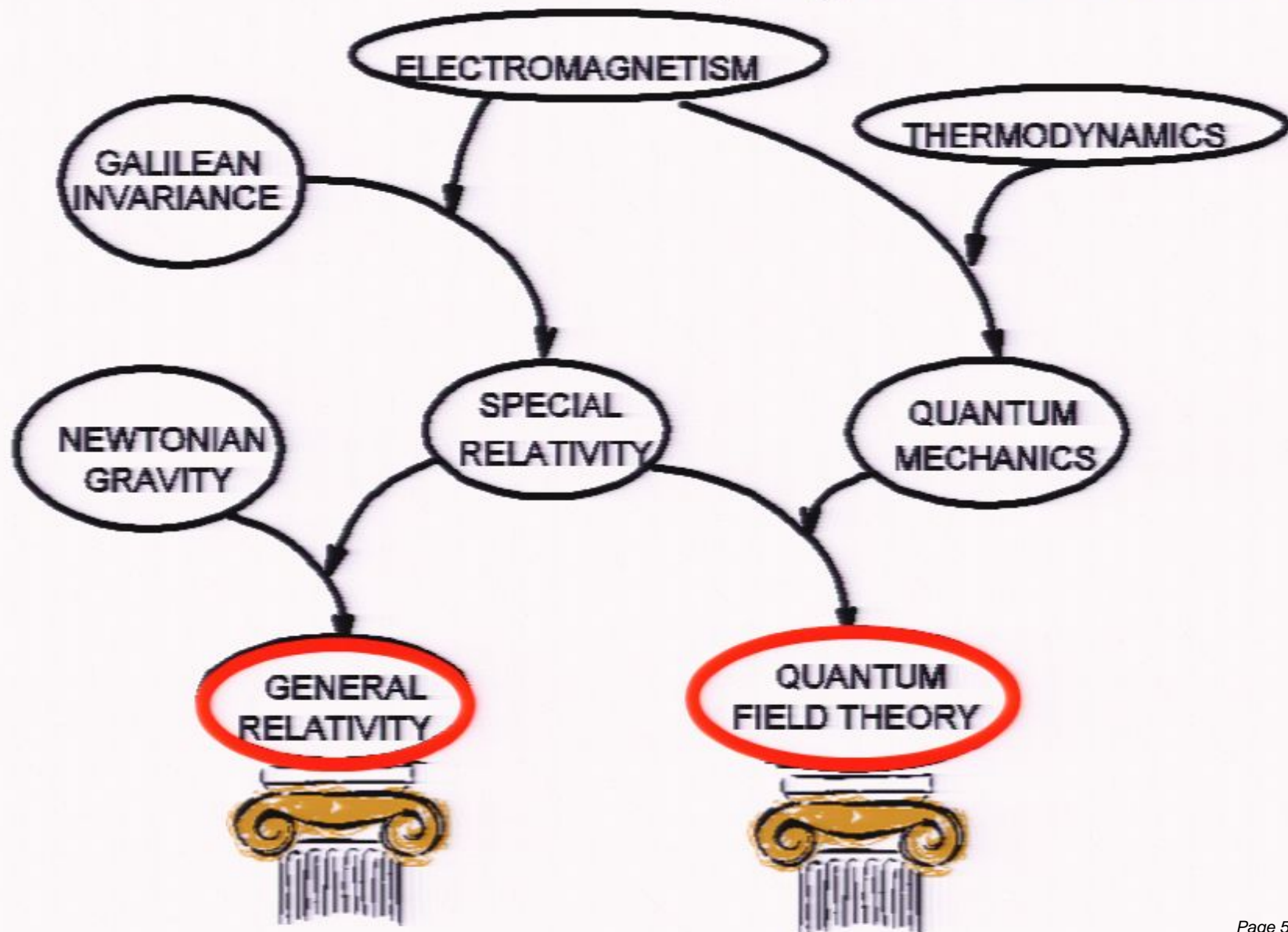
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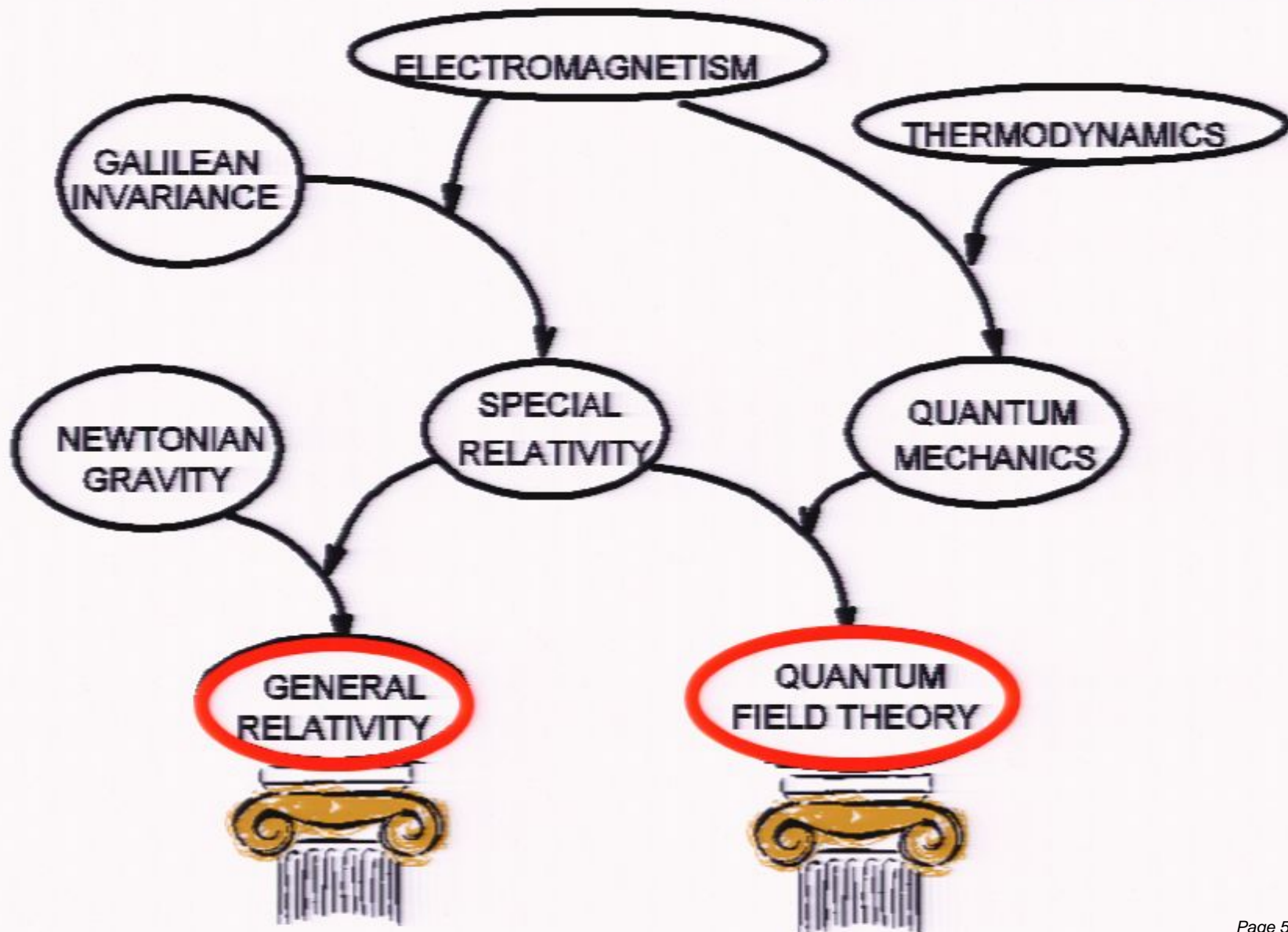
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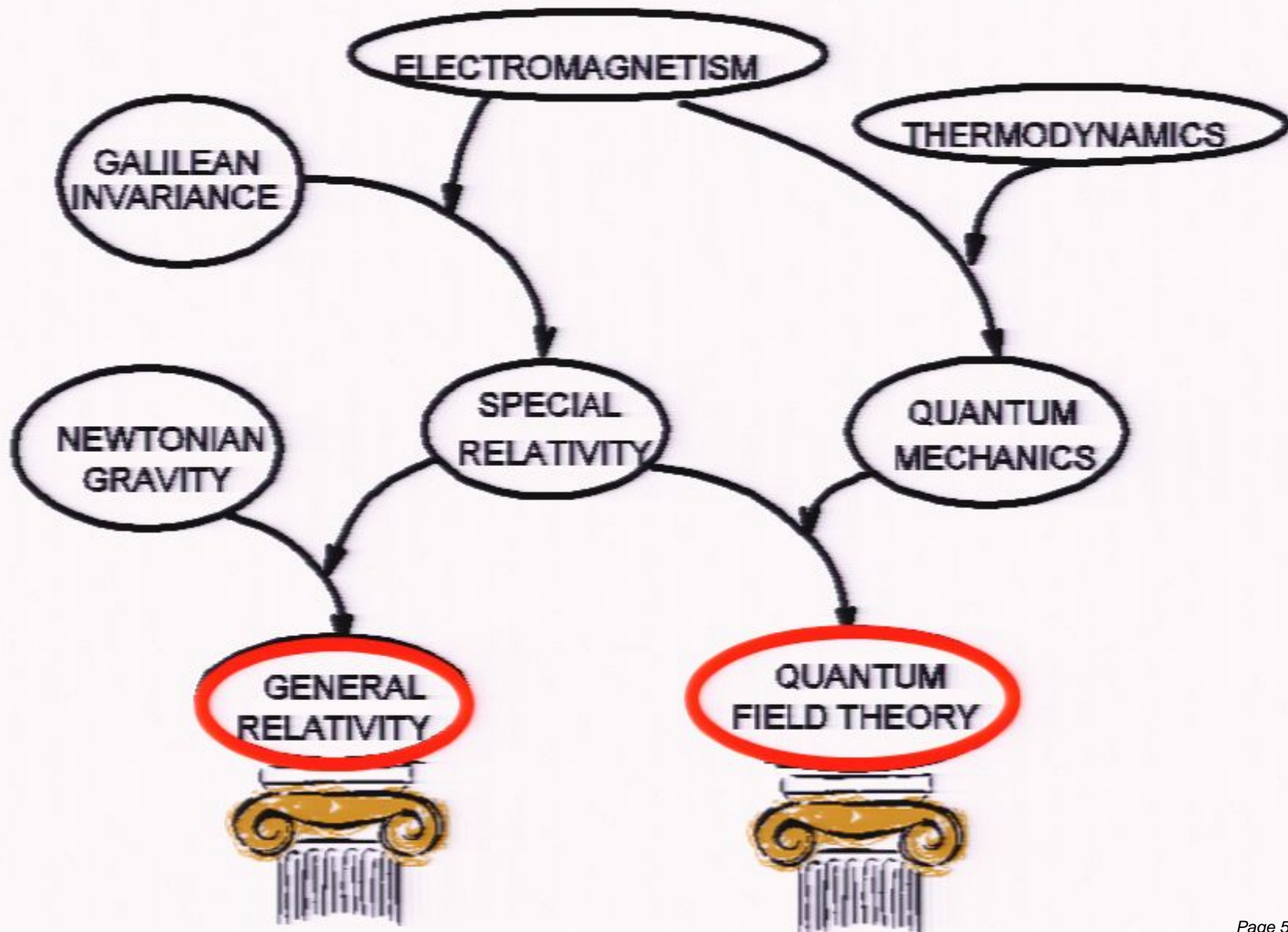
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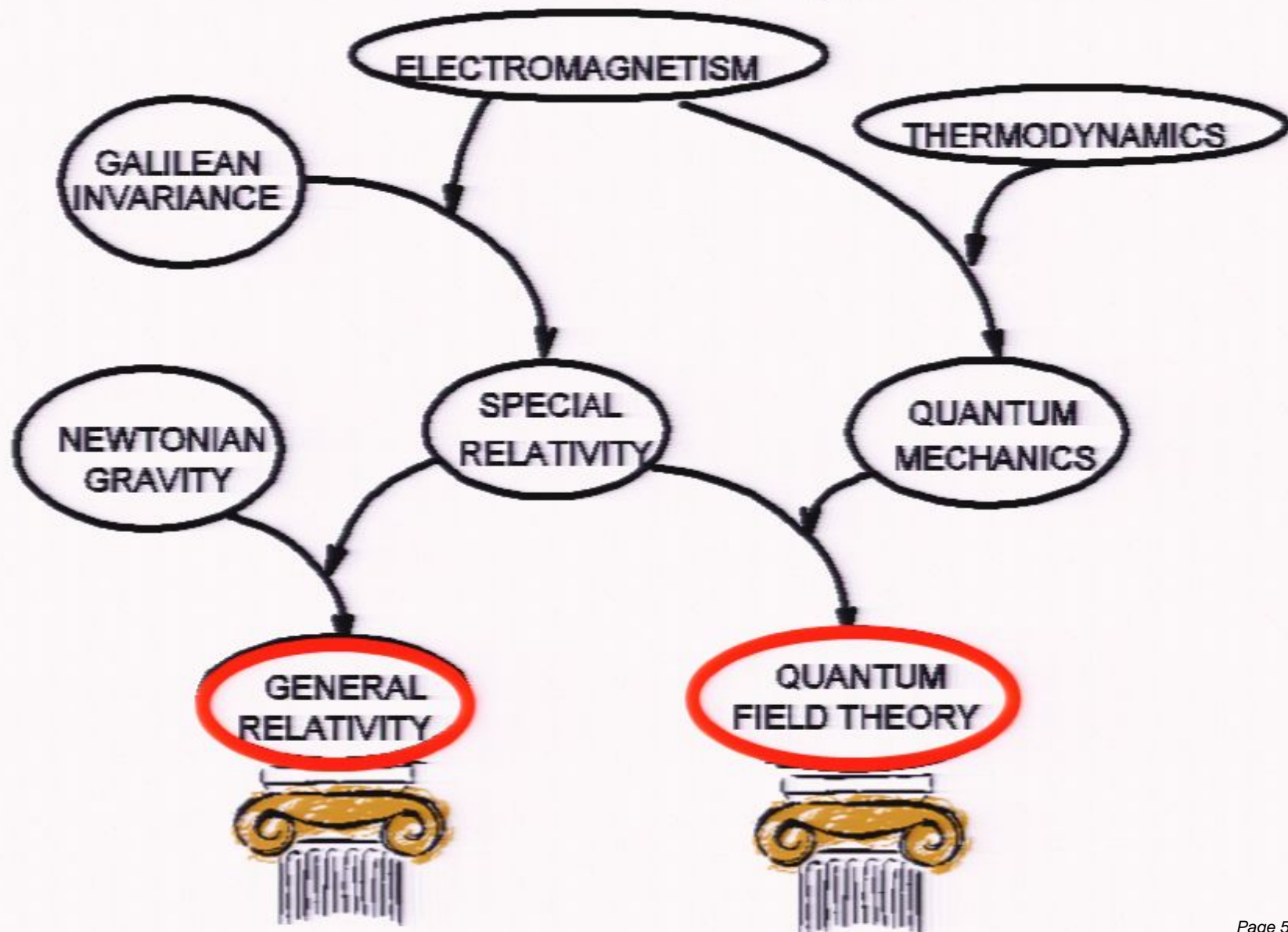
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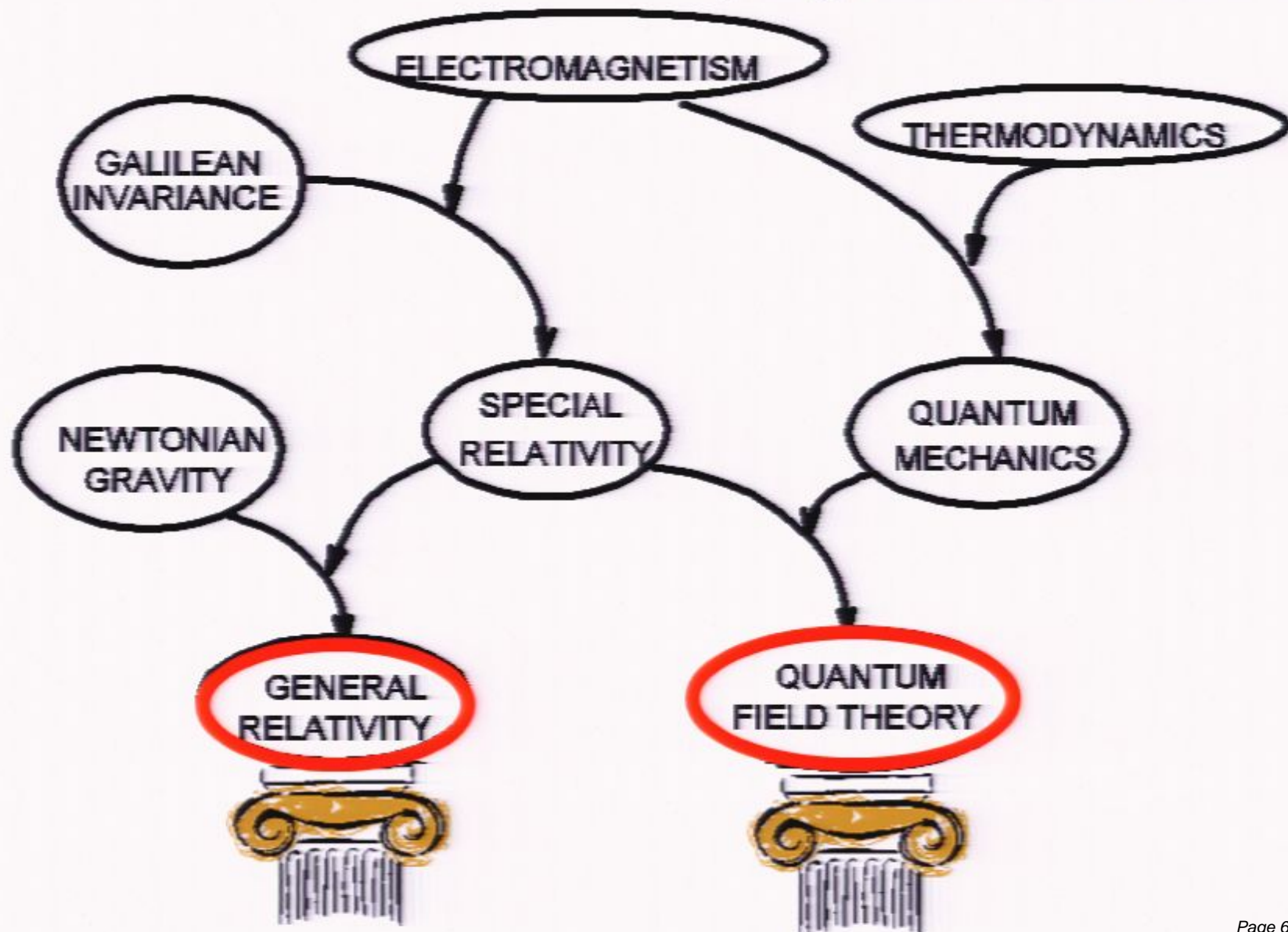
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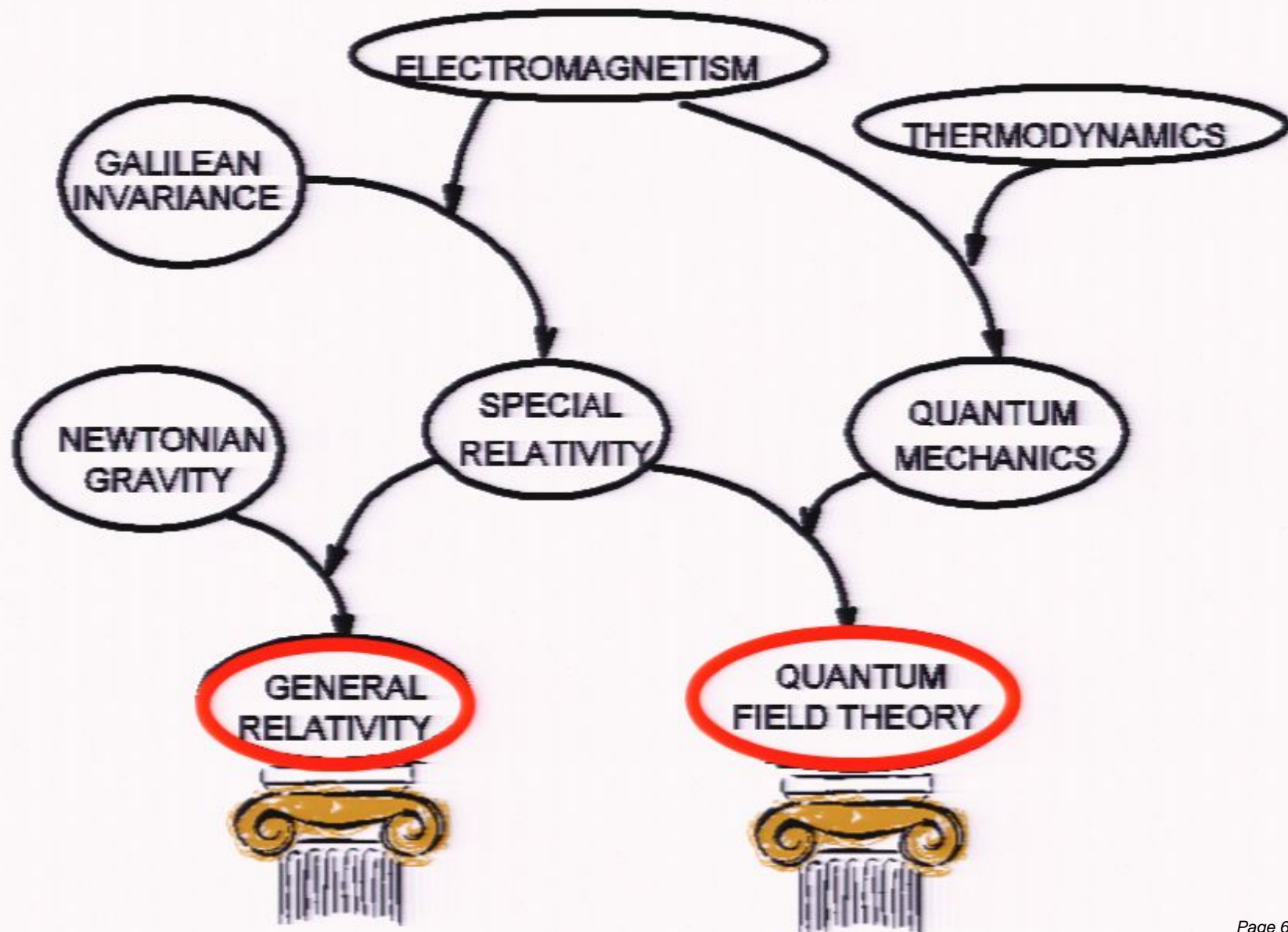
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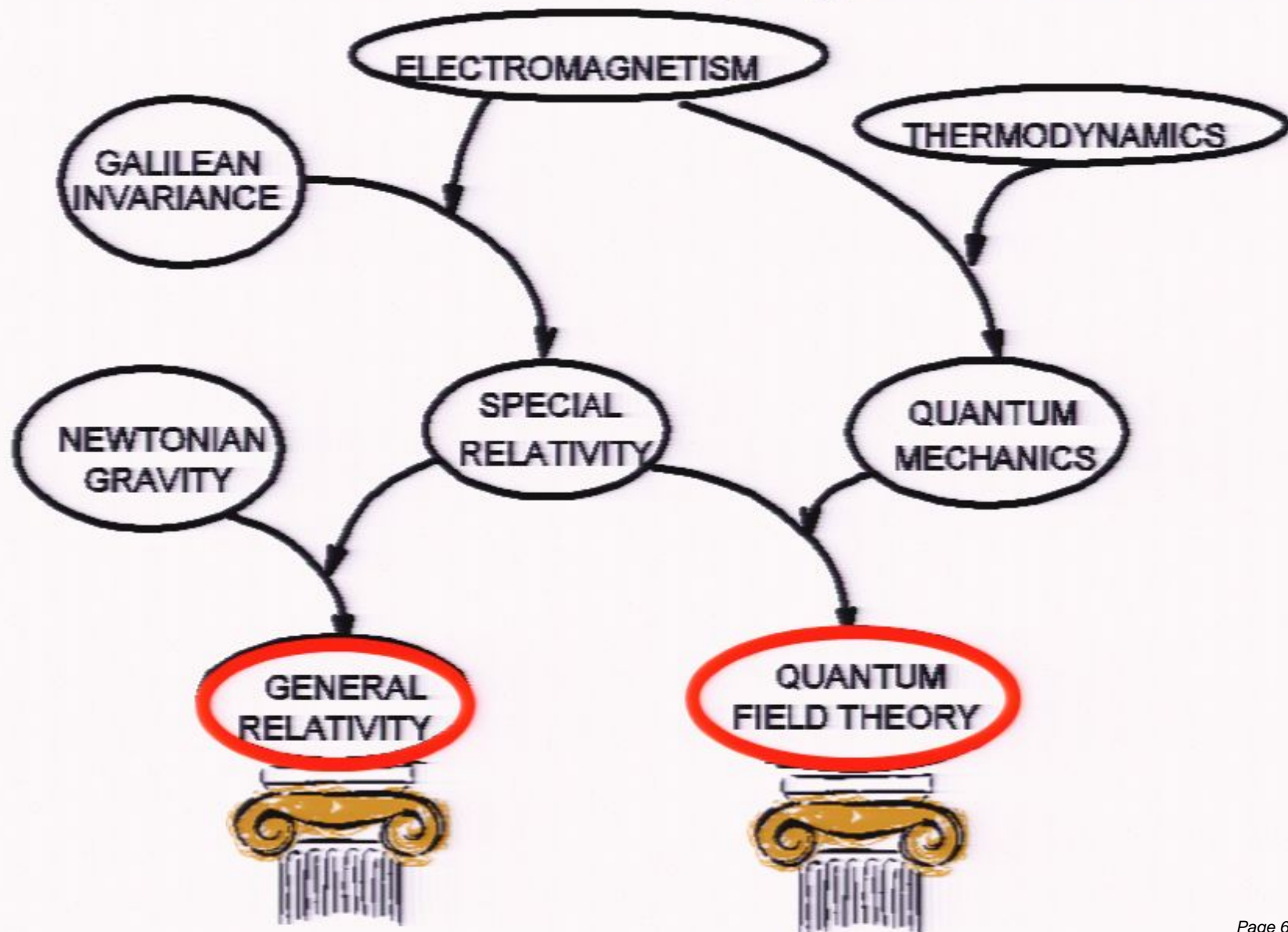
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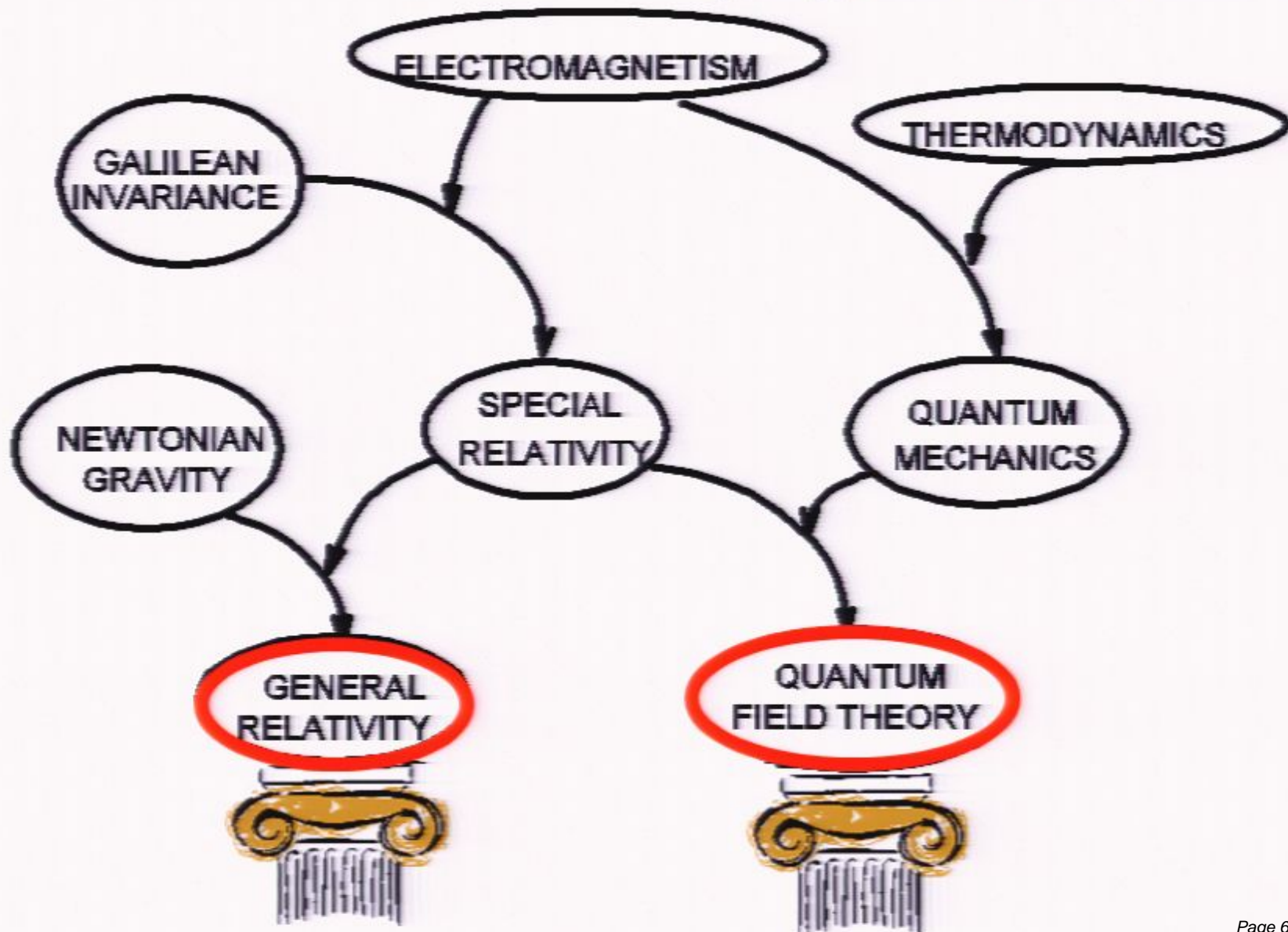
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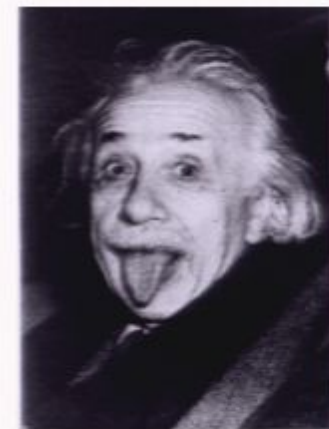


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Einstein:



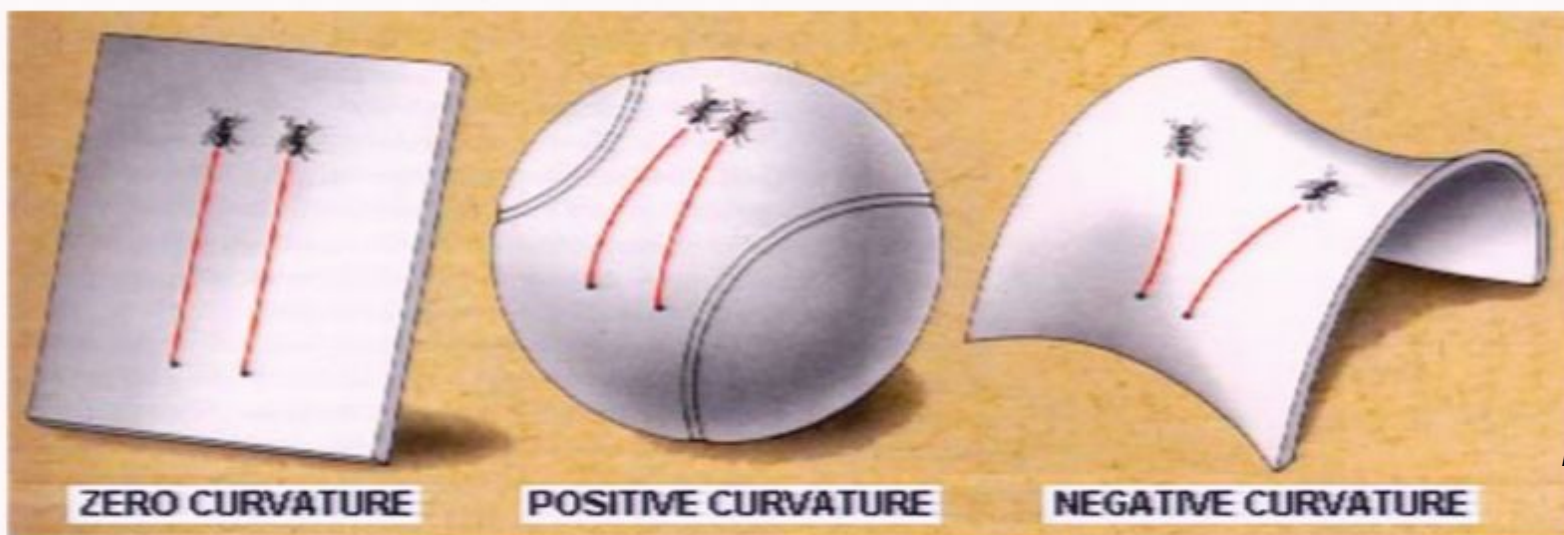
Gravity: It's all just straight lines!

Special Relativity (1905):

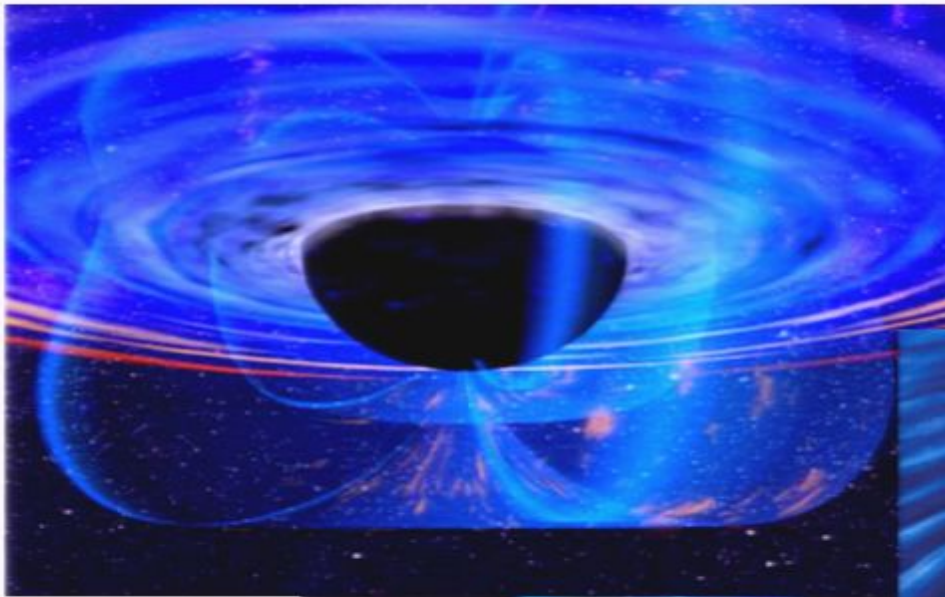
Space and time are inextricably linked  Spacetime

General Relativity (1915):

Gravity is a manifestation of spacetime curvature.

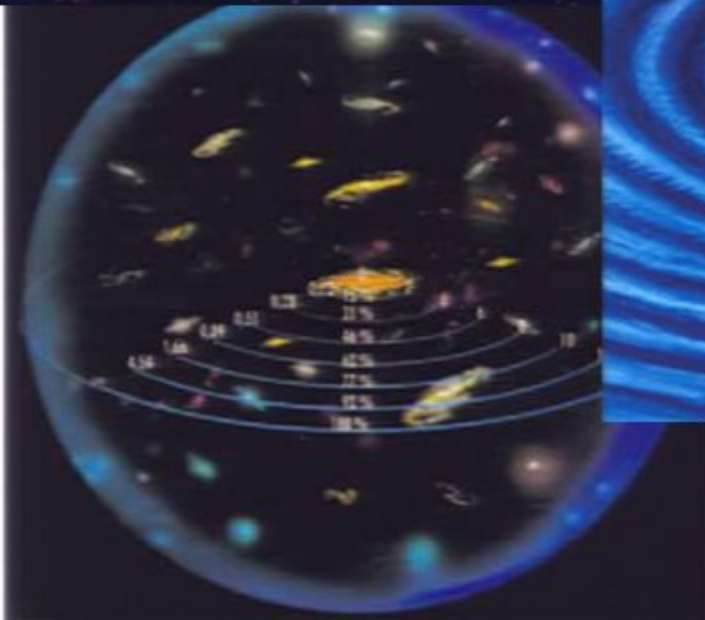


General Relativity: a rich source of new ideas



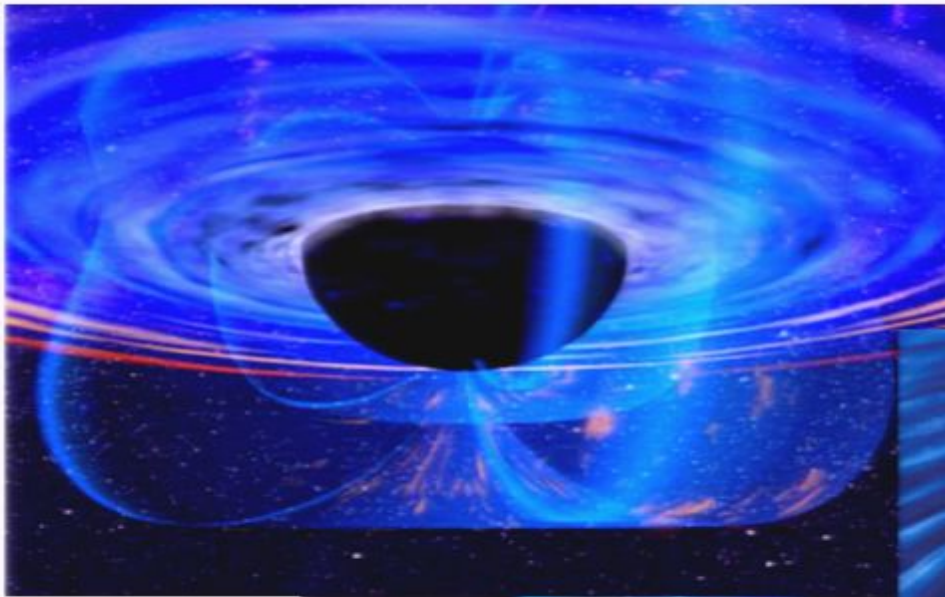
Black holes

Gravitational waves



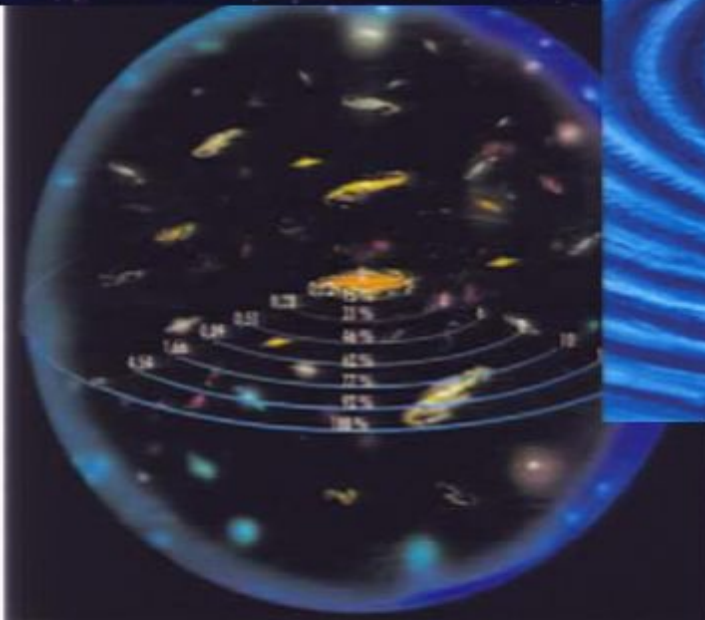
Expanding universe

General Relativity: a rich source of new ideas



Black holes

Gravitational waves

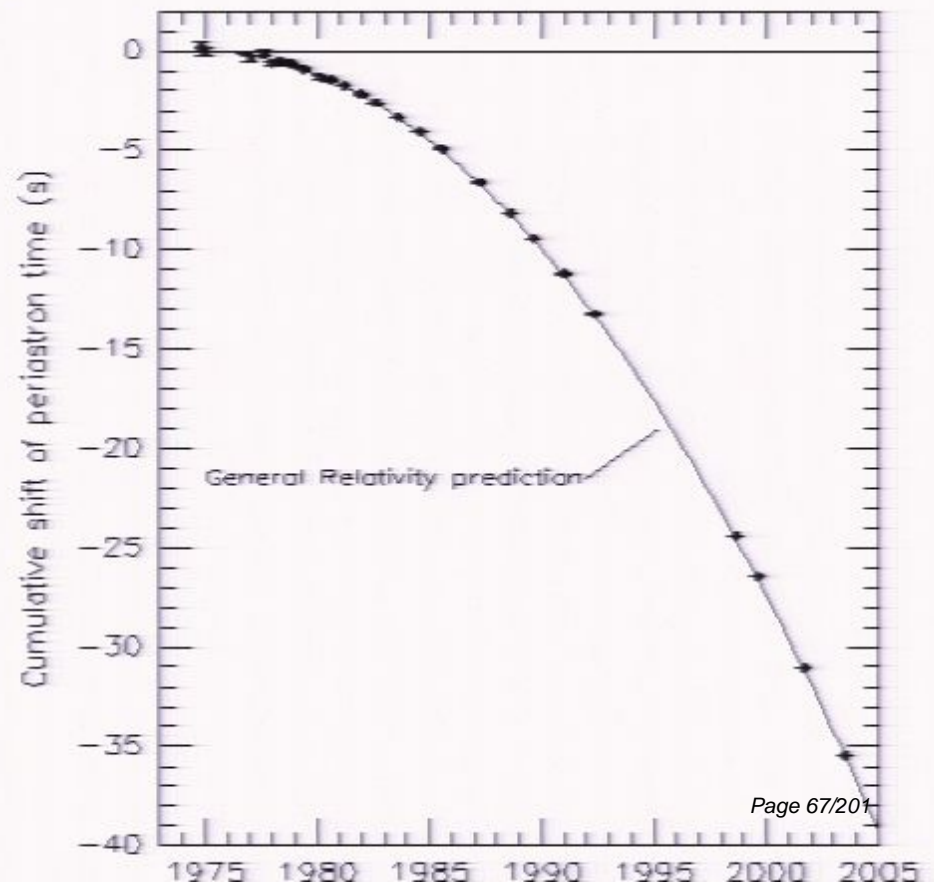
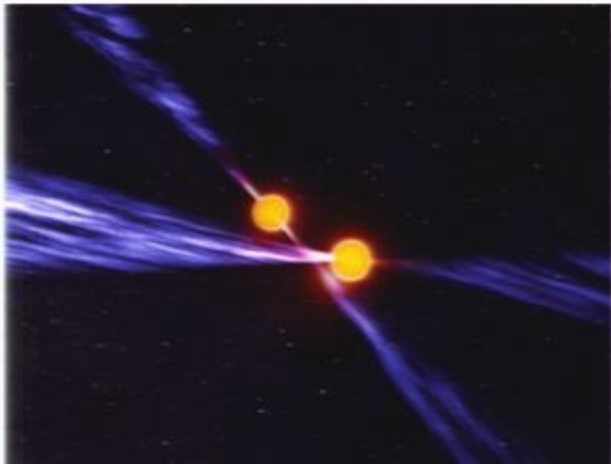


Expanding universe

General Relativity is rigorously tested!!

- Deflection of Light by the Sun
- Gravitational Redshift
- Precession of the Perihelion of Mercury
- Time Delay of Light,

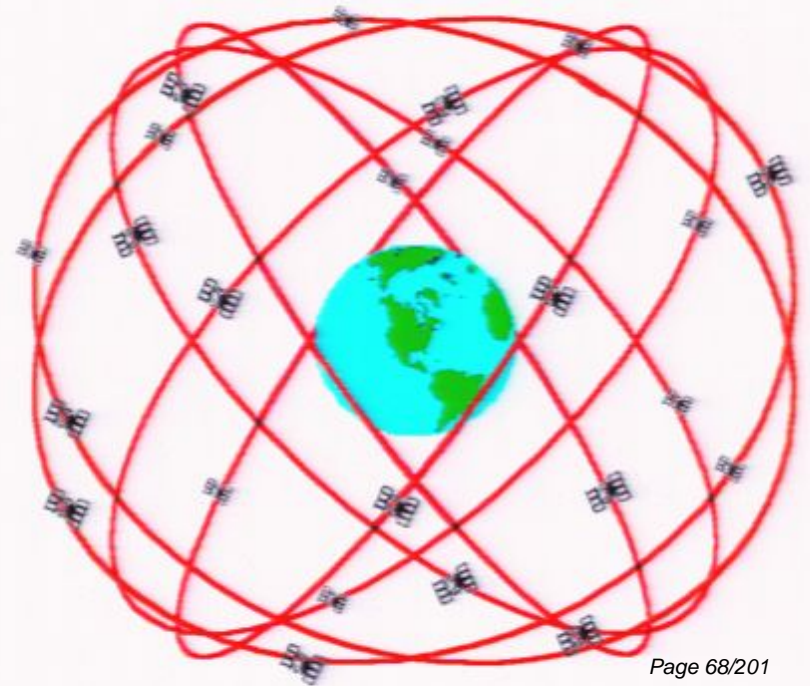
Hulse and Taylor:
Nobel Prize in 1993!!



General Relativity is rigorously tested!!

Global Positioning System (GPS):

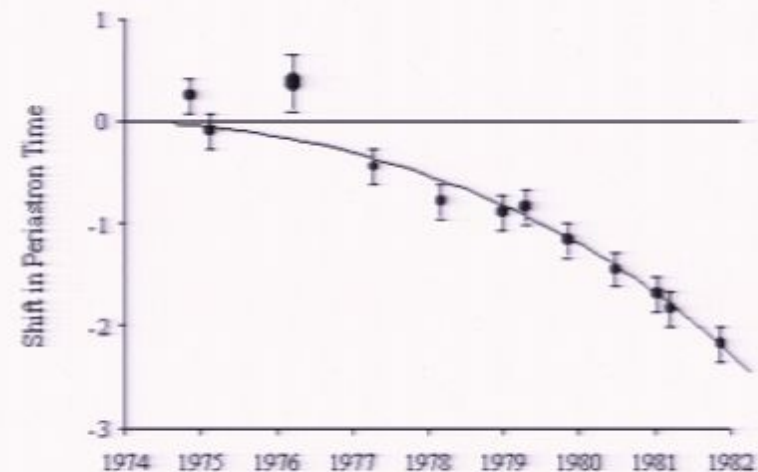
Accurate positioning requires accounting for affects of general relativity on clocks in orbit and on earth



General Relativity is rigorously tested!!

- Deflection of Light by the Sun
- Gravitational Redshift
- Precession of the Perihelion of Mercury
- Time Delay of Light,

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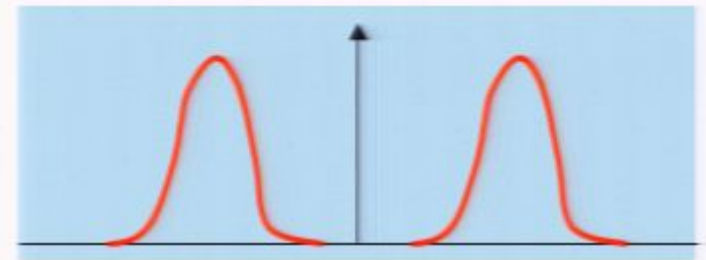
General Relativity is the geometric arena of physics on very **large** scales:
planets, stars, galaxies, cosmology

Quantum Mechanics (or Quantum Field Theory) is the probabilistic arena of physics on very **small** scales

Particles can act like waves!

de Broglie wavelength: $\lambda = \frac{2\pi \hbar}{p}$ ← Planck's constant

$$\lambda_{\text{rain drop}} \approx 4 \times 10^{-30} \text{ m}$$

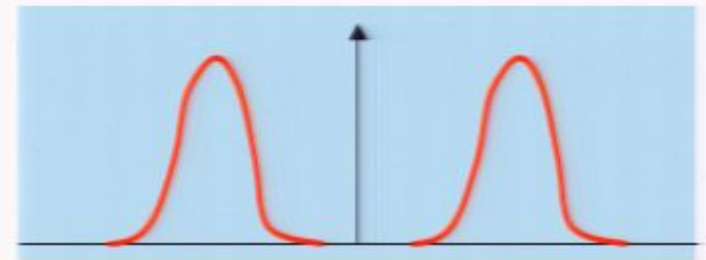


Positions are uncertain
for the very small !

Quantum Mechanics (or Quantum Field Theory) is the probabilistic arena of physics on very **small** scales

Particles can act like waves!

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$$\lambda_{\text{rain drop}} \approx 4 \times 10^{-30} \text{ m}$$
$$\approx .000000\dots0000004 \text{ m}$$



30 digits

Positions are uncertain
for the very small !



water
jet

Quantum Mechanics (or Quantum Field Theory) is the probabilistic arena of physics on very **small** scales

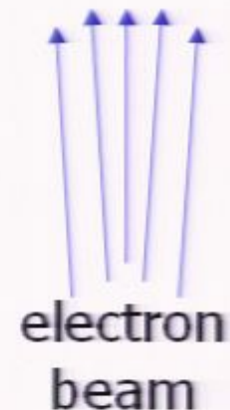
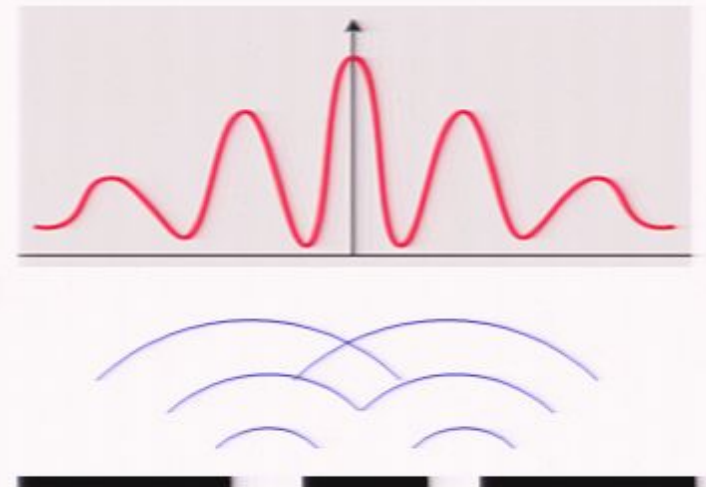
Particles can act like waves!

de Broglie wavelength: $\lambda = \frac{2\pi \hbar}{p}$ ← Planck's constant

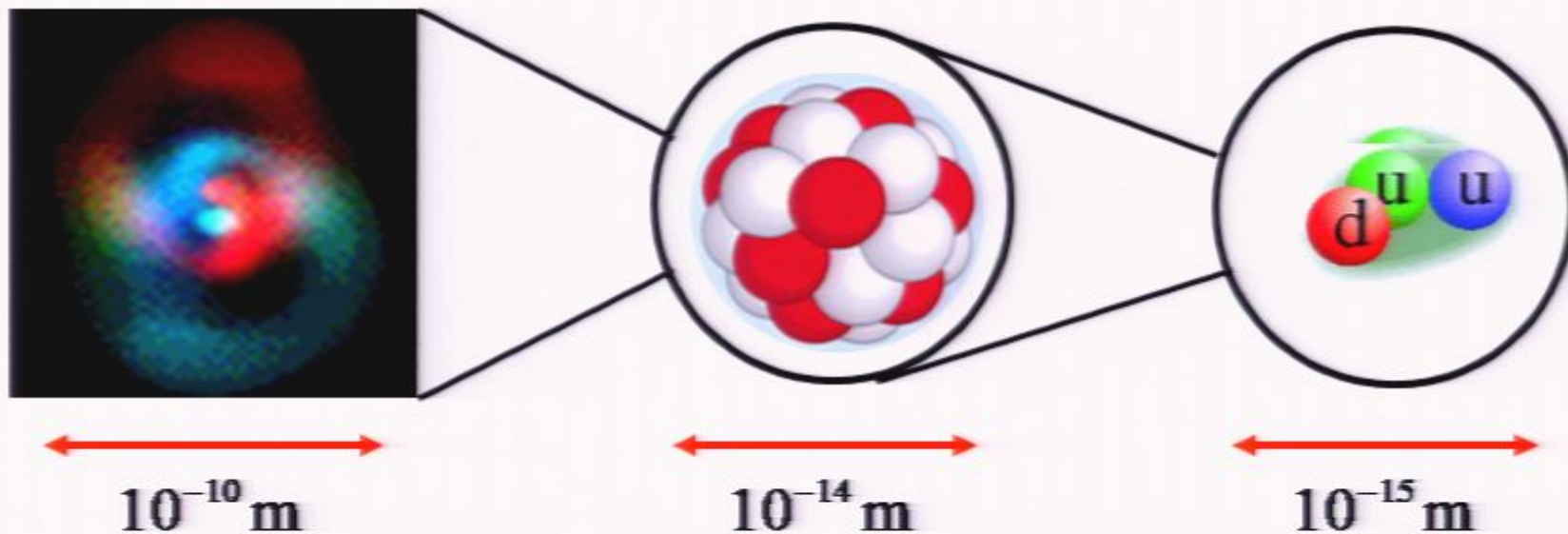
$$\lambda_{\text{rain drop}} \approx 4 \times 10^{-30} \text{ m}$$

$$\lambda_{\text{electron}} \approx 3 \times 10^{-10} \text{ m} = 3 \text{ \AA}$$

Quantum fluctuations are manifest in behavior of **subatomic** particles



Quantum Field Theory is the probabilistic arena of physics on very **small** scales



Elementary Particles (10^{-17} m)

Fermions:

electron, muon, tauon
 neutrinos (3 flavors)
 quarks - up, down, strange,
 charm, bottom, top

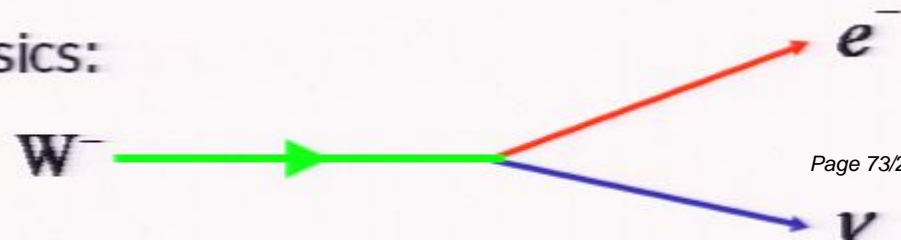
Bosons (Force Mediators):

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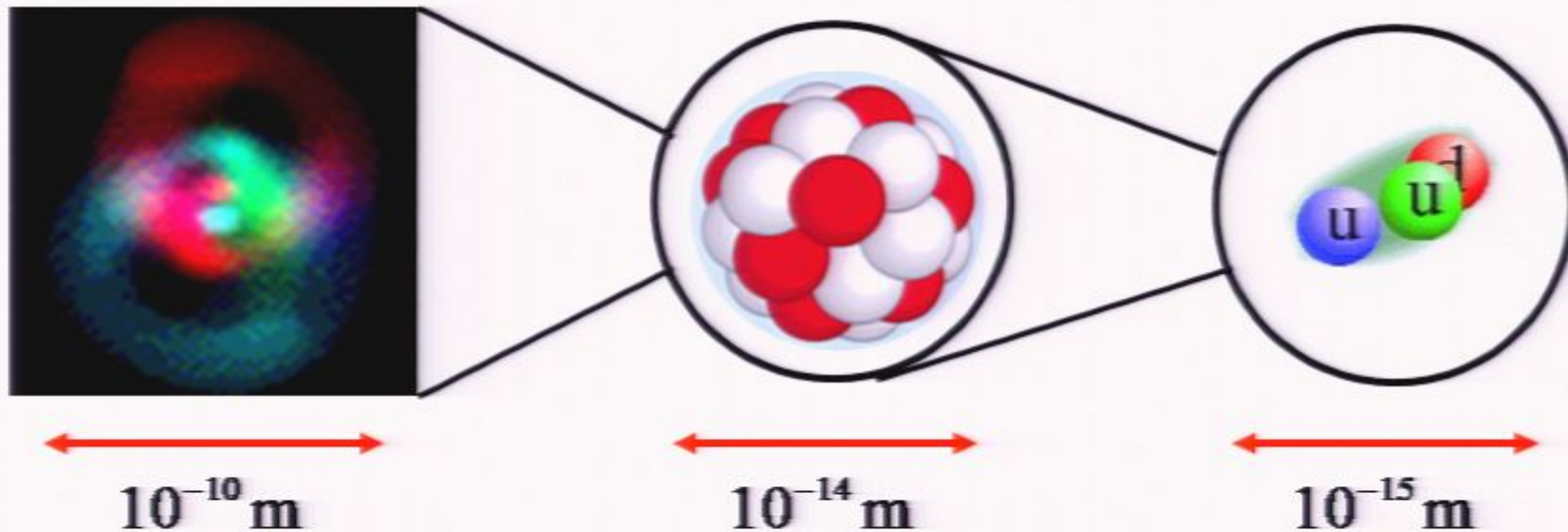
Higgs particle

Standard Model of Subatomic Physics:

above particles plus **interactions**
 (and ~ 20 free parameters)



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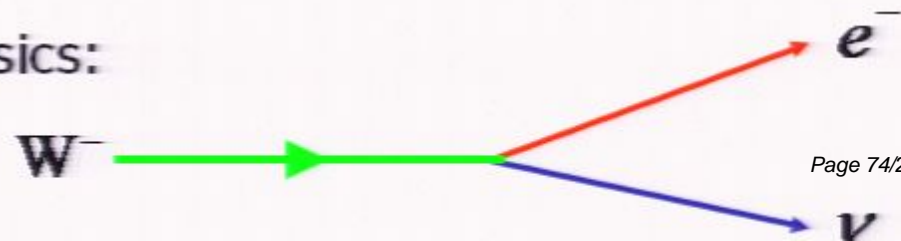
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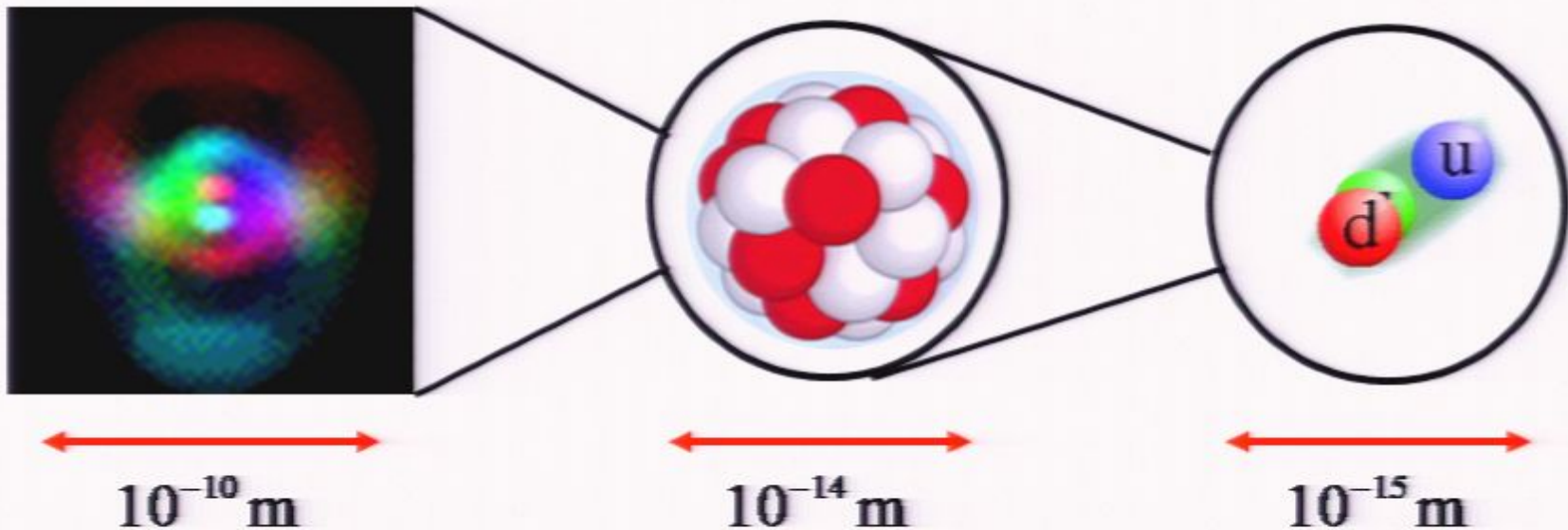
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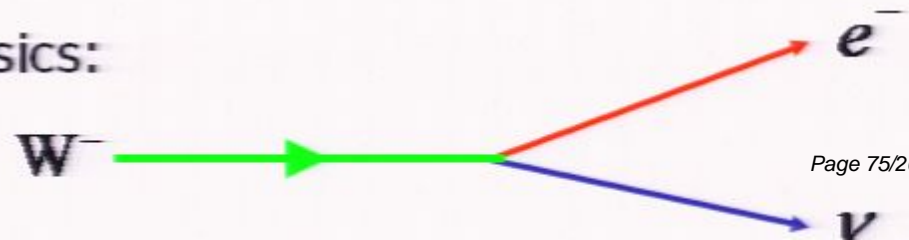
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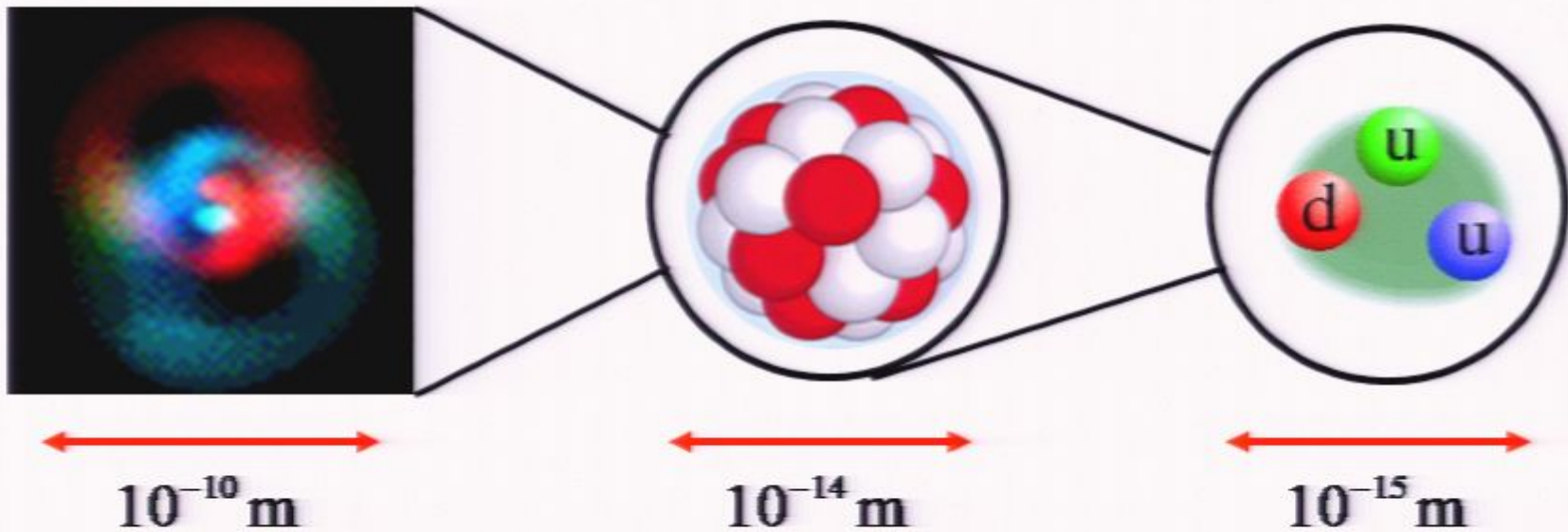
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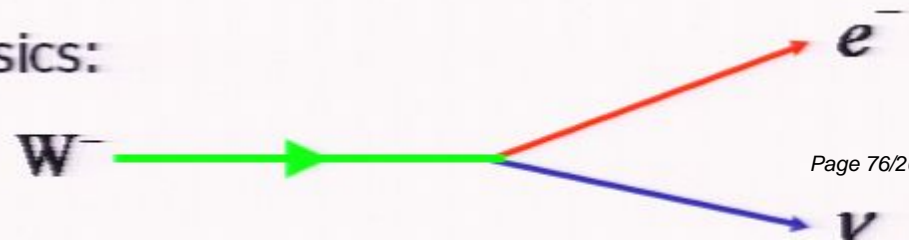
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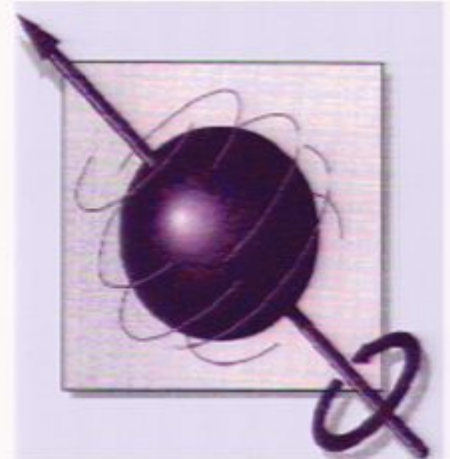


Quantum theory is rigorously tested!!

Example: electrons are tiny magnets

$$\mu_e = g e \hbar / 4m_e \quad \text{with } g \approx 2$$

precise value of magnetic moment depends
on **quantum fluctuations**

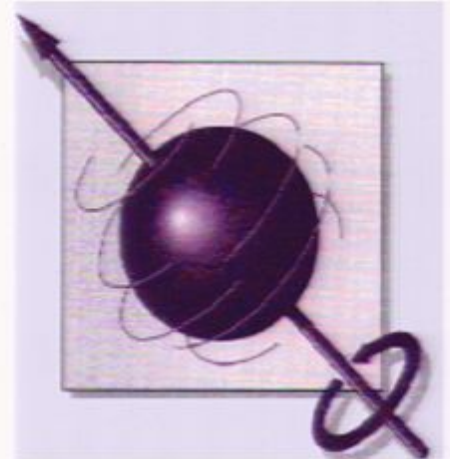


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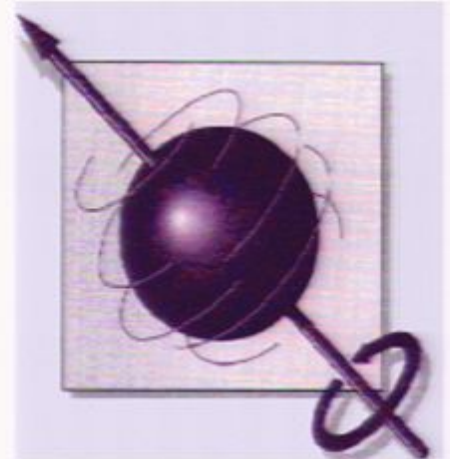


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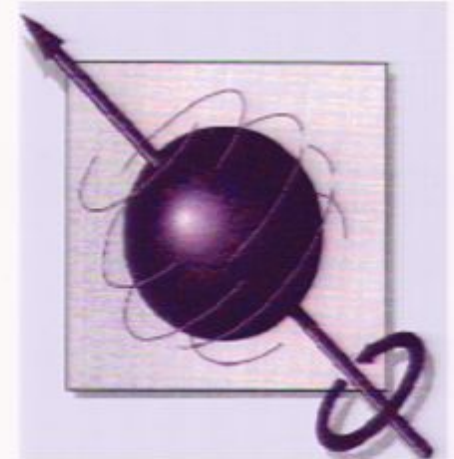
$$\mu_{\text{measured}} = 2.0023193043738$$

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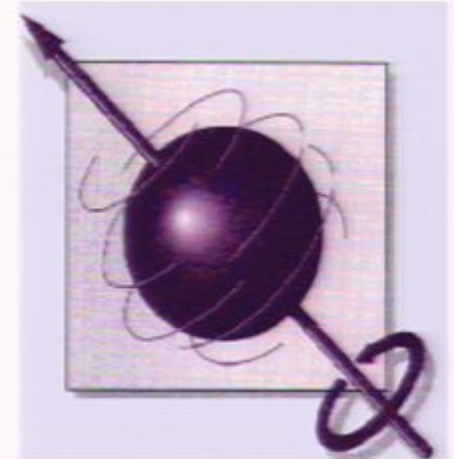
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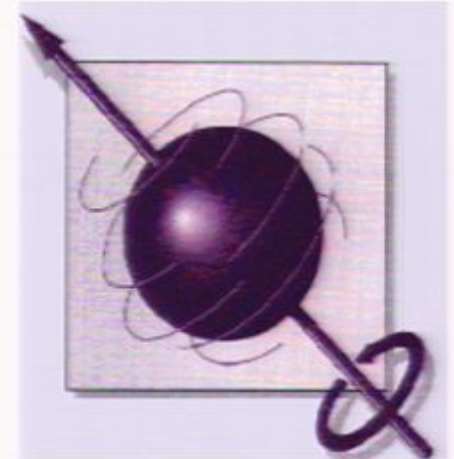
$$\left| \frac{\mu_{\text{calculated}} - \mu_{\text{measured}}}{\mu_{\text{measured}}} \right| < 10^{-10}$$

Quantum theory is rigorously tested!!

Example: electrons are tiny magnets

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precise value of magnetic moment depends
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$$\mu_{\text{measured}} = 2.0023193043738$$

$$\mu_{\text{calculated}} = 2.0023193043070$$

(neither answer absolutely correct)

Quantum theory is rigorously tested!!

e.g., magnetic moment of the electron, $\mu_e = g \frac{e\hbar}{4m_e} I$
is modified by quantum fluctuations

$$\left| \frac{\mu_{\text{theory}} - \mu_{\text{experiment}}}{\mu_{\text{experiment}}} \right| \leq 10^{-10}$$

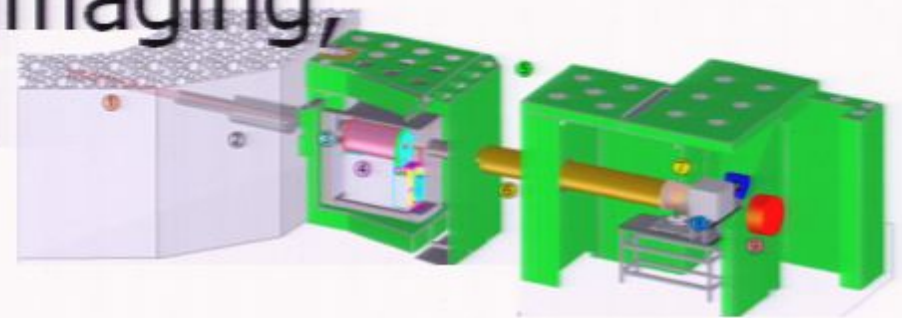
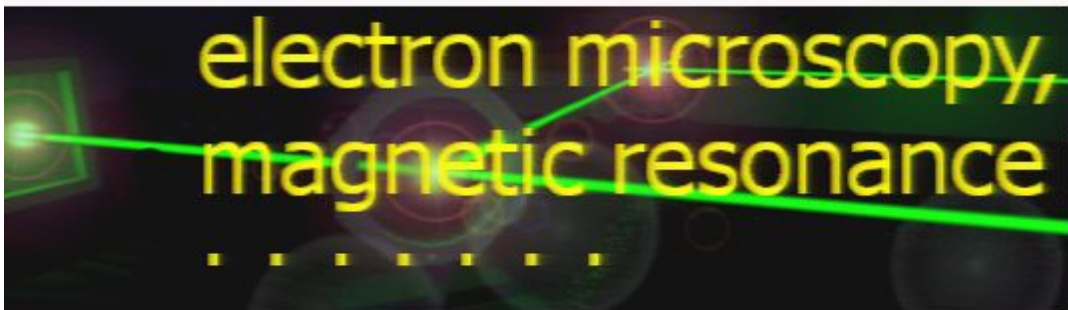
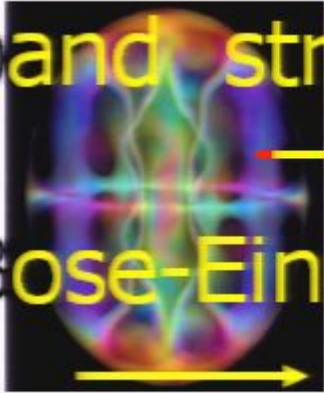


e.g., Lamb shift: shift between $2S_{1/2}$ and $2P_{1/2}$
energy levels of hydrogen atom ($f = 1057$ MHz)

$$\left| \frac{f_{\text{theory}} - f_{\text{experiment}}}{f_{\text{experiment}}} \right| \leq 10^{-6}$$

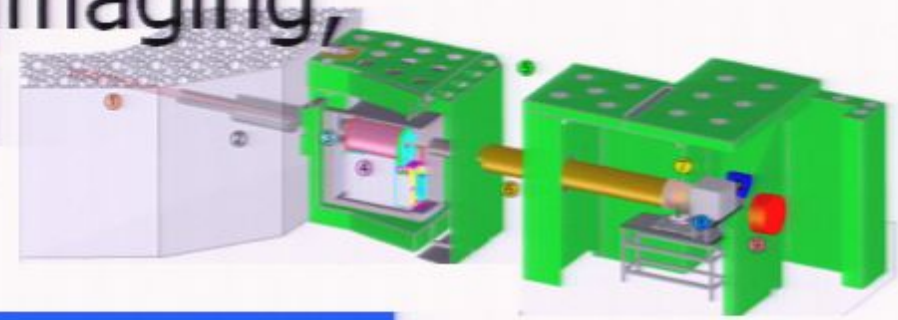
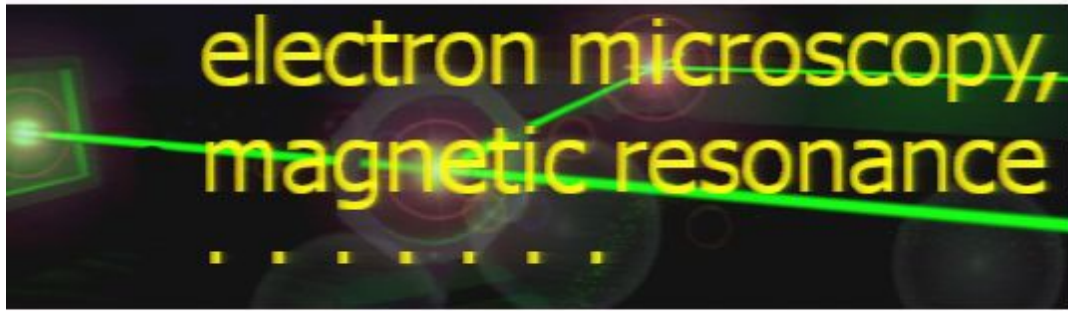
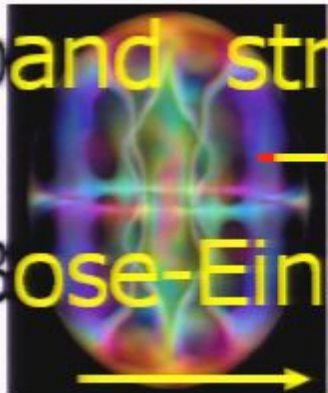
Quantum Theory: a rich source of new ideas

- **band structure** in materials → semiconductor technology
- **Bose-Einstein** condensation → superfluids, superconductors
- quantum Hall effect, neutron diffraction, **electron microscopy, lasers, magnetic resonance imaging, ...**



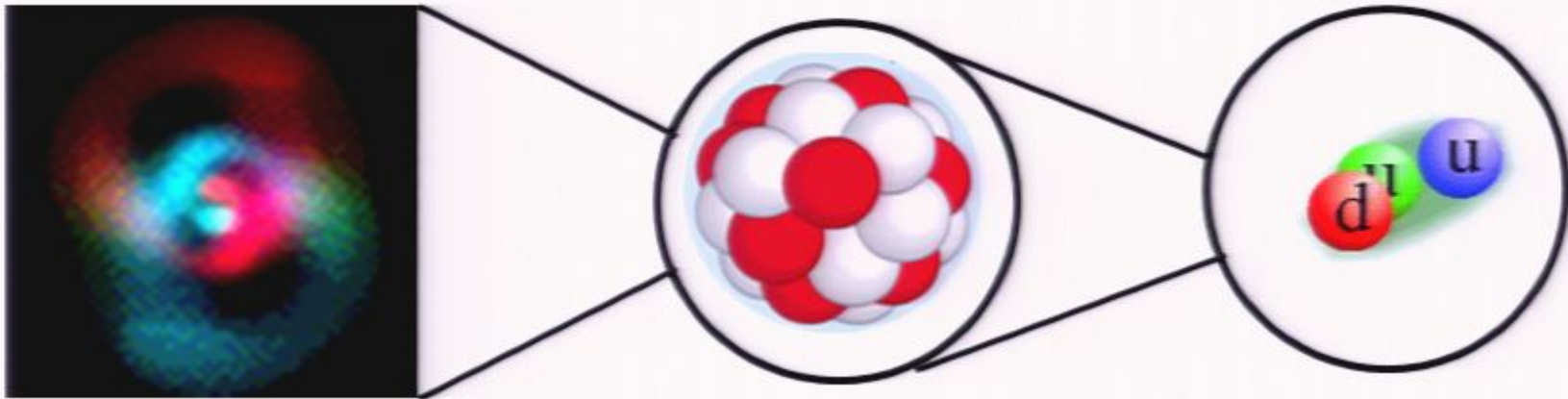
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Nobel prizes galore!!

Subatomic Physics



Elementary Particles (10^{-17} m)

Fermions:

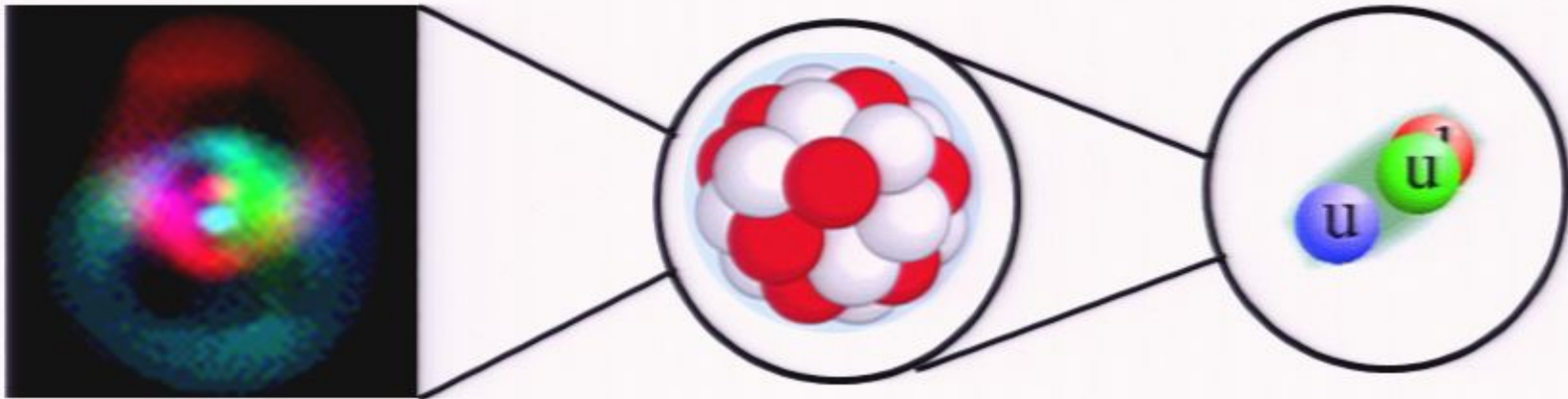
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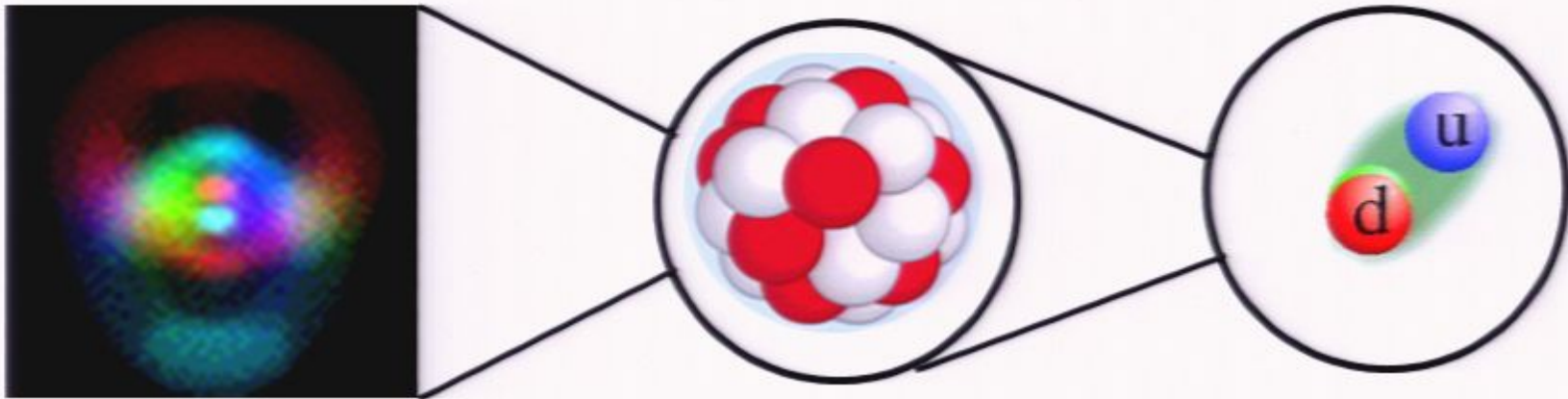
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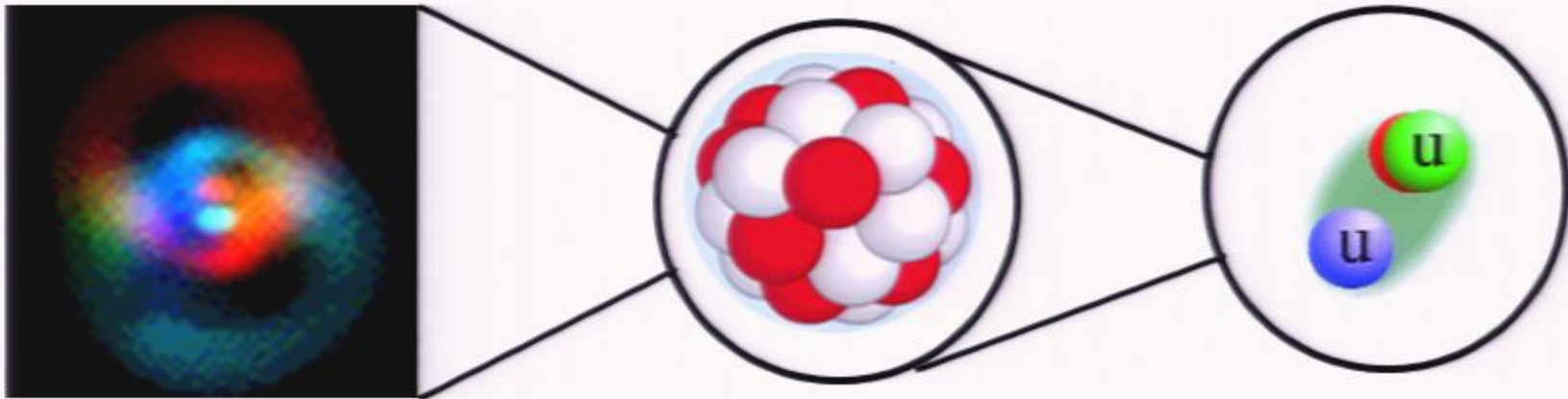
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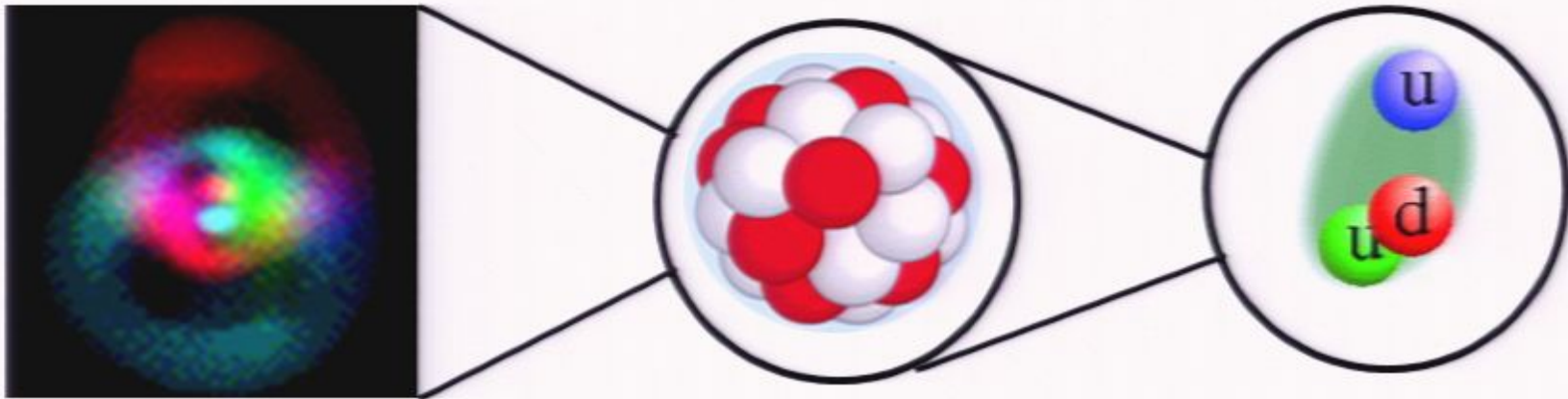
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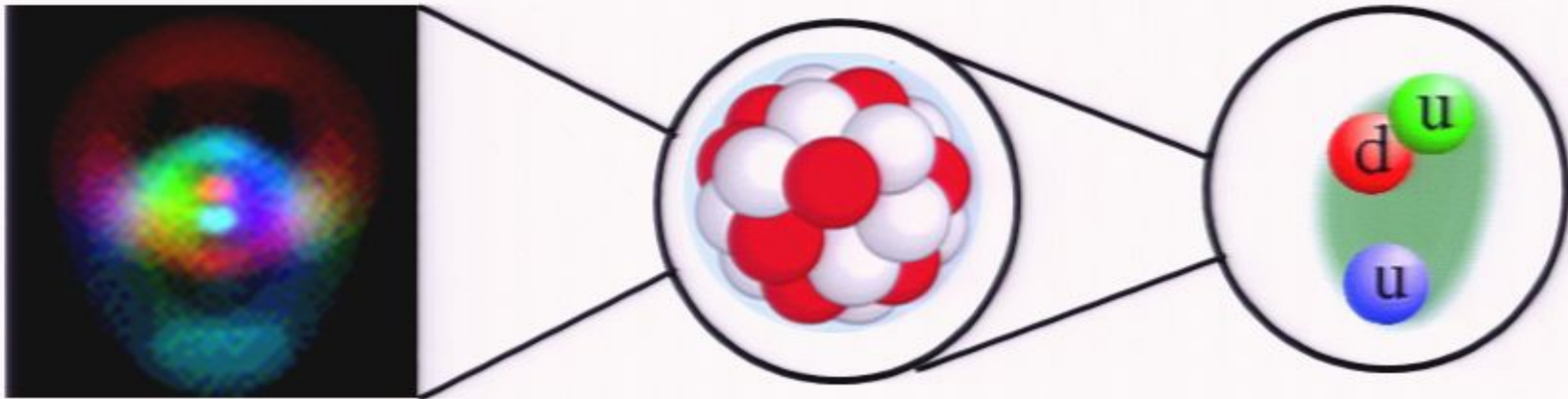
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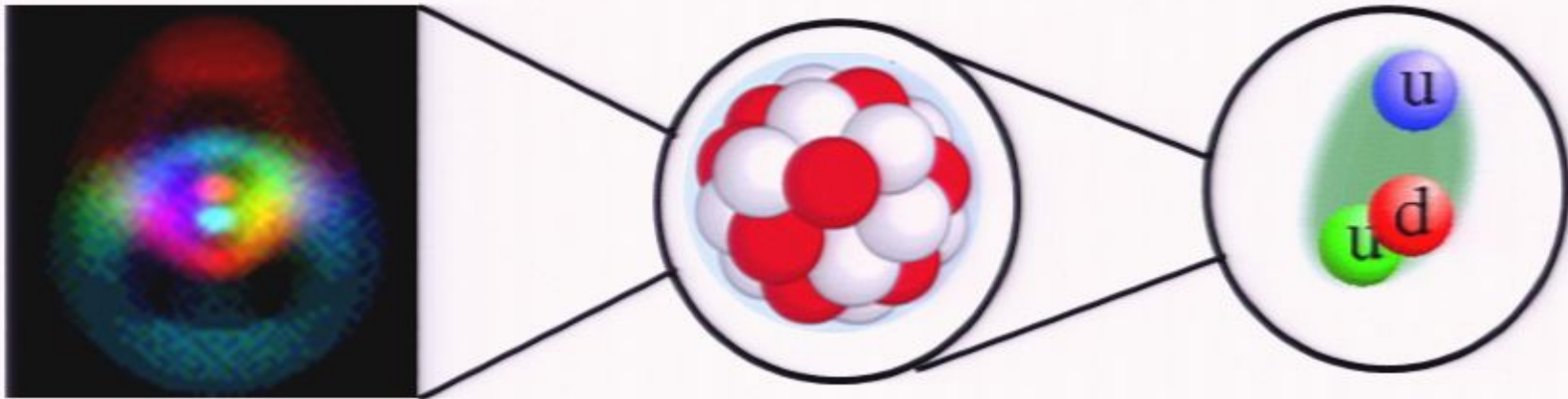
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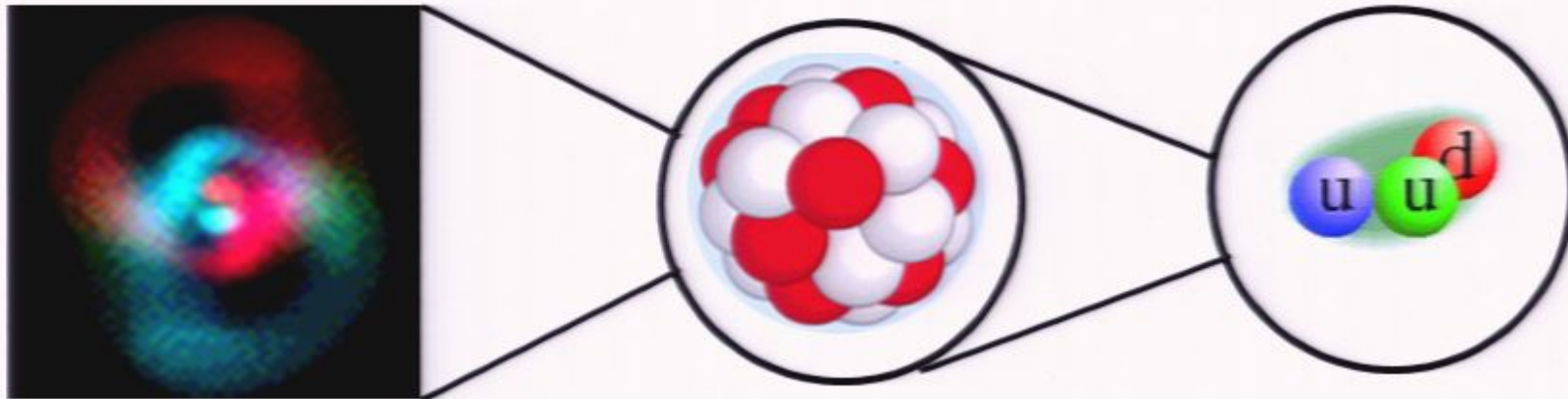
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Subatomic Physics \longrightarrow a theory of strings!



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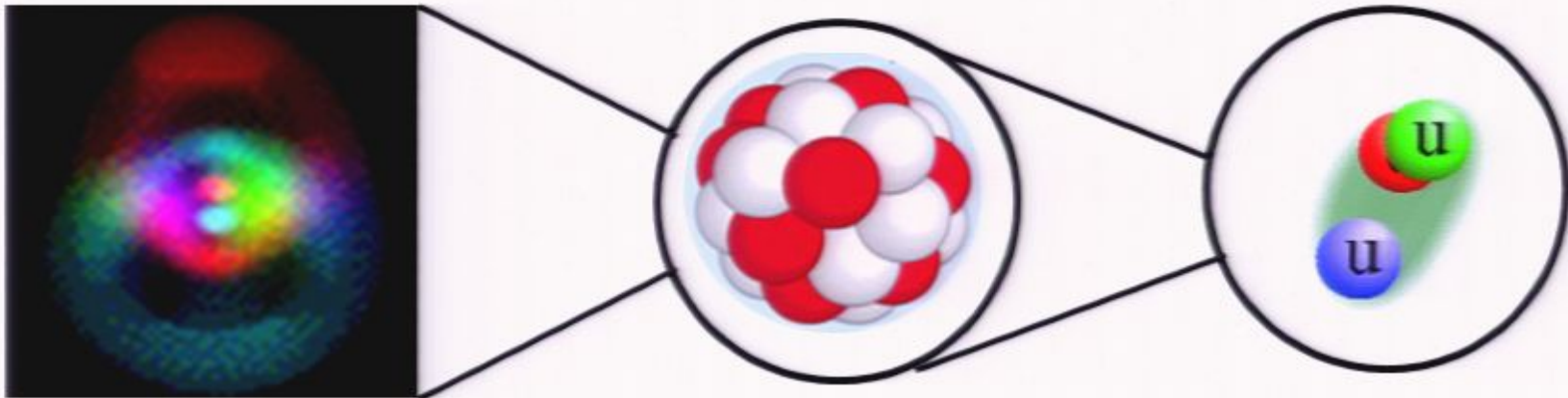
Higgs particle

10^{-35} m



Strings tame
the particle zoo!

Subatomic Physics \longrightarrow a theory of strings!



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Superstrings: the theory of subatomic physics

The essential idea:

with sufficient resolution, all elementary particles are one-dimensional objects (strings)



all particle types are the same kind of string vibrating or rotating in different ways

Superstrings: the theory of subatomic physics

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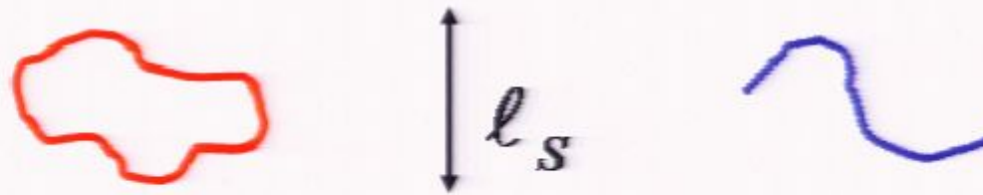


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Superstrings: the theory of subatomic physics

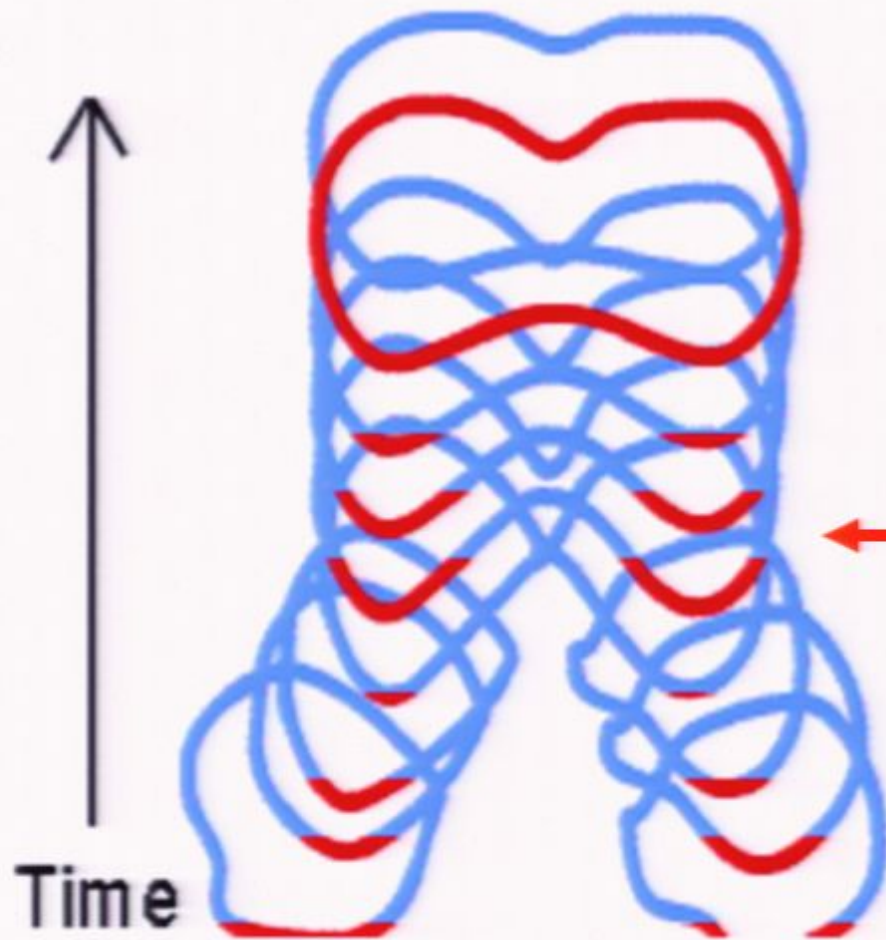
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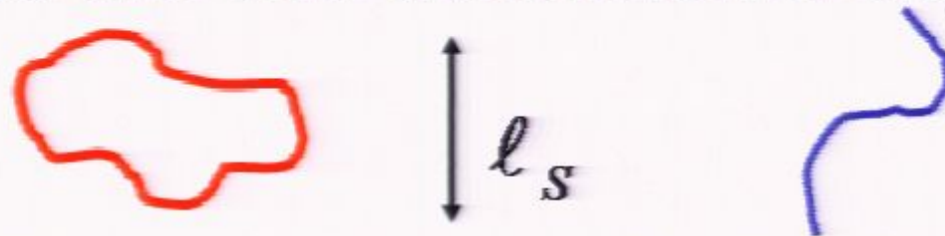
the typical size of the strings is the fundamental scale of the theory, $l_s = 10^{-35} \text{ m}$



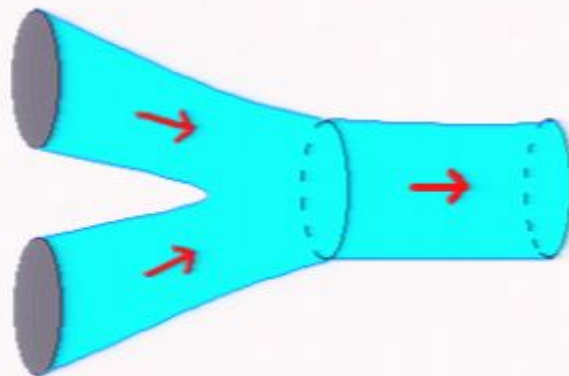
coupling constant, g ,
determines probability
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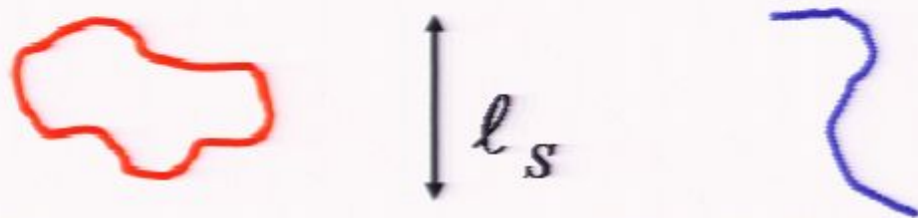
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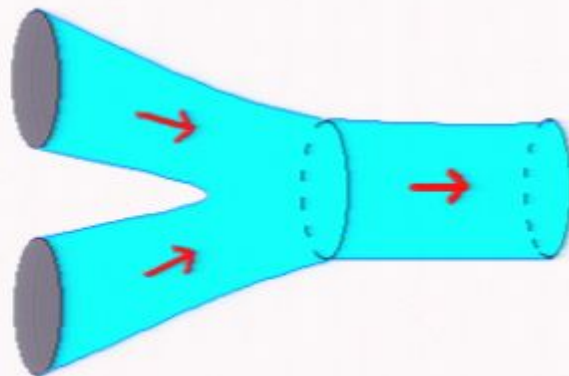
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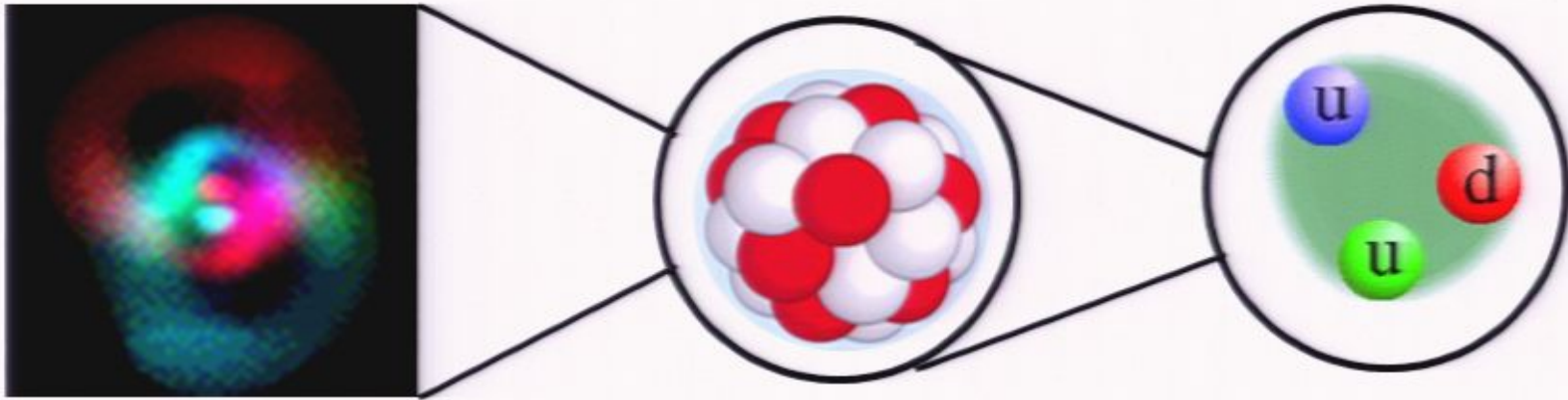


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What's missing here?

Superstrings: the theory of **gravitational** physics

consistency **requires** appearance of **the graviton!**

at long distances much greater than ℓ_s , reproduces Einstein's gravitational equations

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Superstrings naturally provides a unified framework for **Quantum Field Theory** and **General Relativity**

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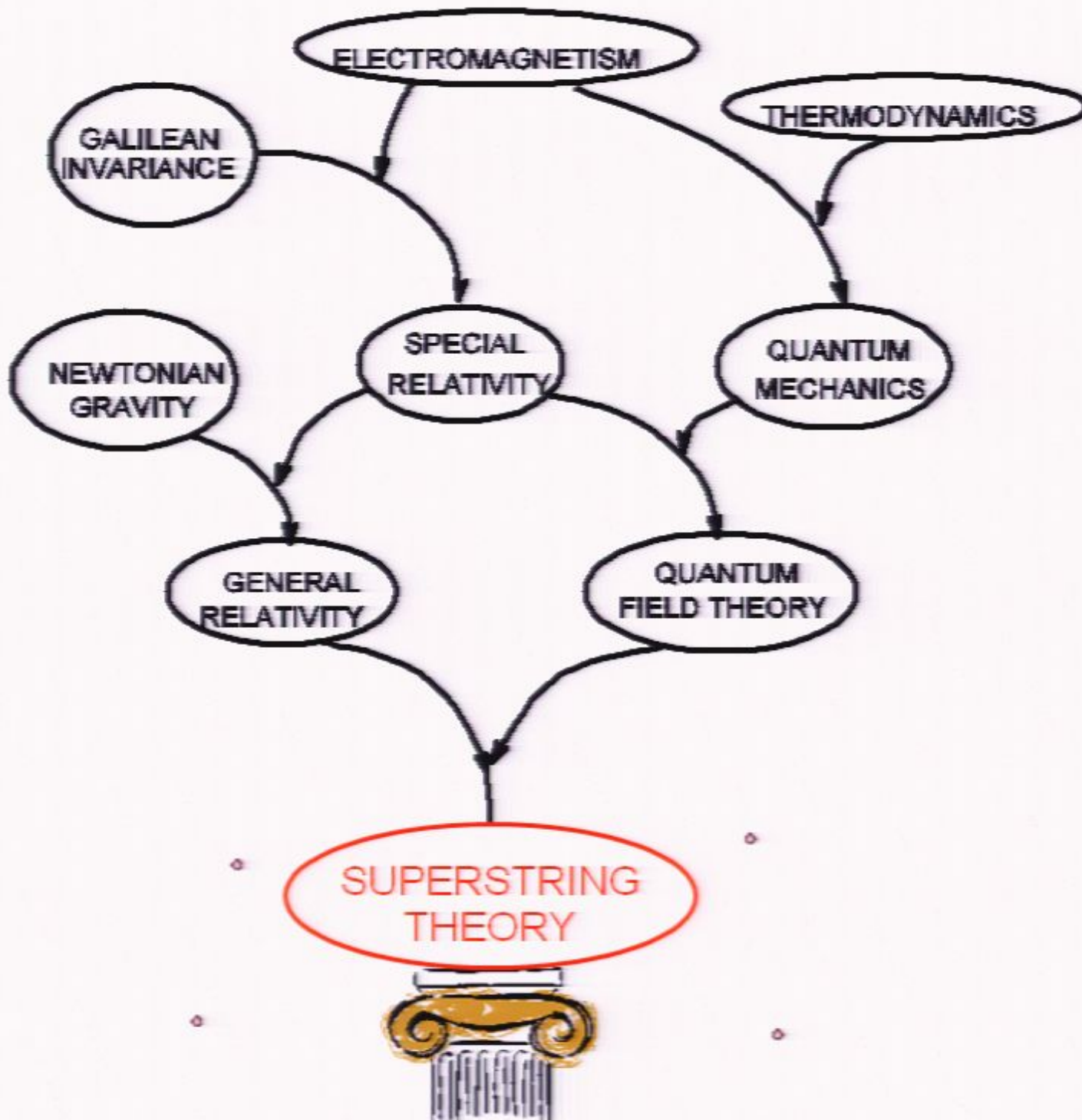
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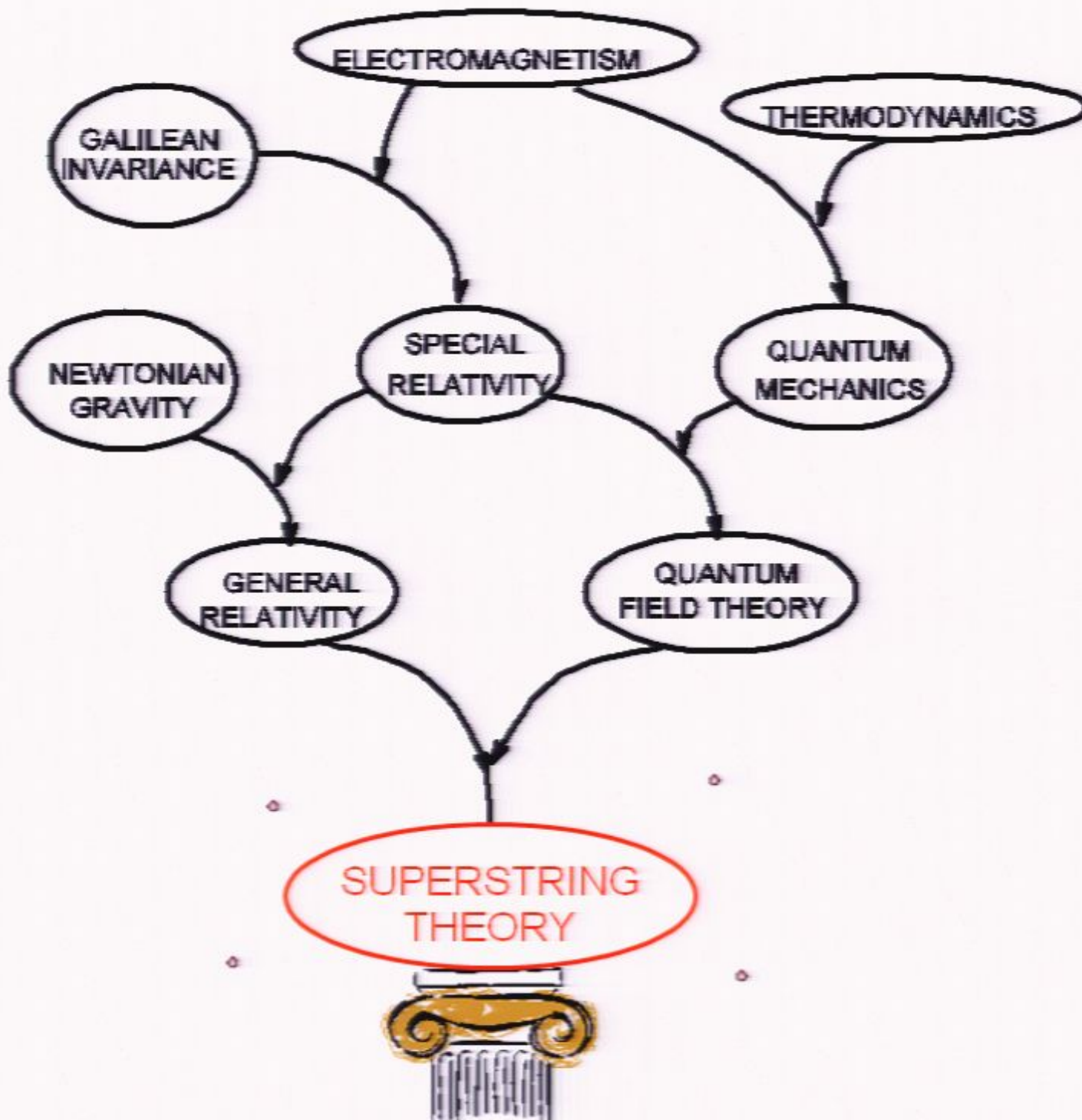
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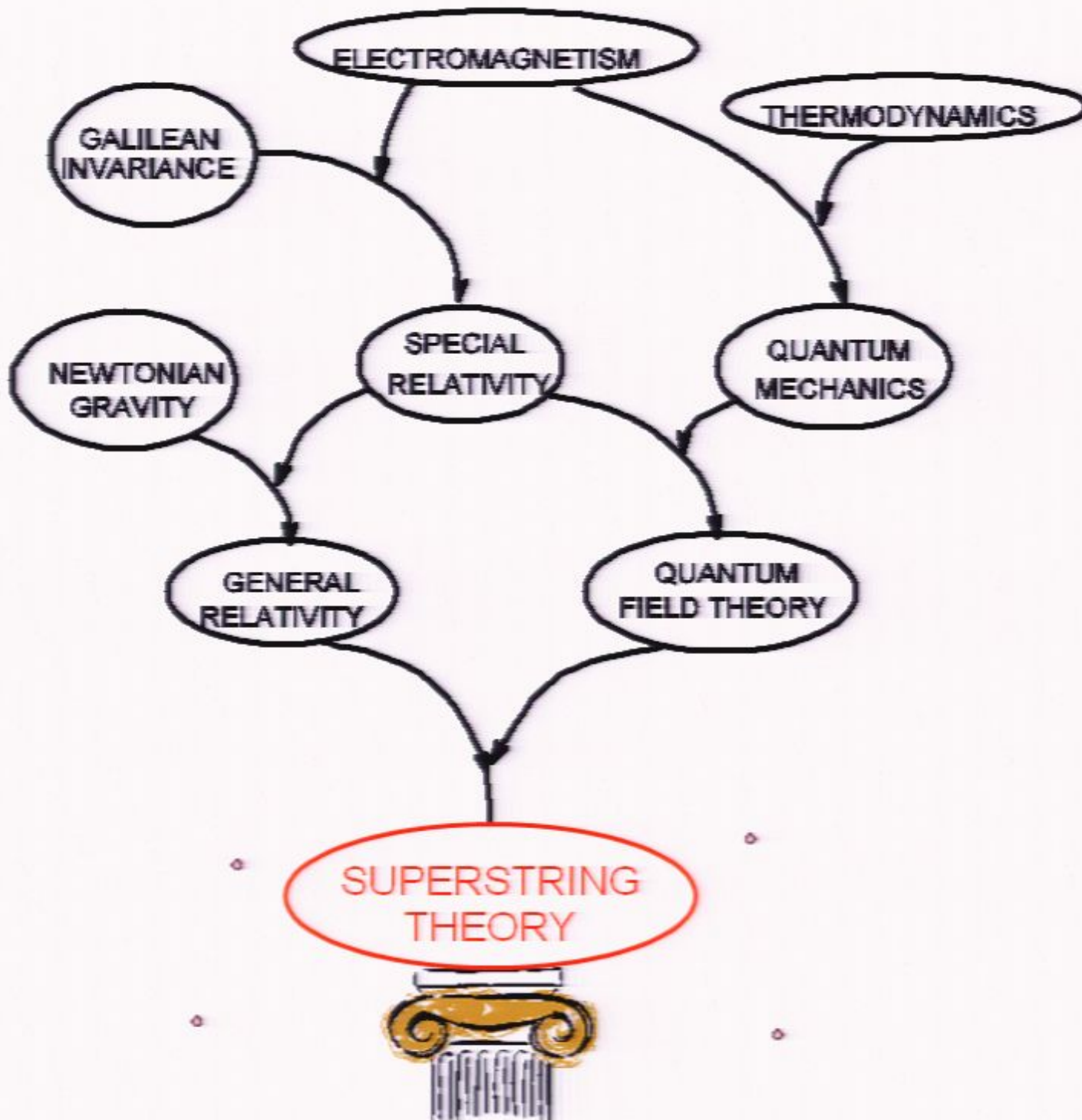
$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = 8\pi \mathbf{G} T_{\mu\nu} \quad \text{Newton's constant}$$

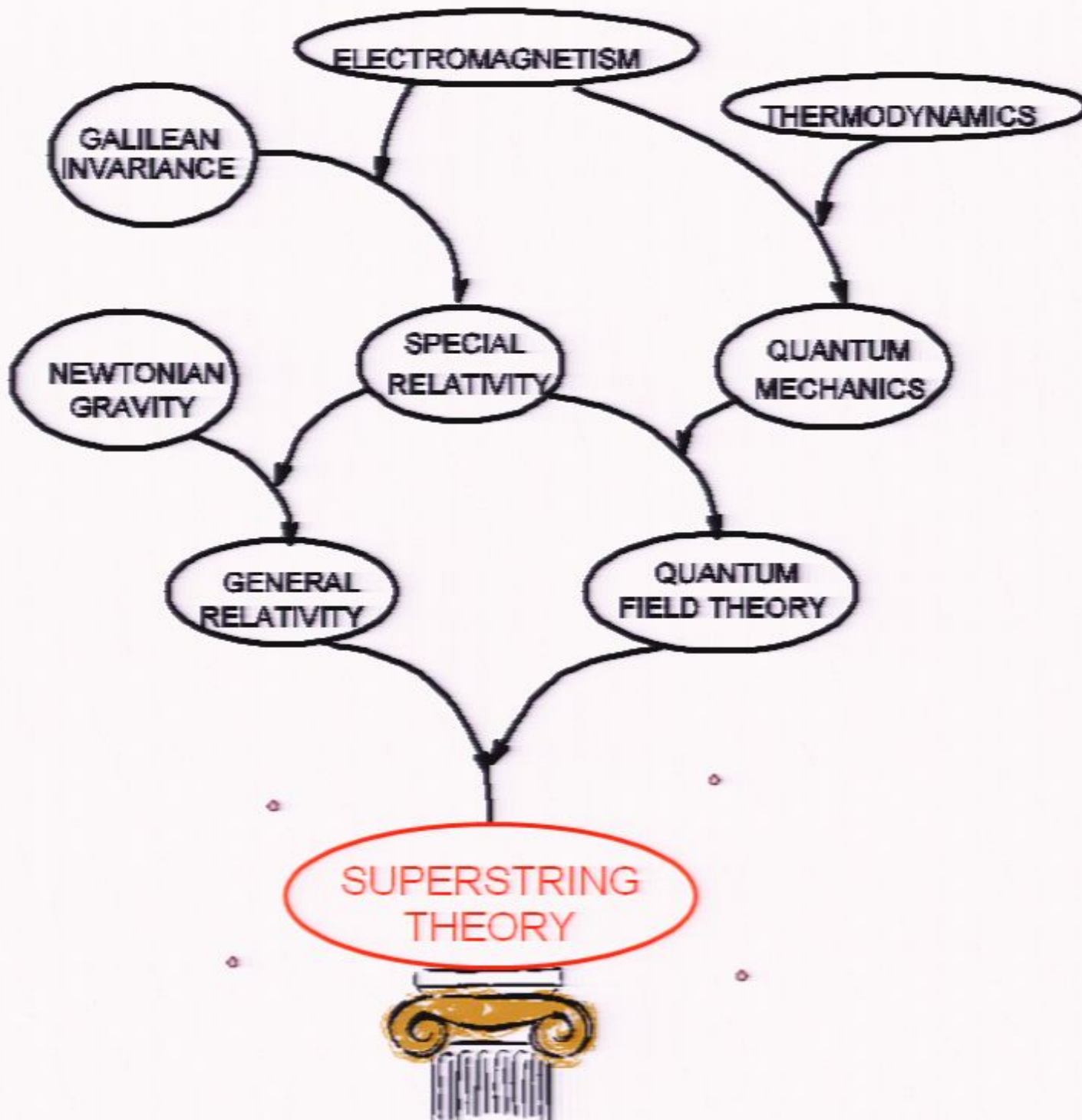
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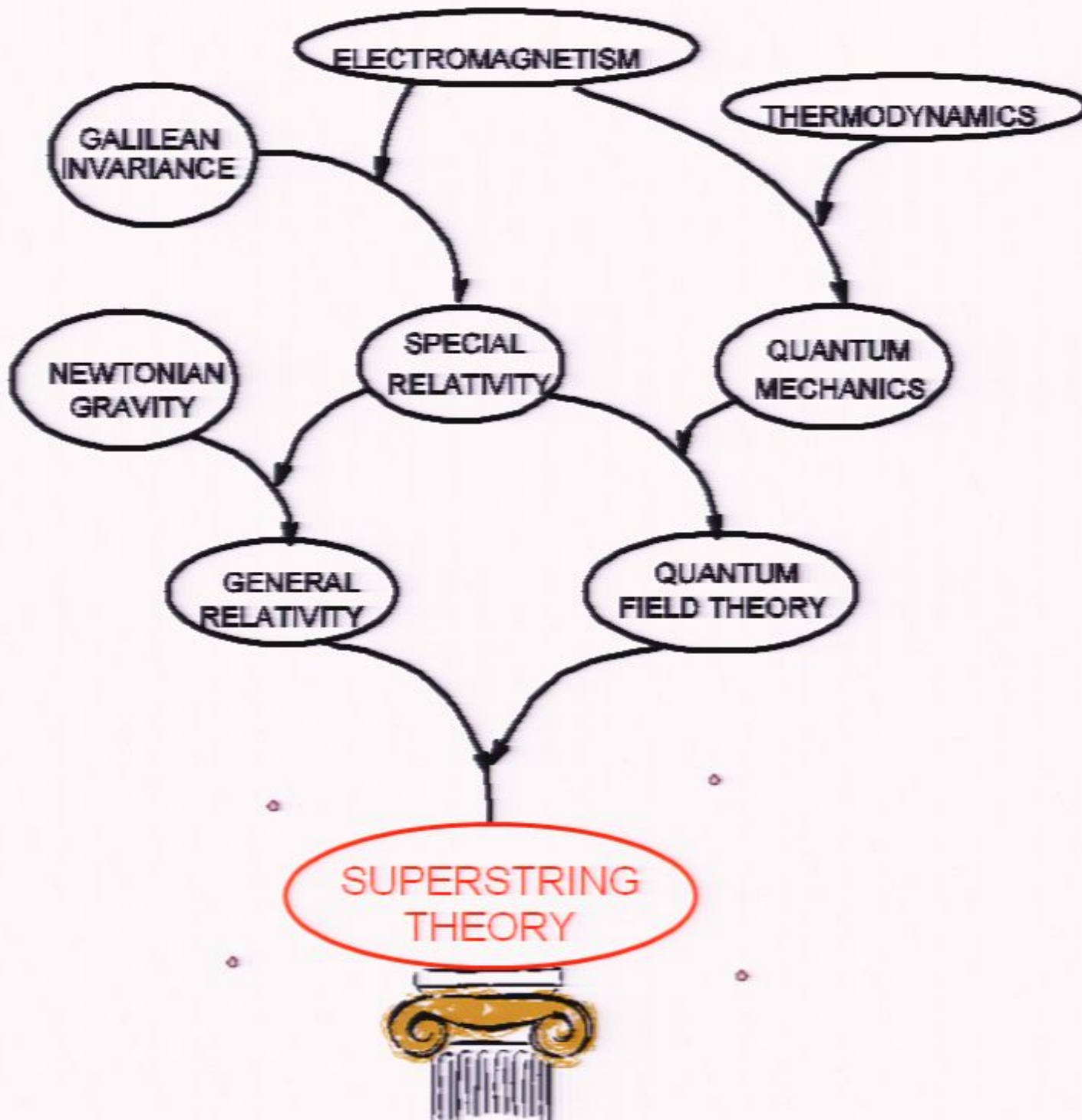
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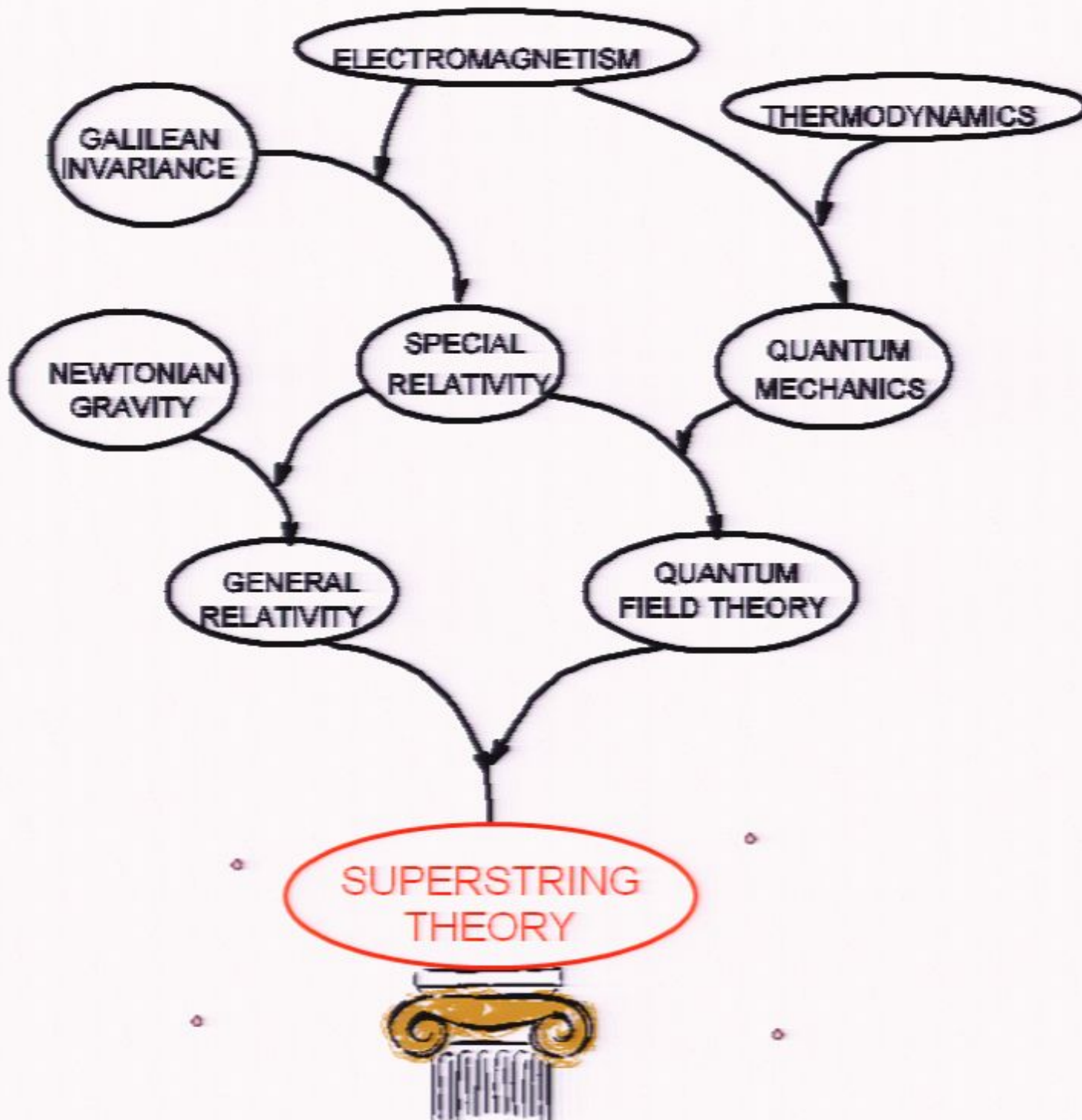


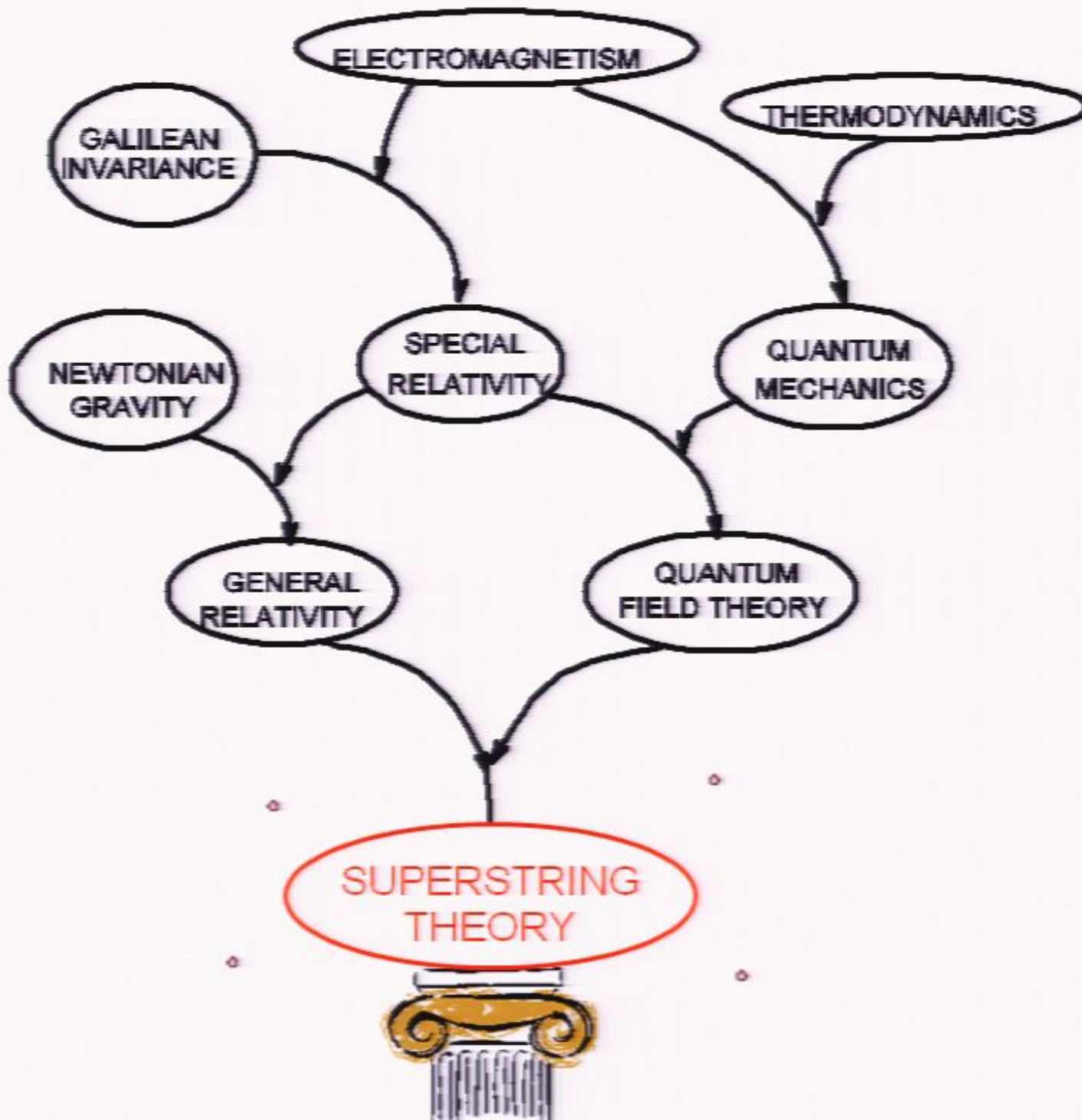


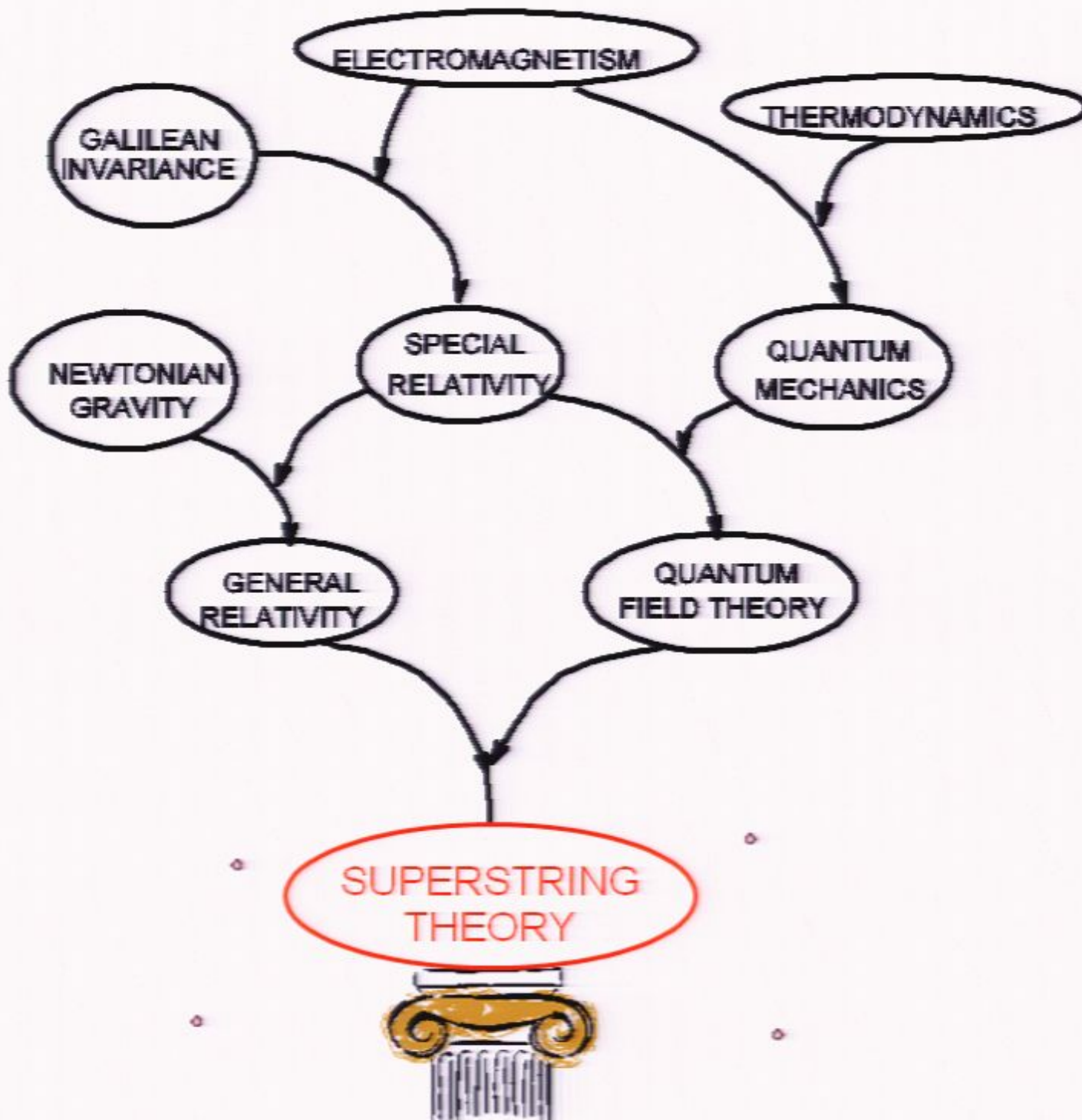


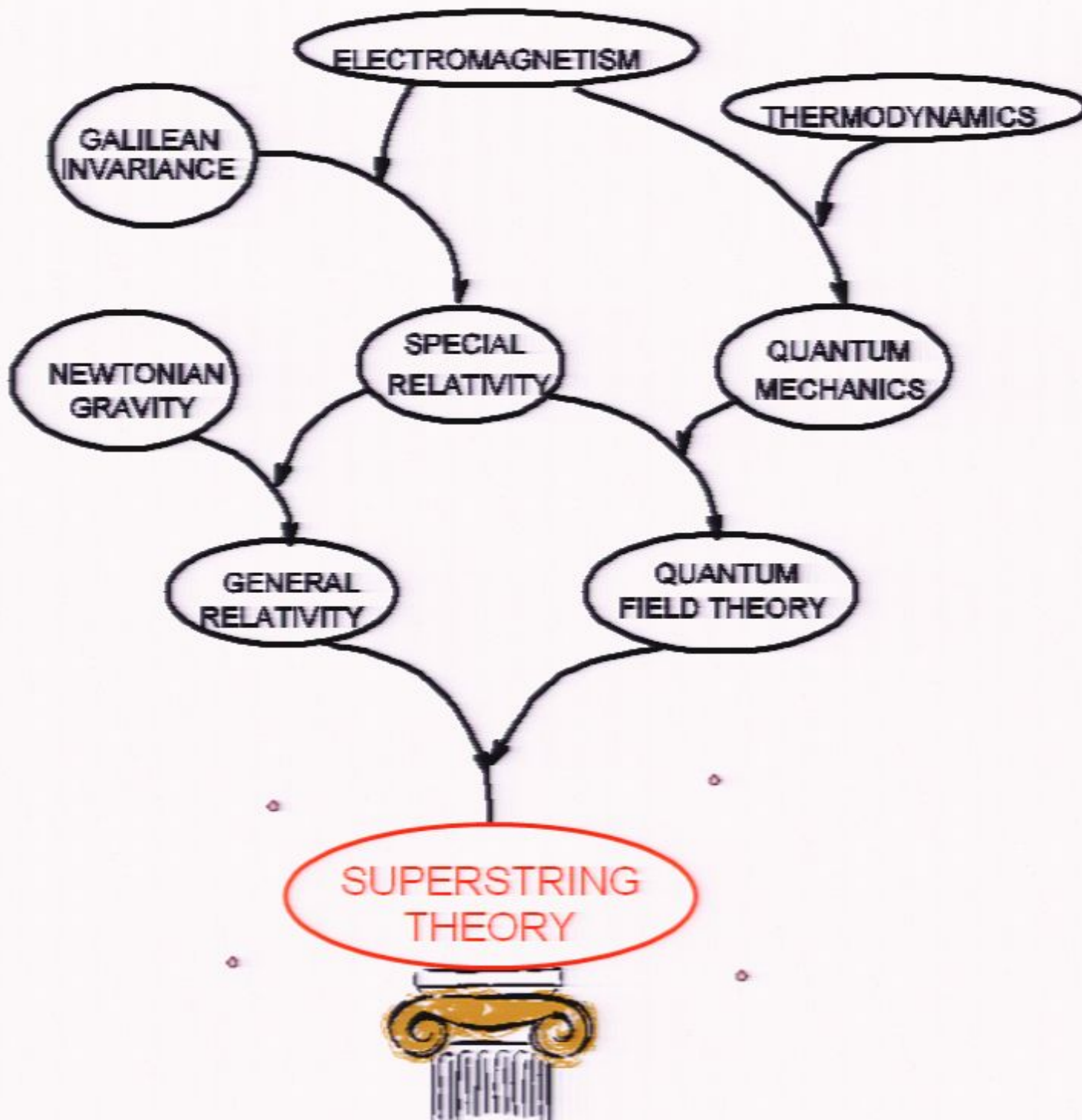


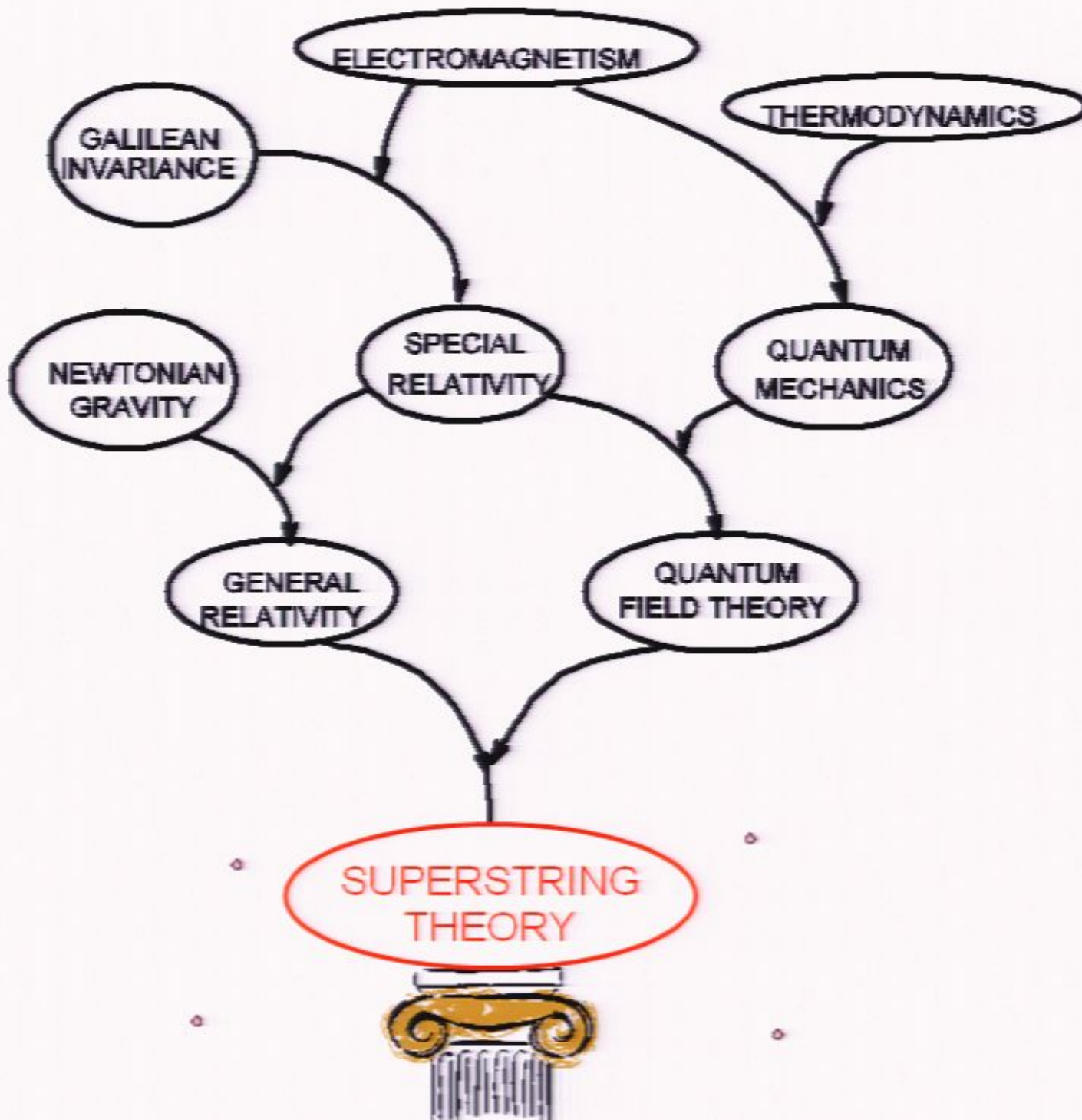


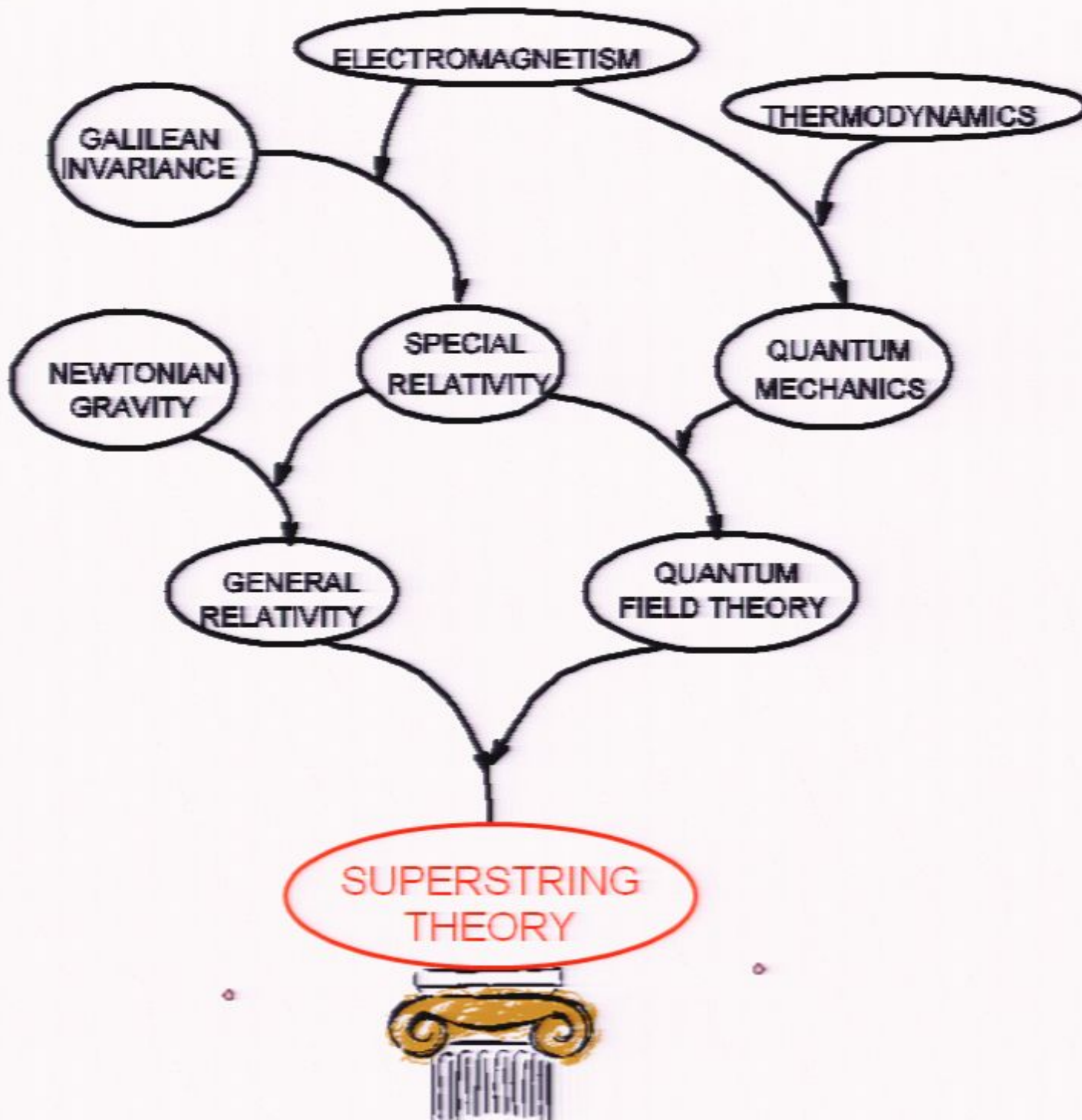


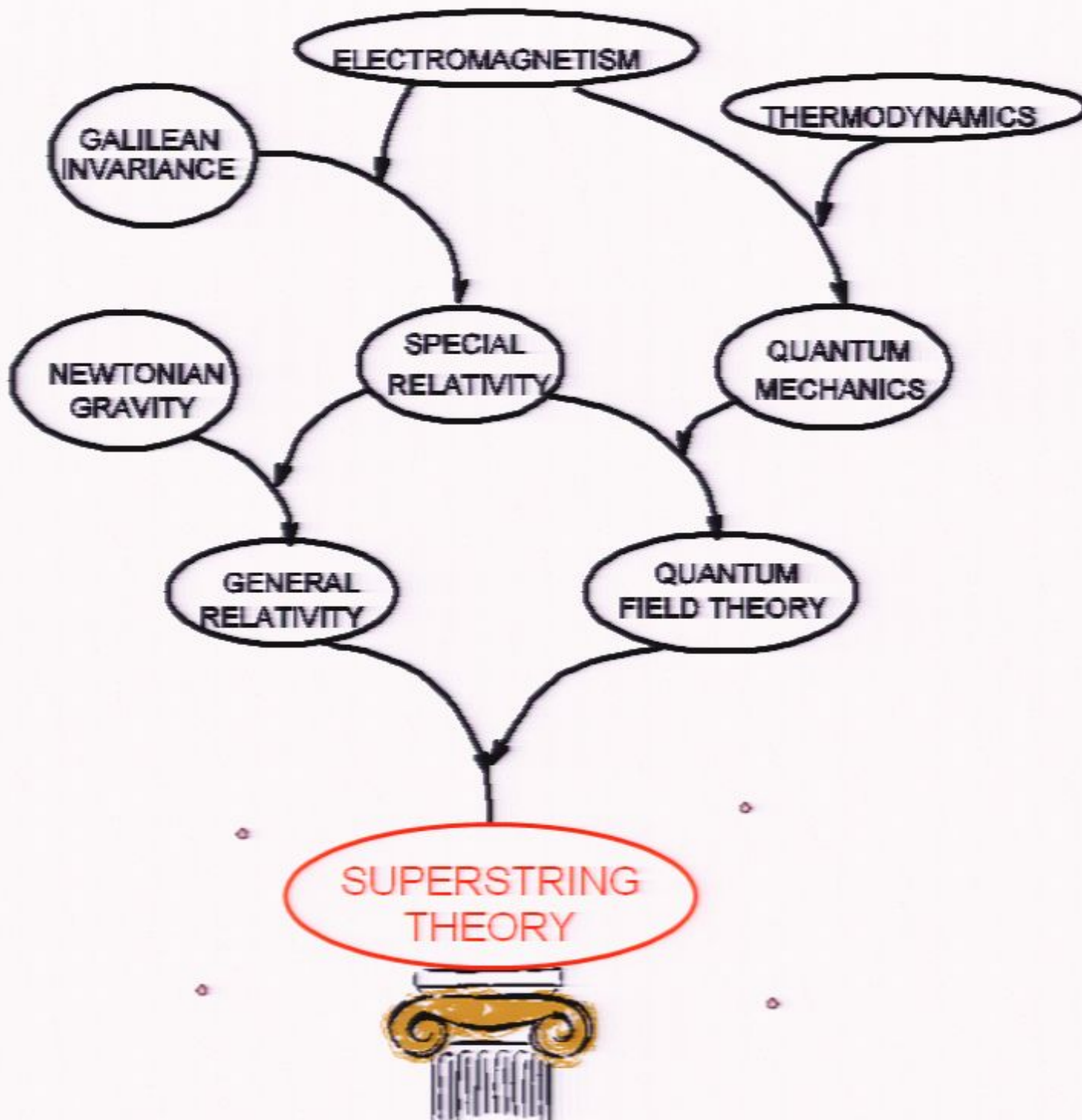


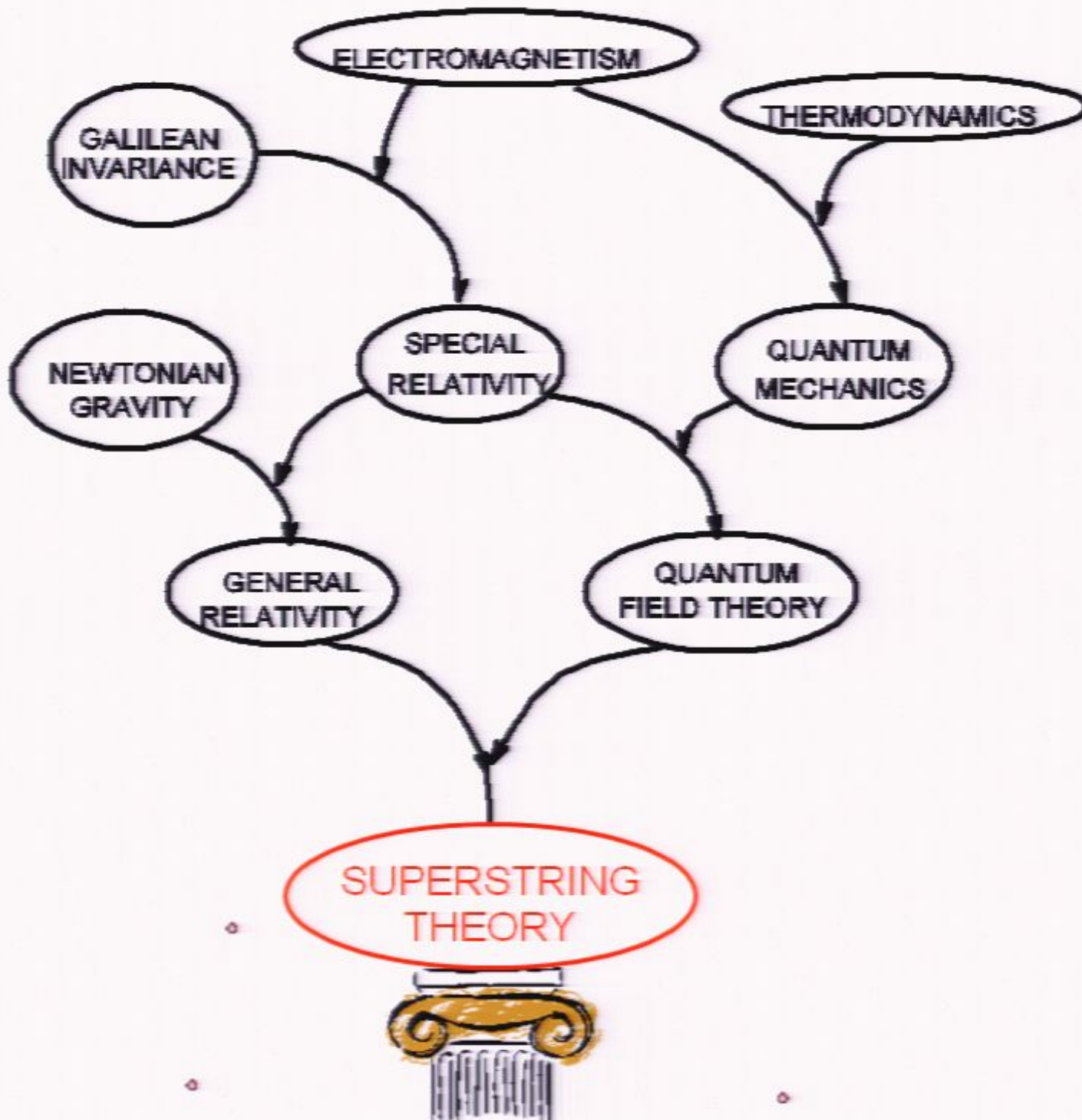


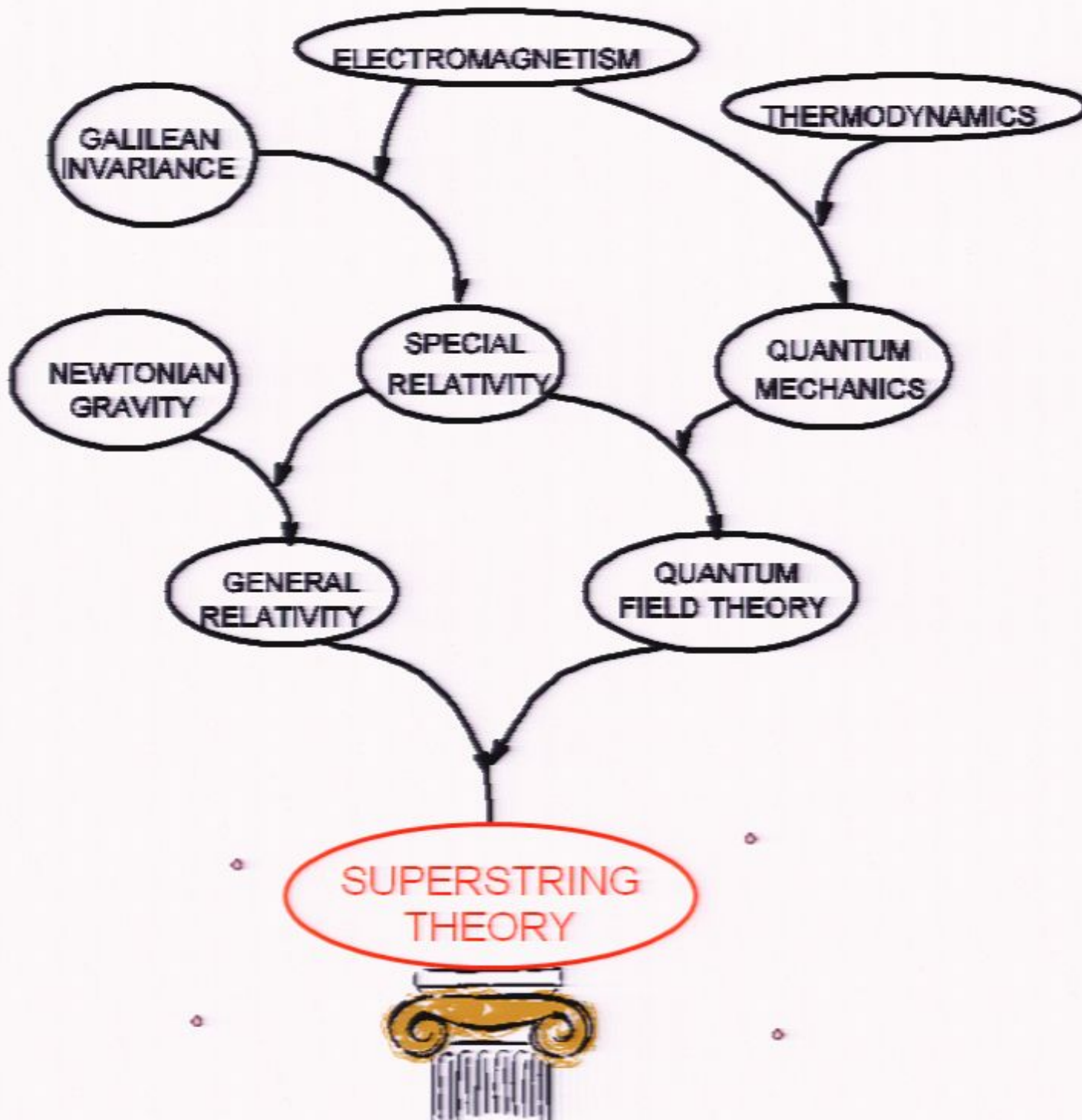


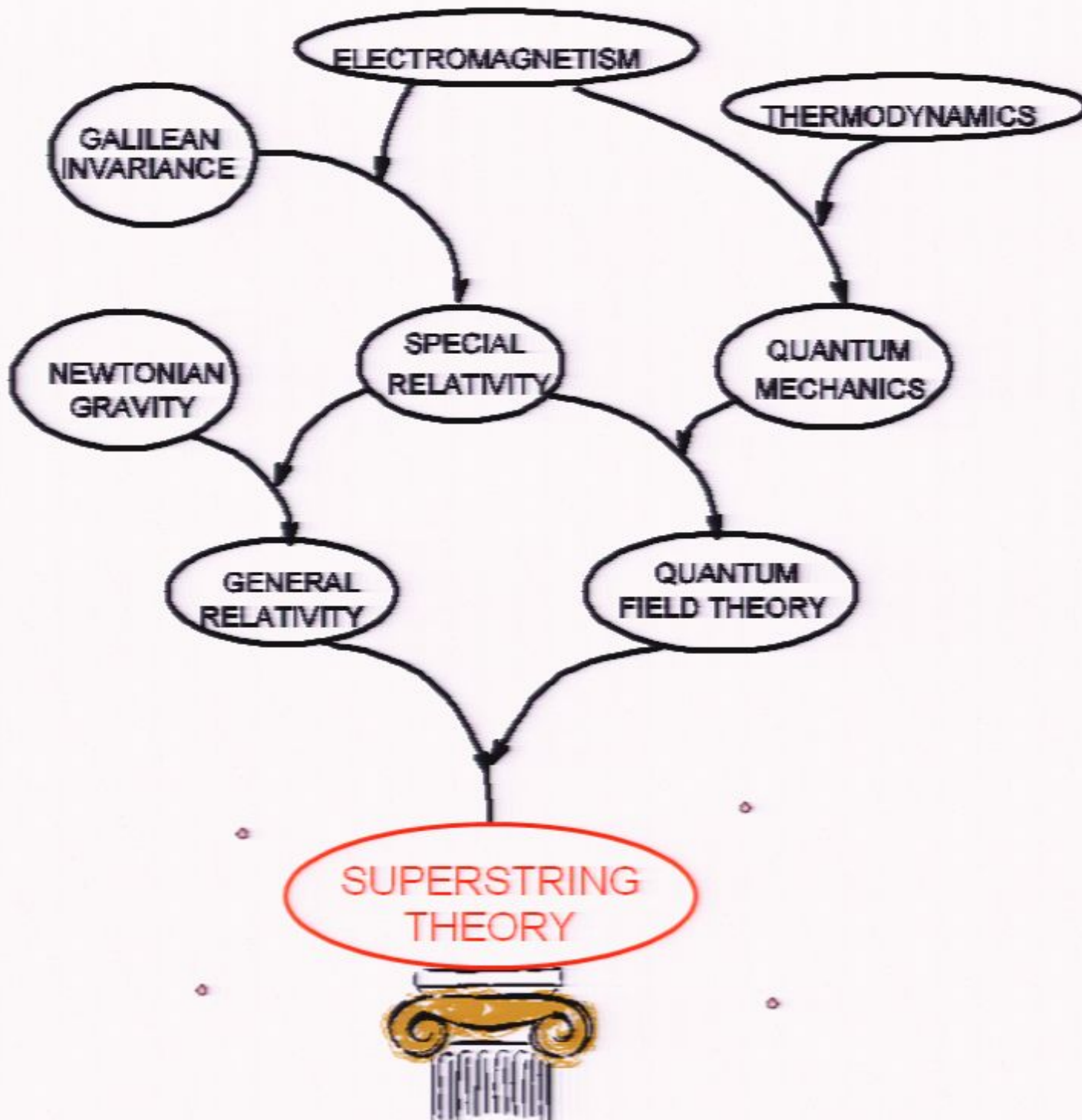












Superstring theory: The devil is in the “details”

- Predicts we live in **10 spacetime dimensions!!**

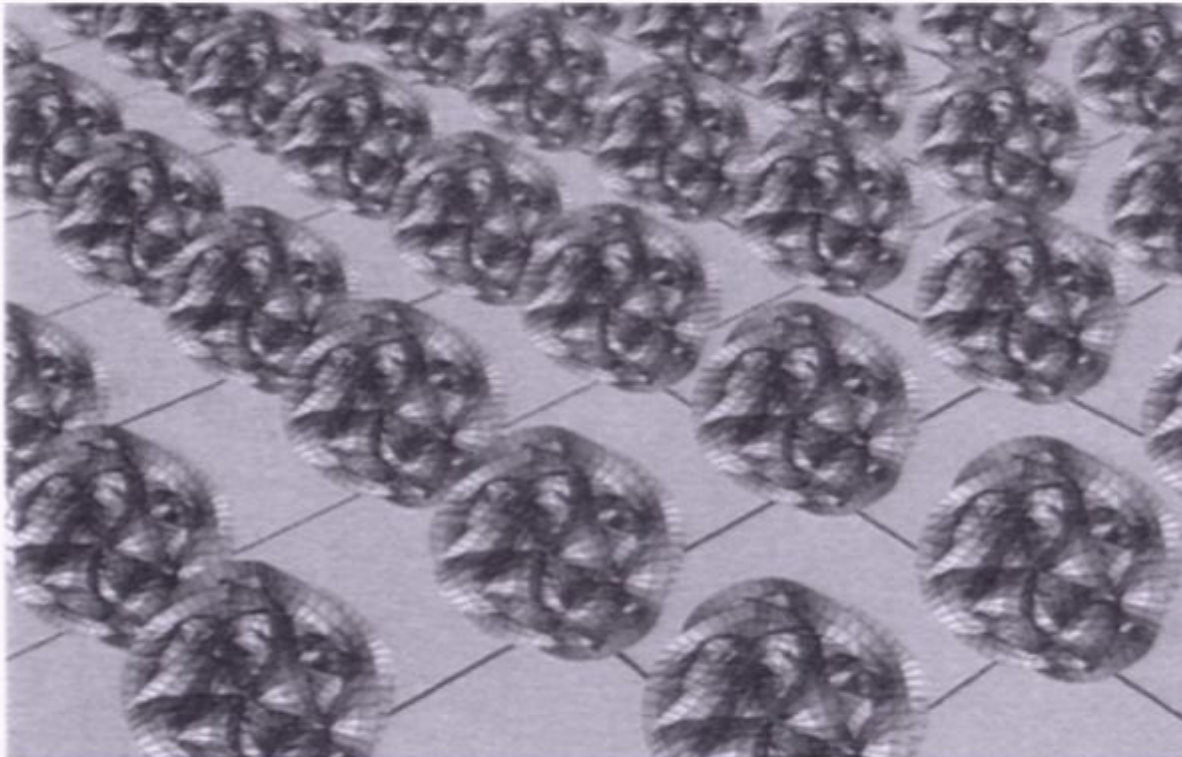
*Experimental update: we live in 4 dimensions!
(1 time and 3 space)*

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Experimental update: we live in 4 dimensions!

Big fix: Perhaps we haven't seen the extra dimensions yet.

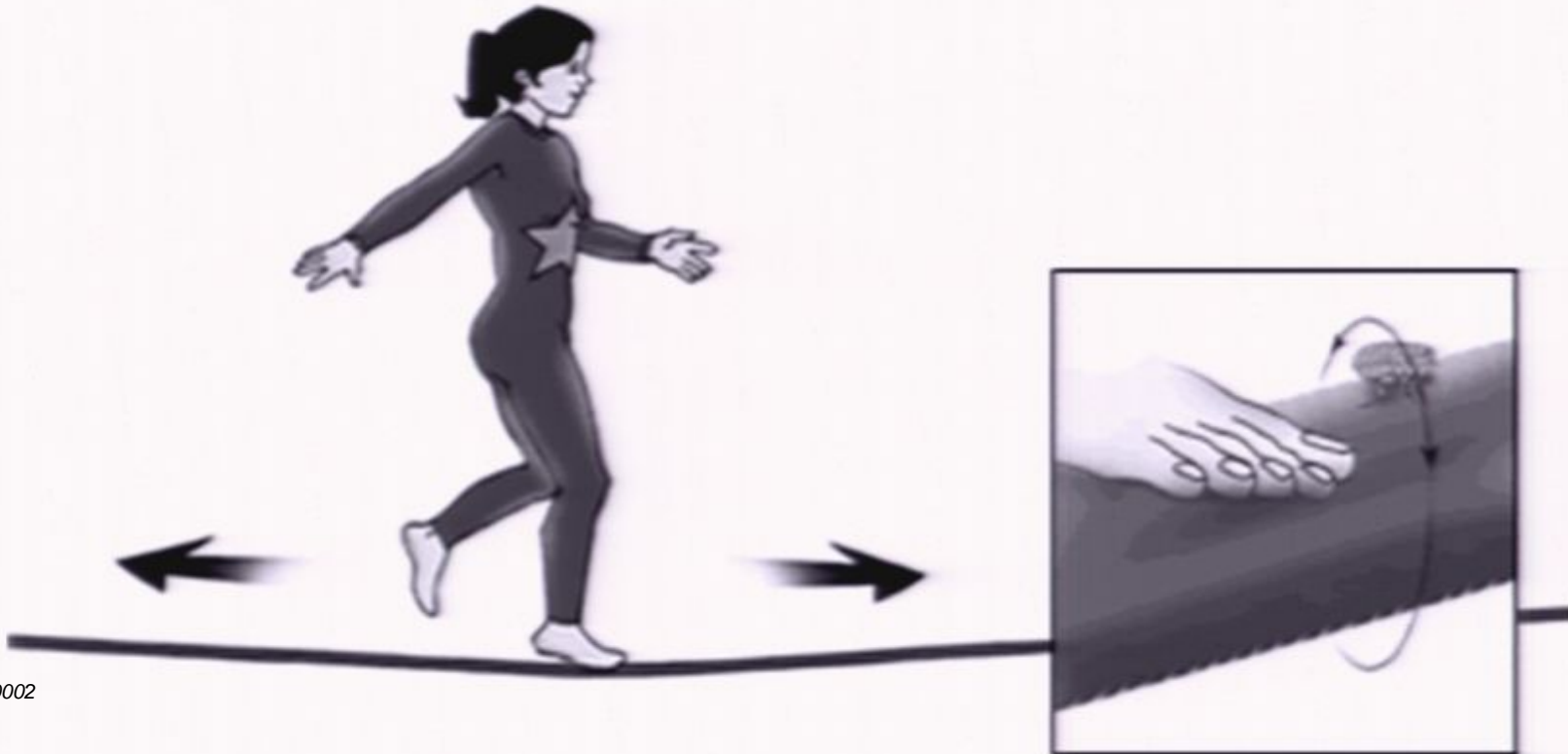


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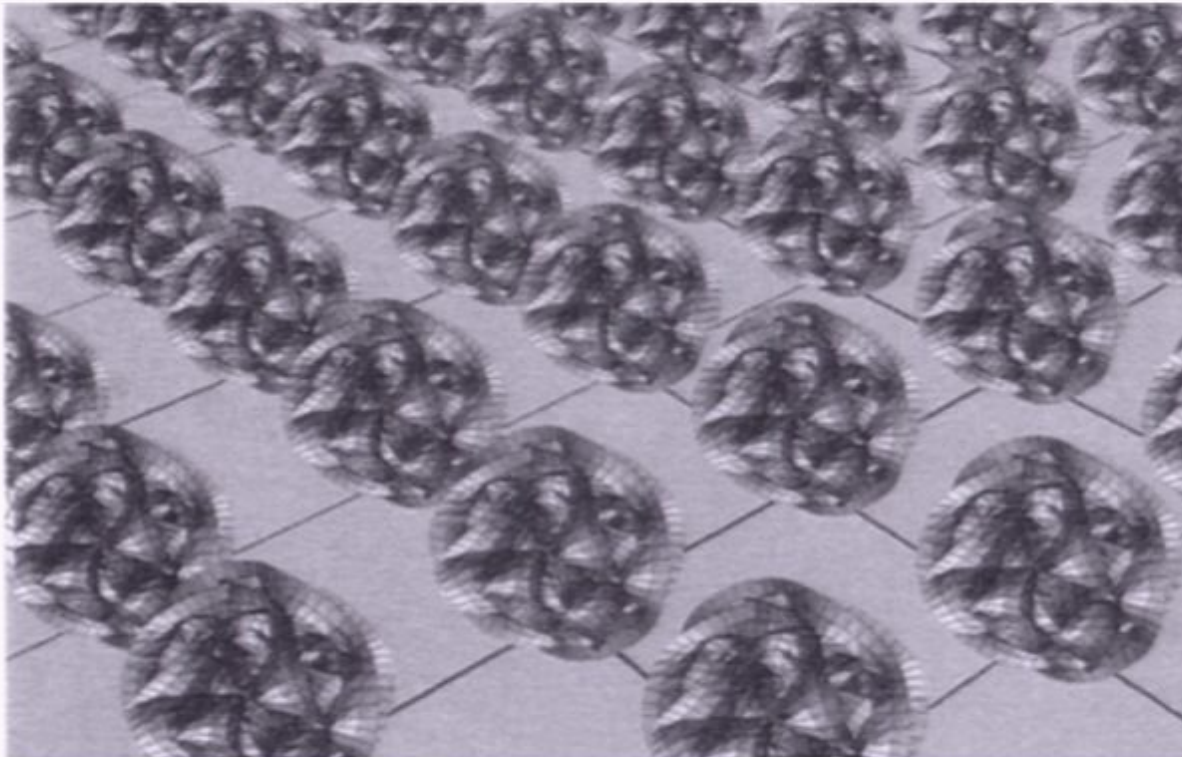


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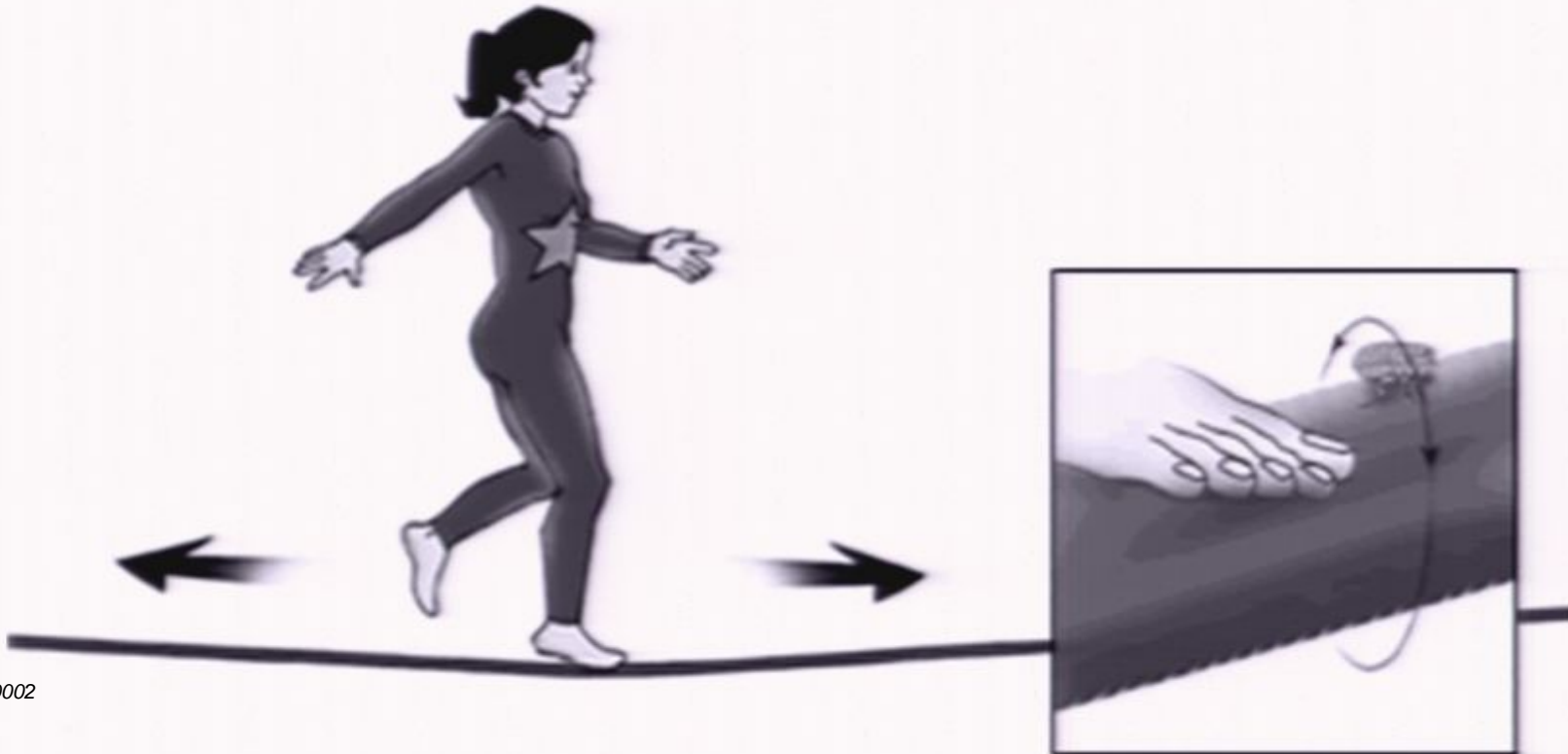


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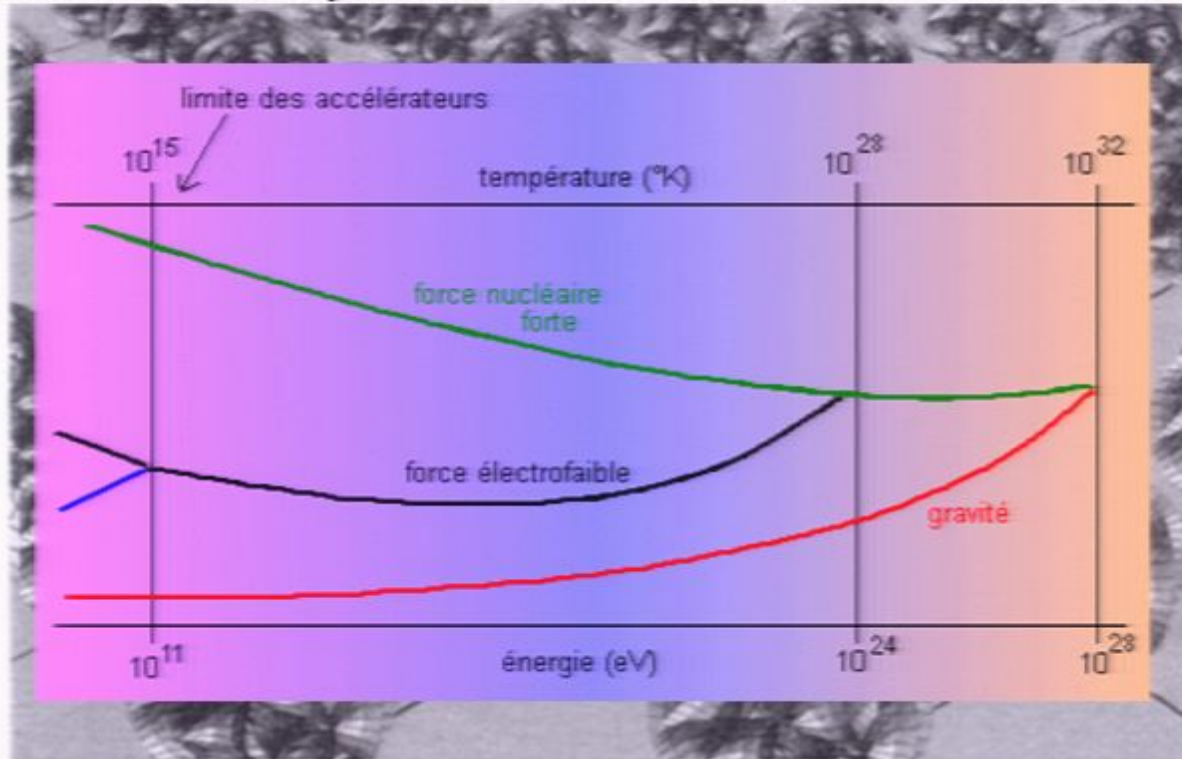
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Benefit: richness of four-dimensional physics comes from geometry of the extra dimensions

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Big fix: Perhaps we should look harder.

Benefit: SUSY tames the short distance (quantum) fluctuations of the theory

Superstring theory: Details, details, details,

- Have **five** consistent superstring theories:
Type I, Type IIA, Type IIB,
Heterotic $E_8 \times E_8$, Heterotic $SO(32)$

one universe \longrightarrow **four** too many theories?!?

Superstring theory: Details, details, details,

- Have **five** consistent superstring theories:
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- Conjecture: all known string theories are different solutions of single fundamental theory

→ M-theory

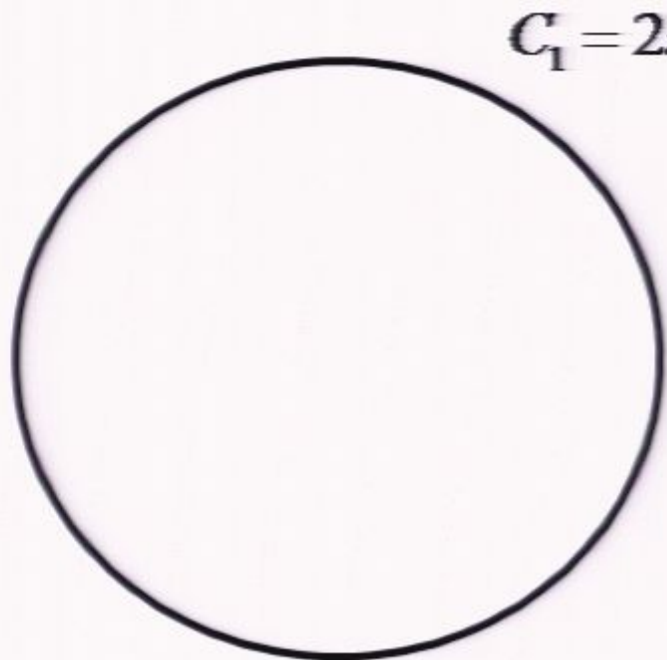
Essential ingredients for M-theory conjecture:

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Eg, T-duality relates large and small circle compactifications



$$C_1 = 2\pi R$$

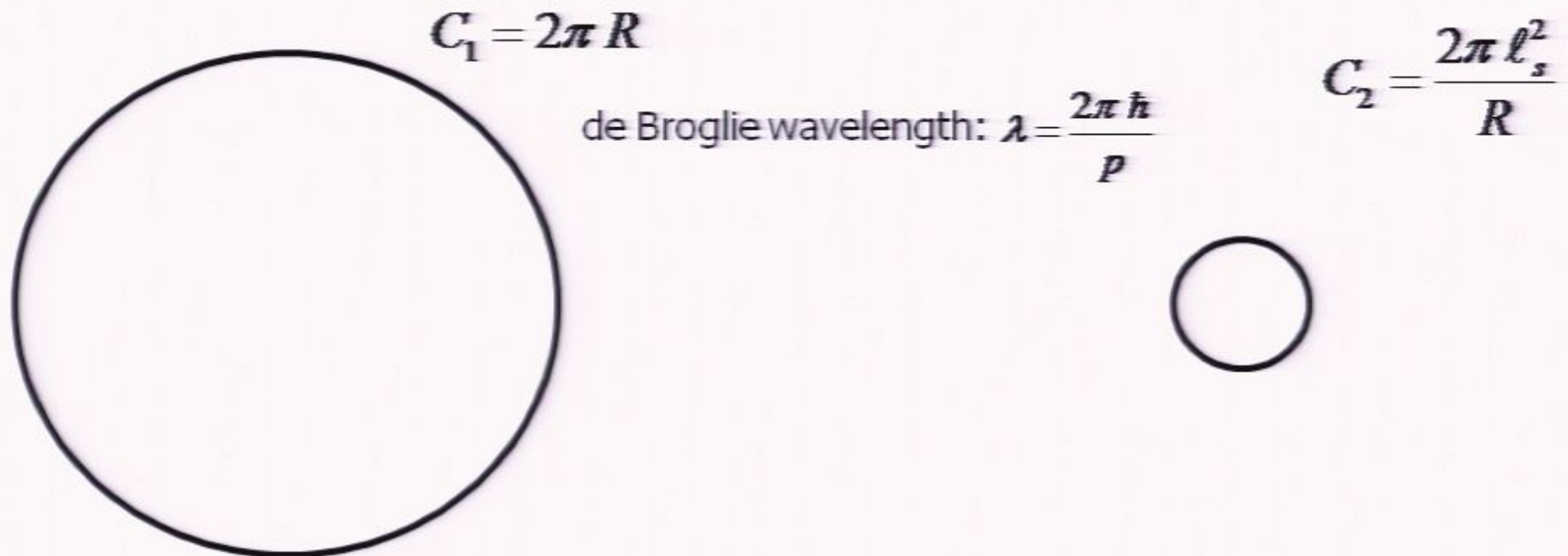


$$C_2 = \frac{2\pi \ell_s^2}{R}$$

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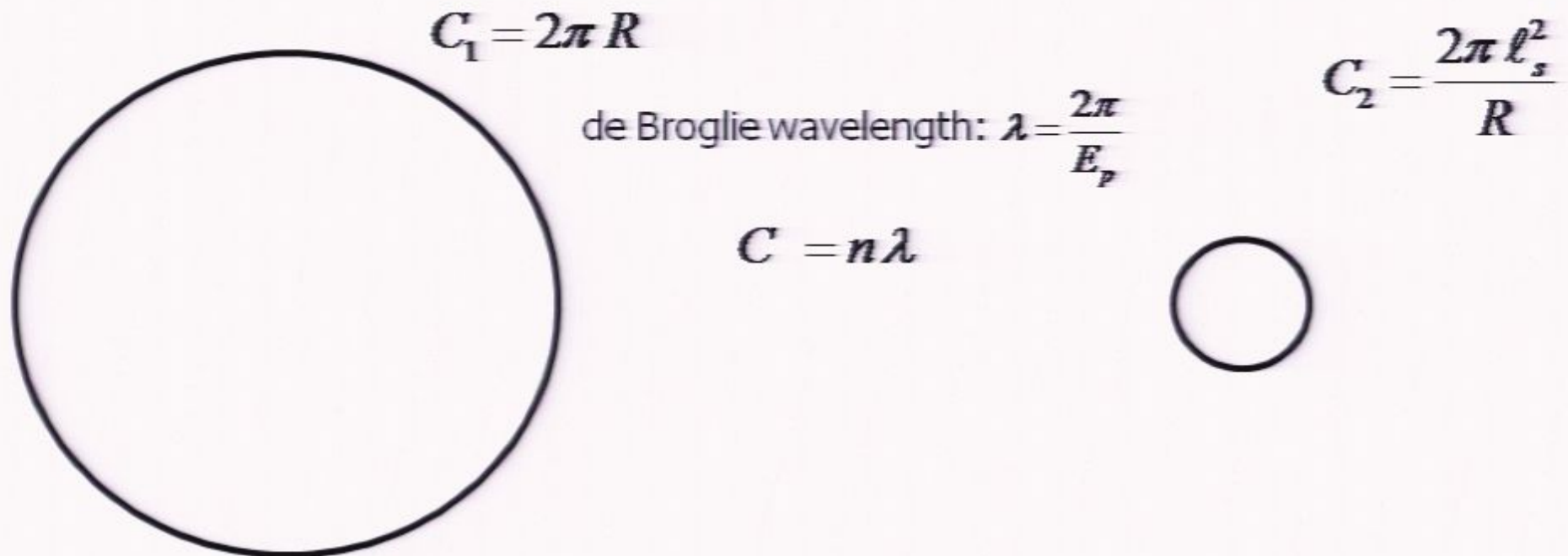
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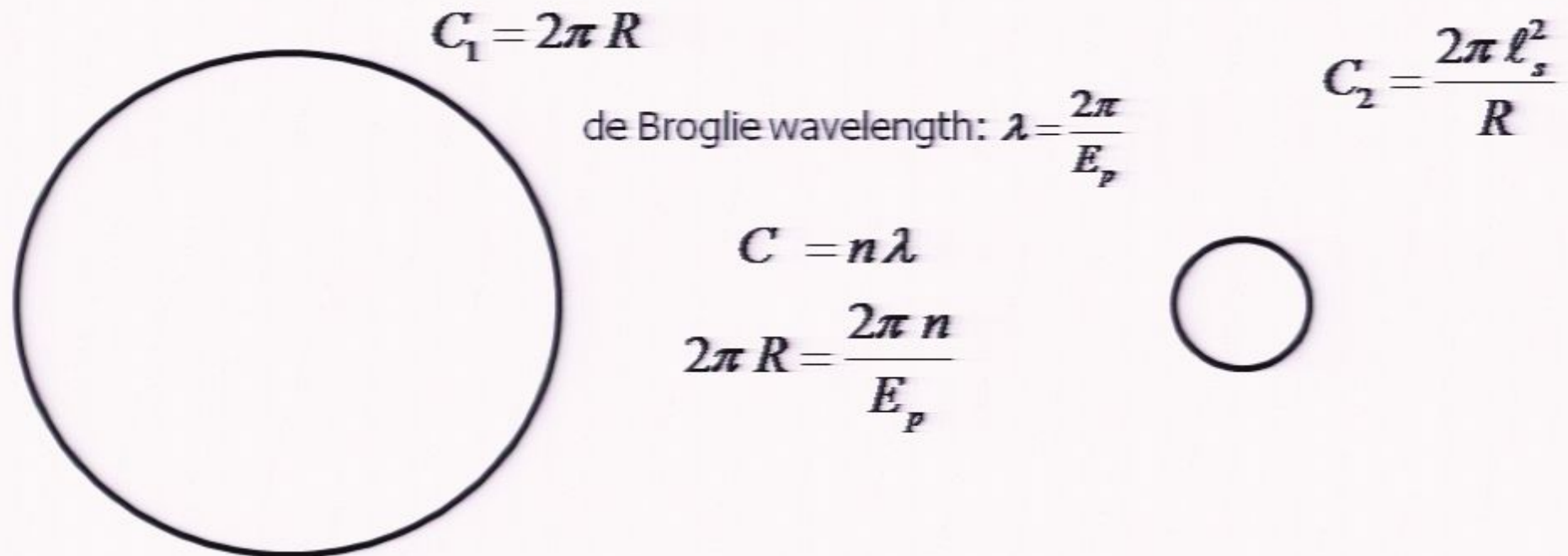
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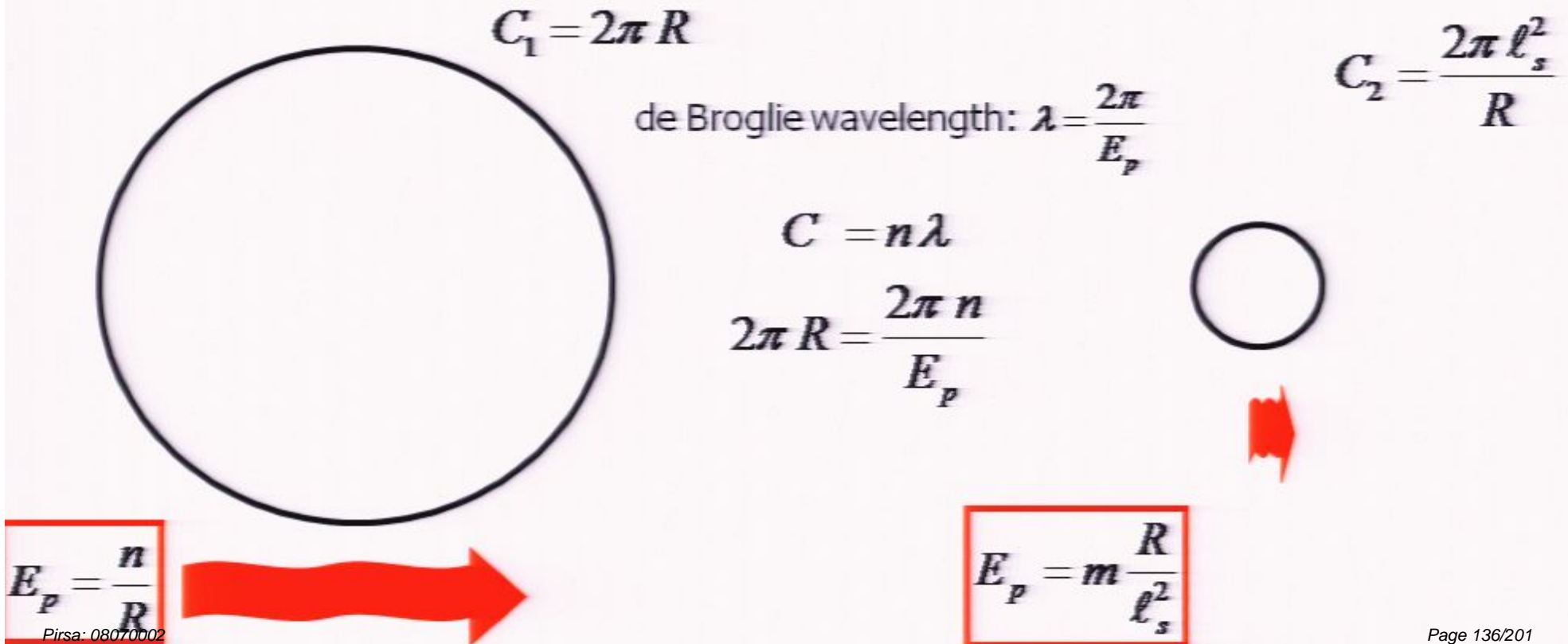
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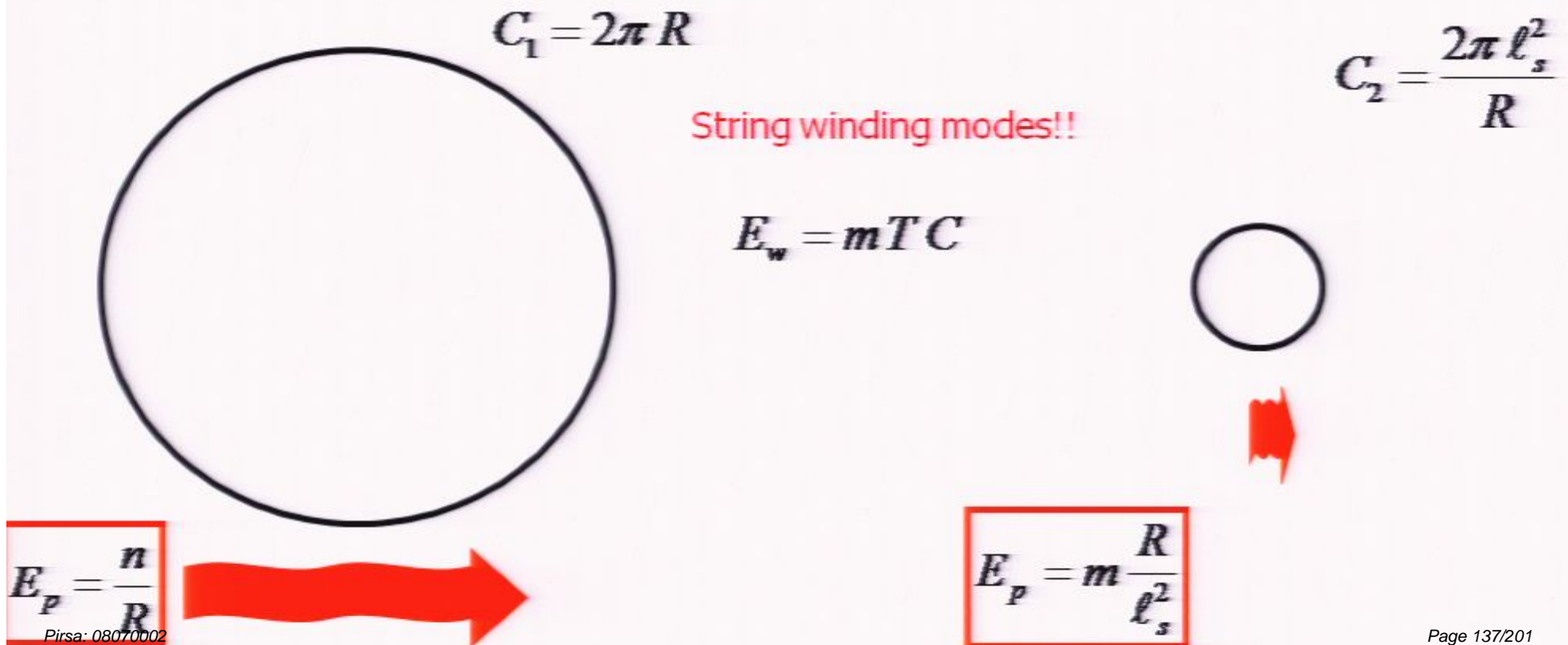
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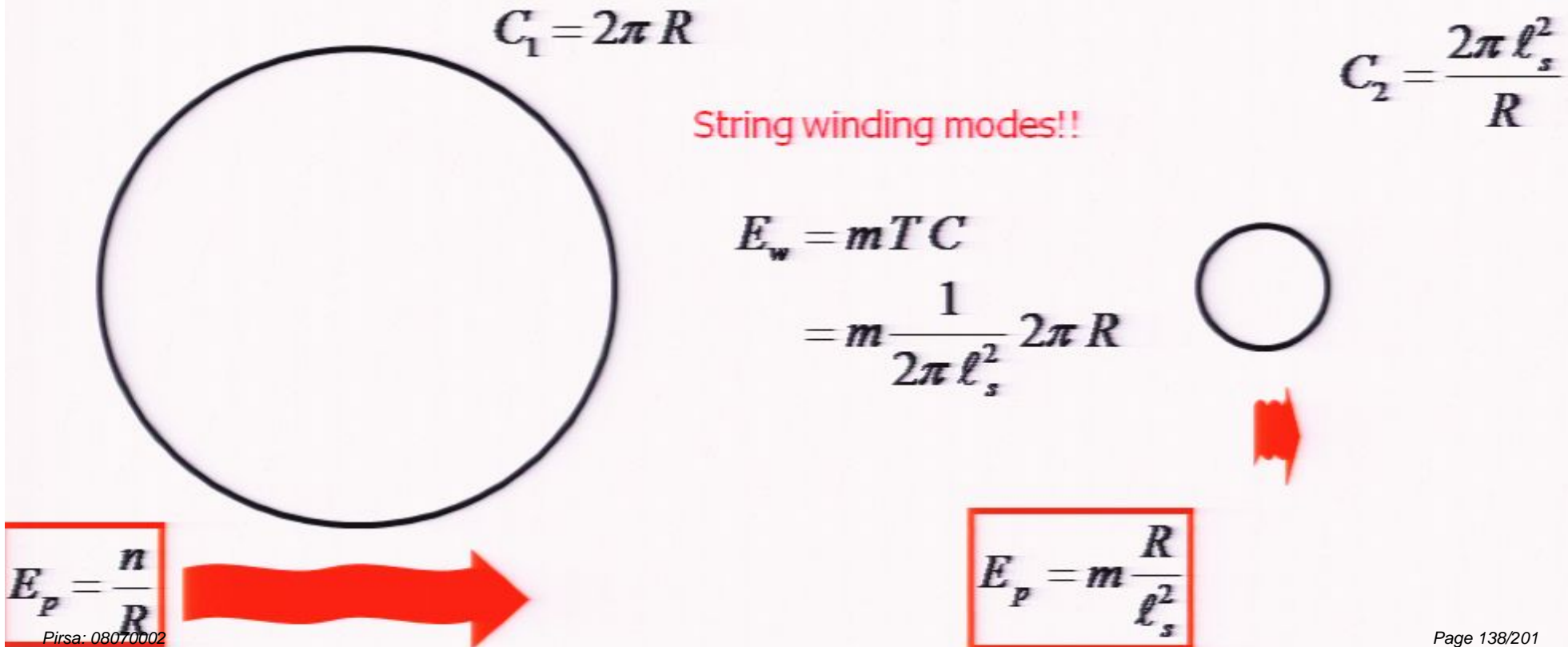
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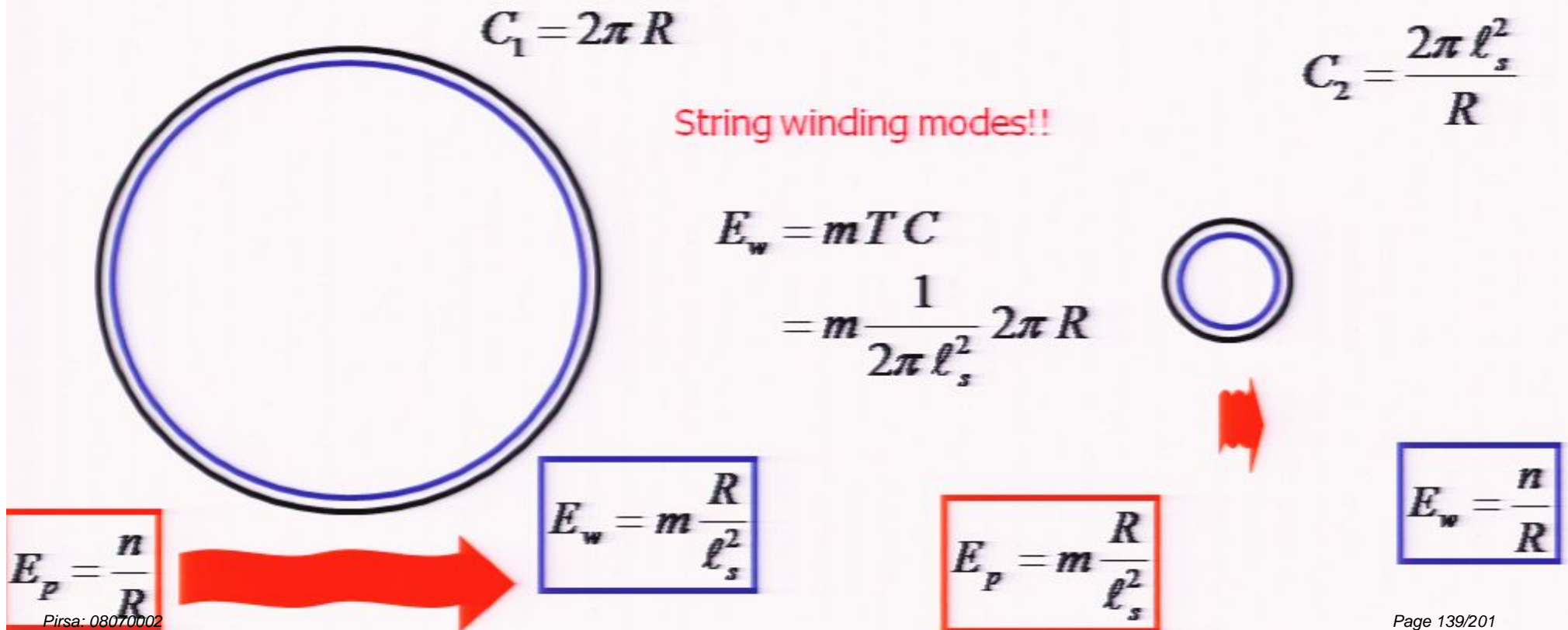
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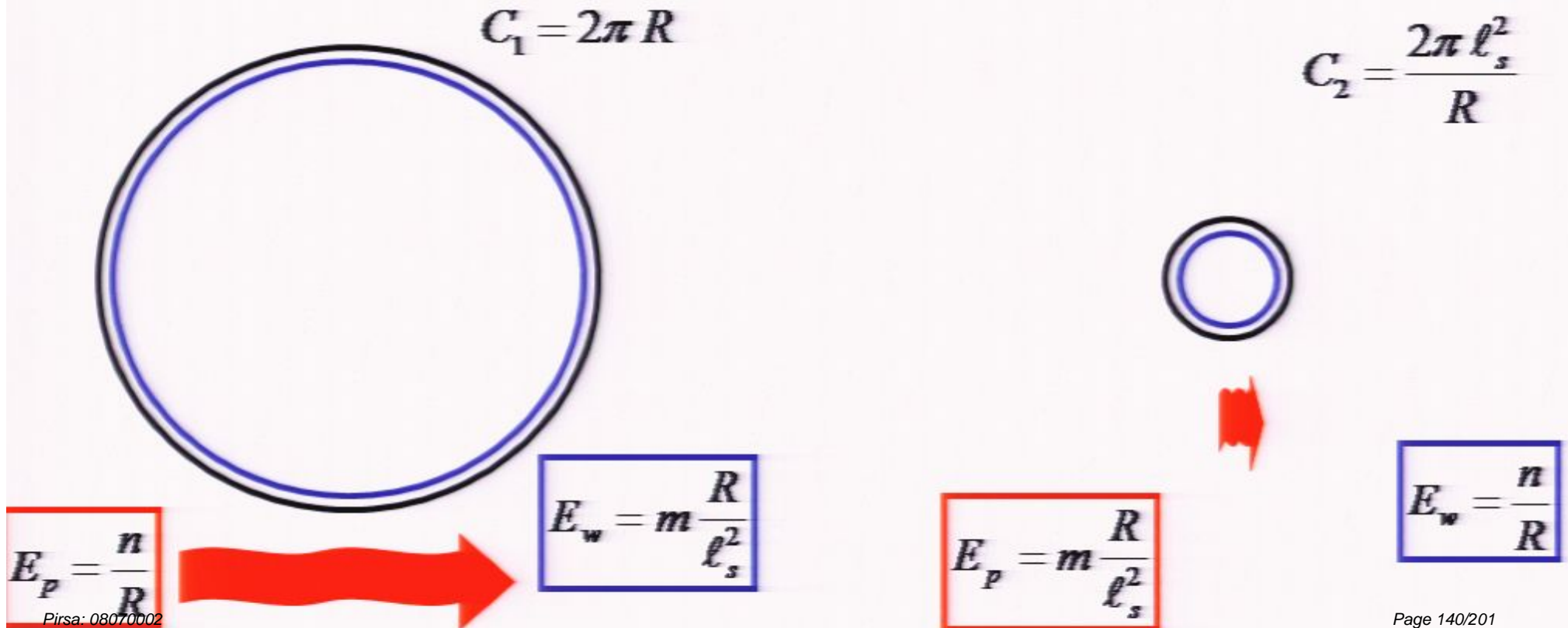
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String theory is more than a theory of strings!

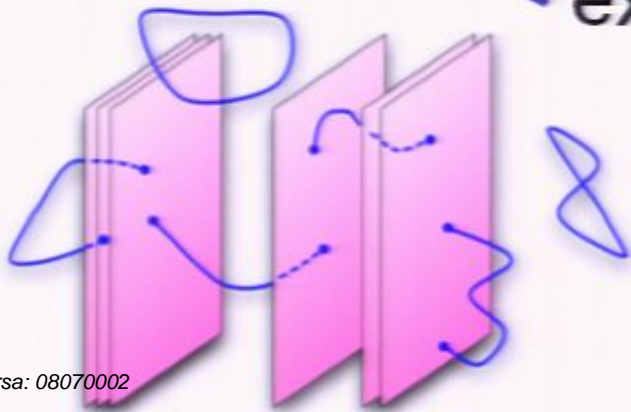
- D-branes: string theory contains other kinds of objects extended in 0, 1, 2, ... dimensions



$$T_p = \frac{2\pi}{(2\pi\ell_s)^{p+1}} g$$

← extremely heavy in **weak** coupling

← extremely important in **strong** coupling



Superstring theory: Unique theory of everything

- **M-theory** Conjecture: all known string theories are different solutions of single fundamental theory

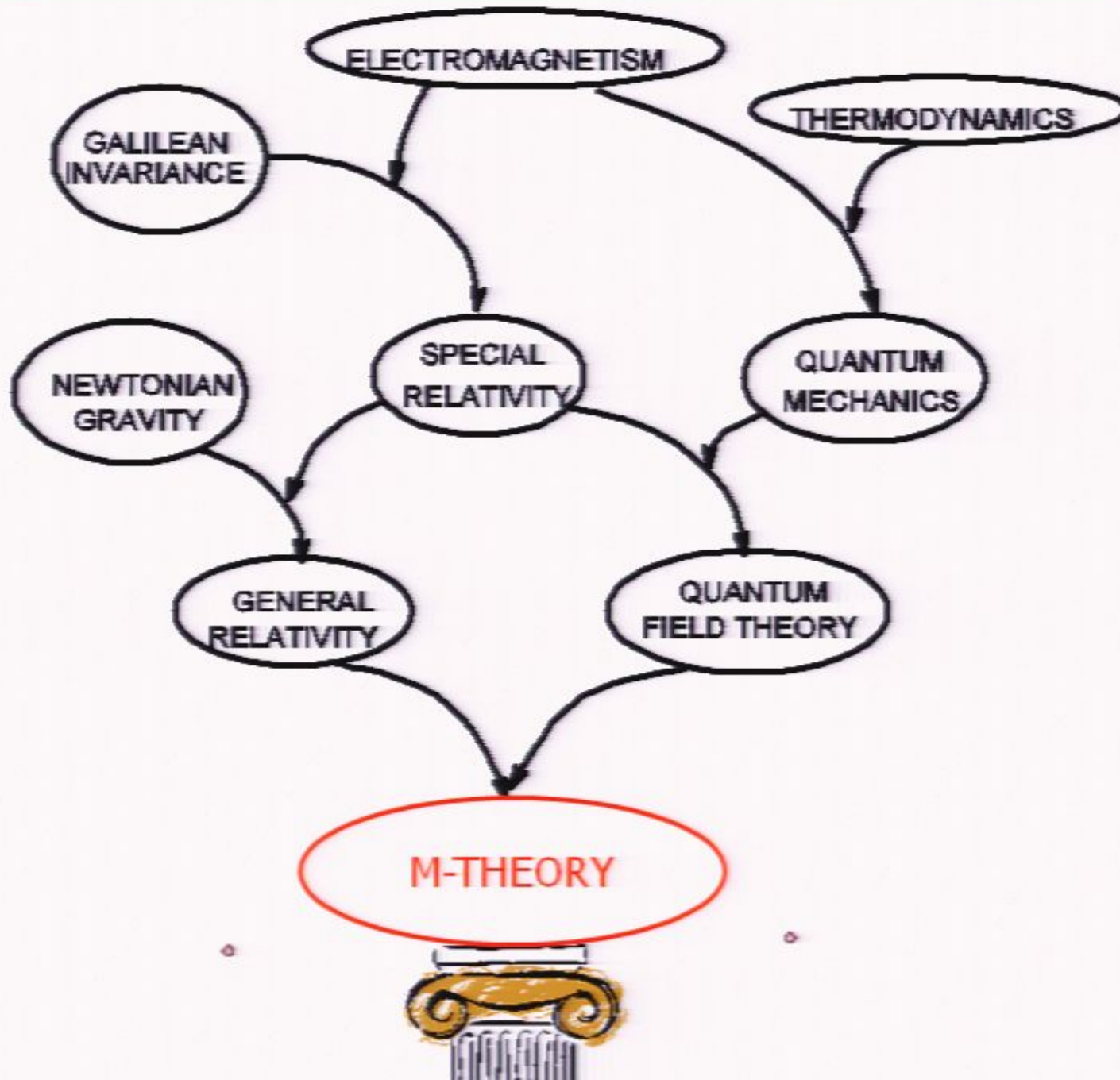


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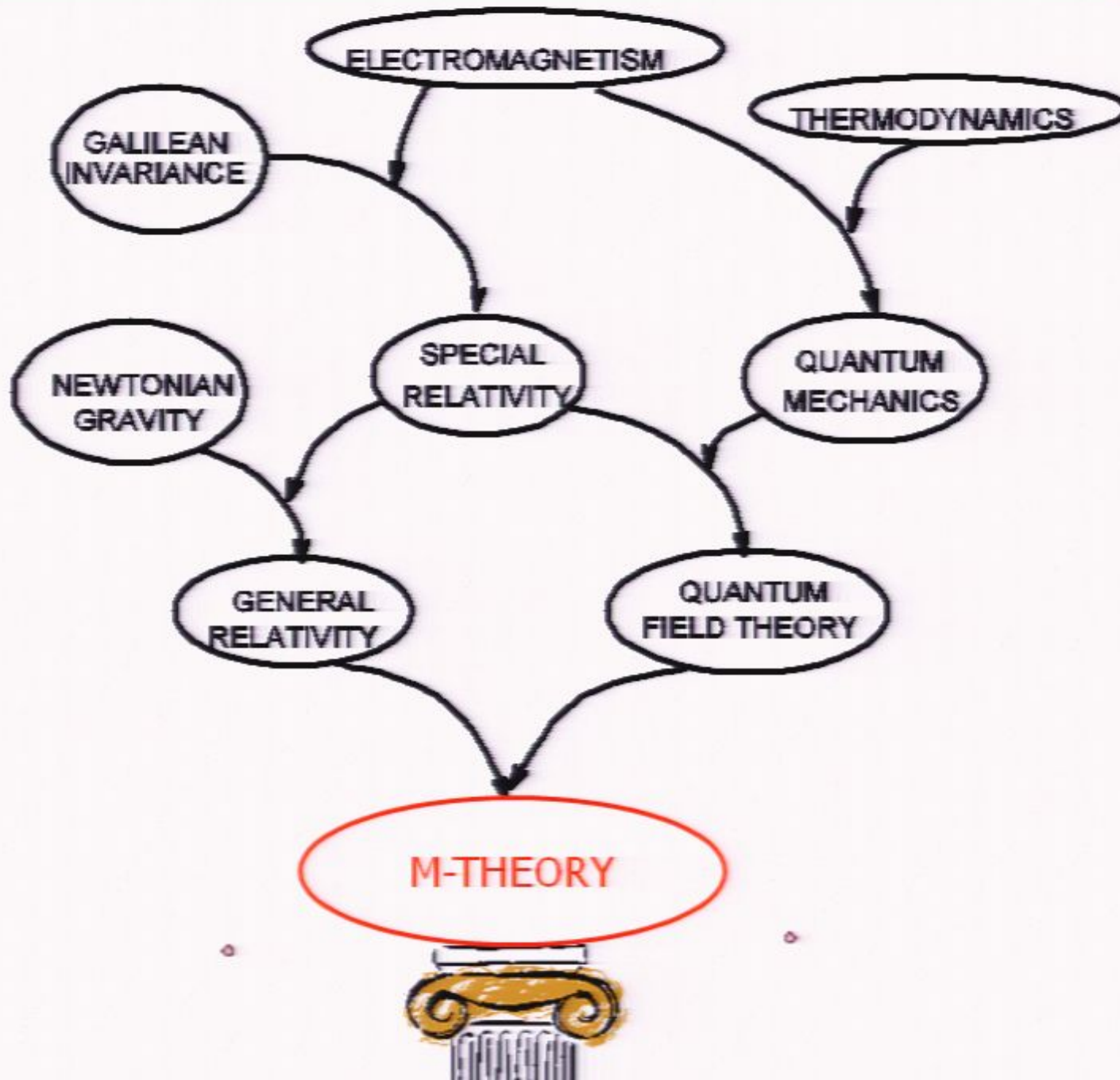
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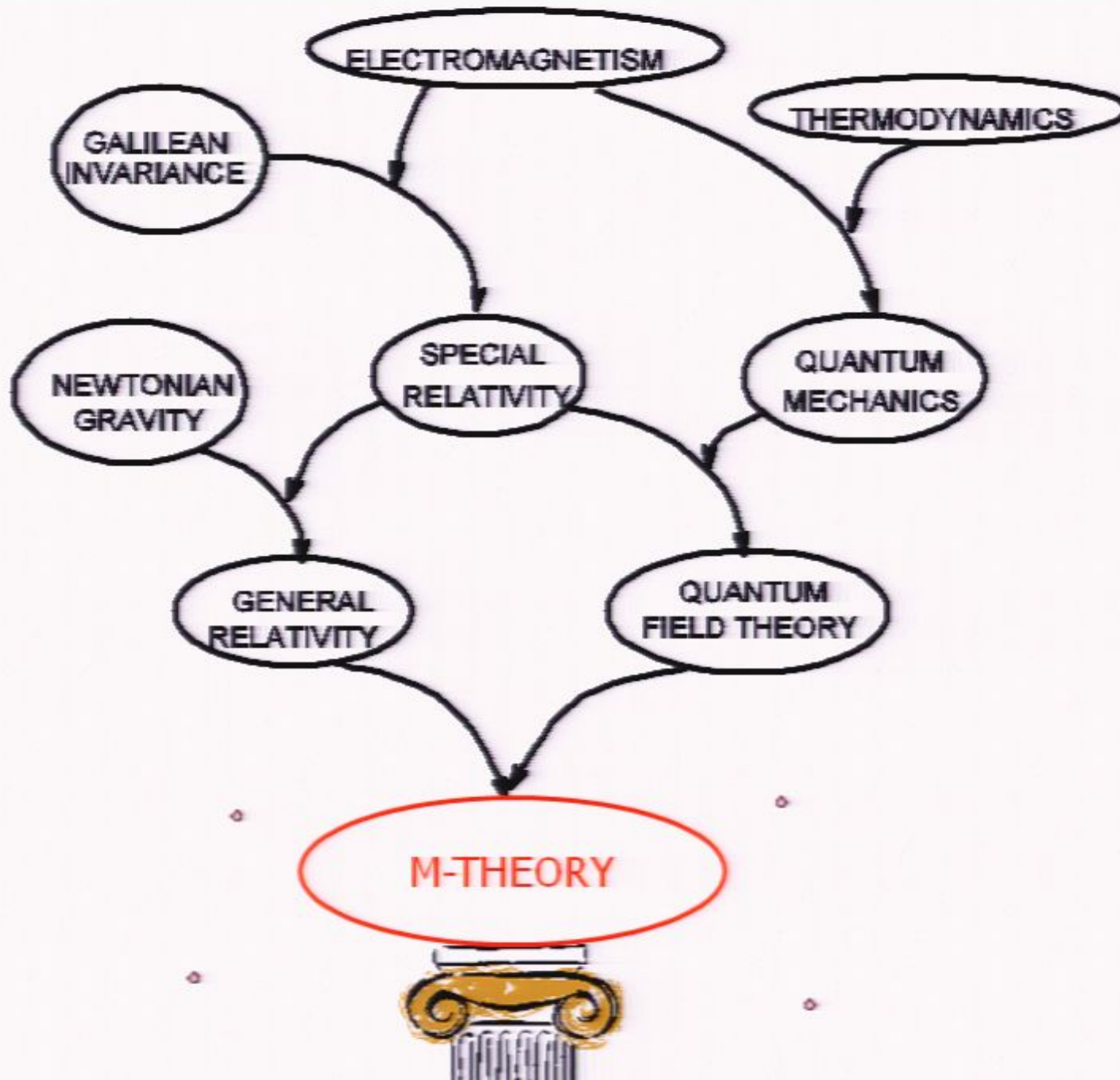
String/M-theory is a rich source of new ideas



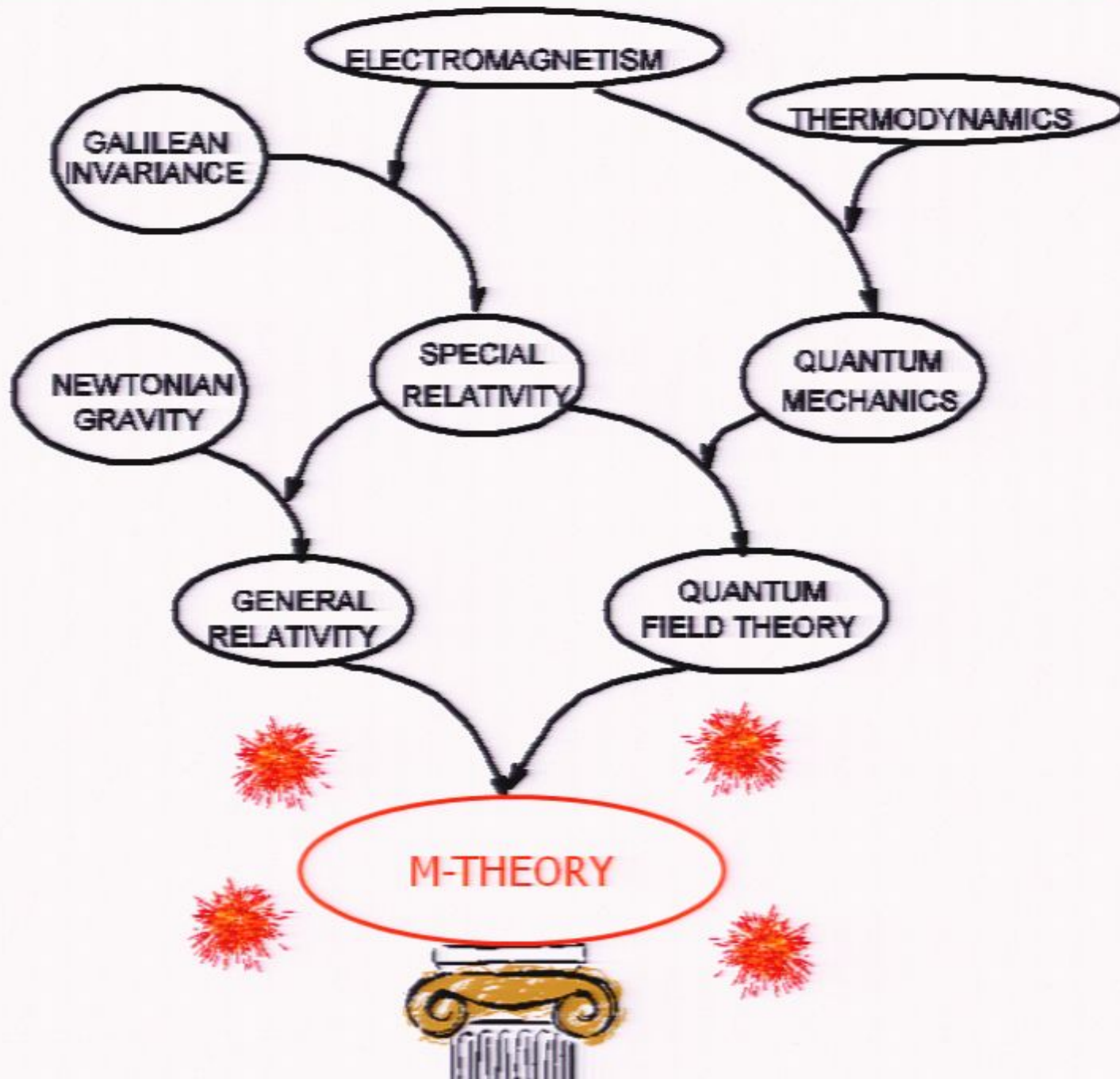
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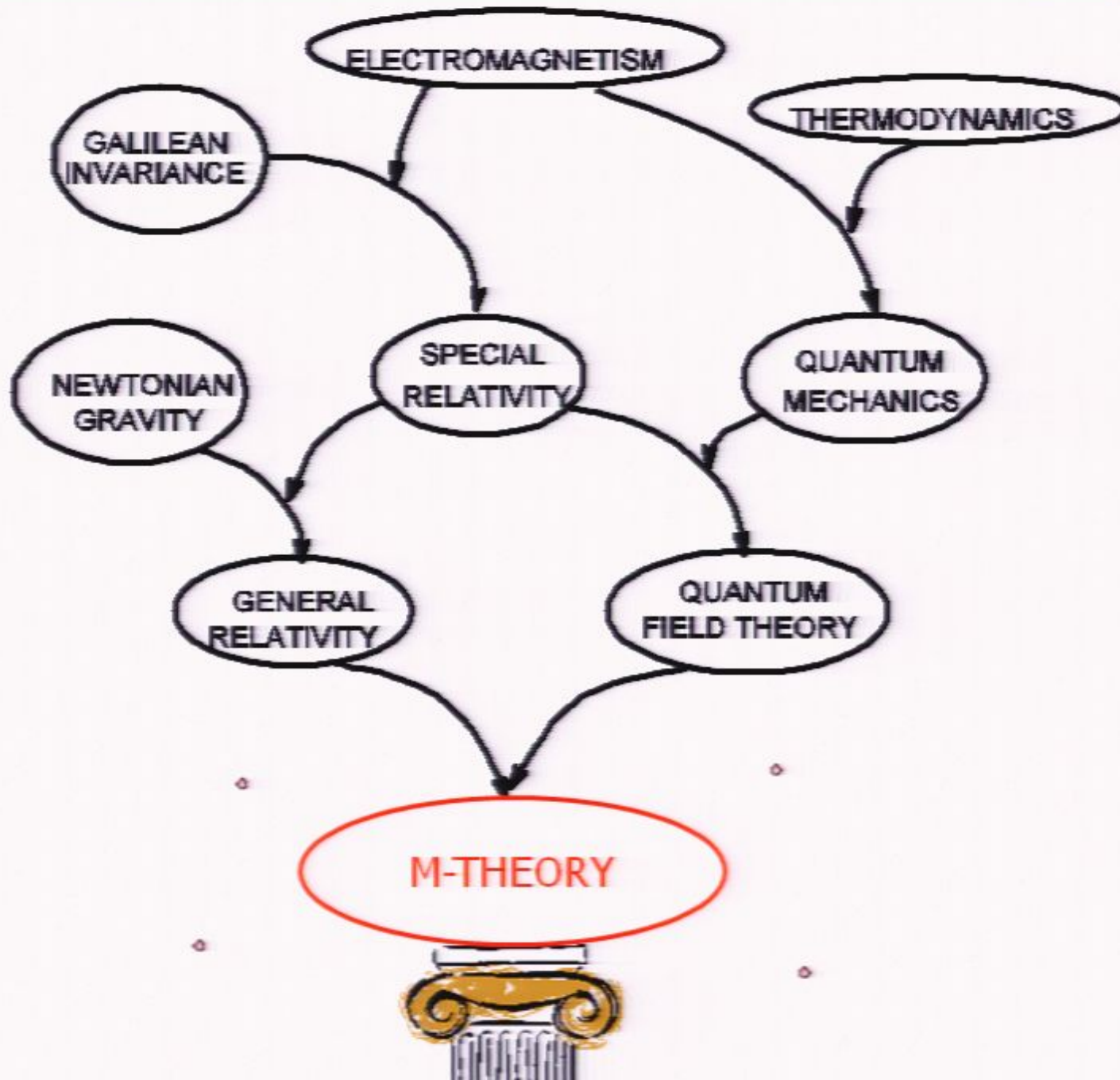
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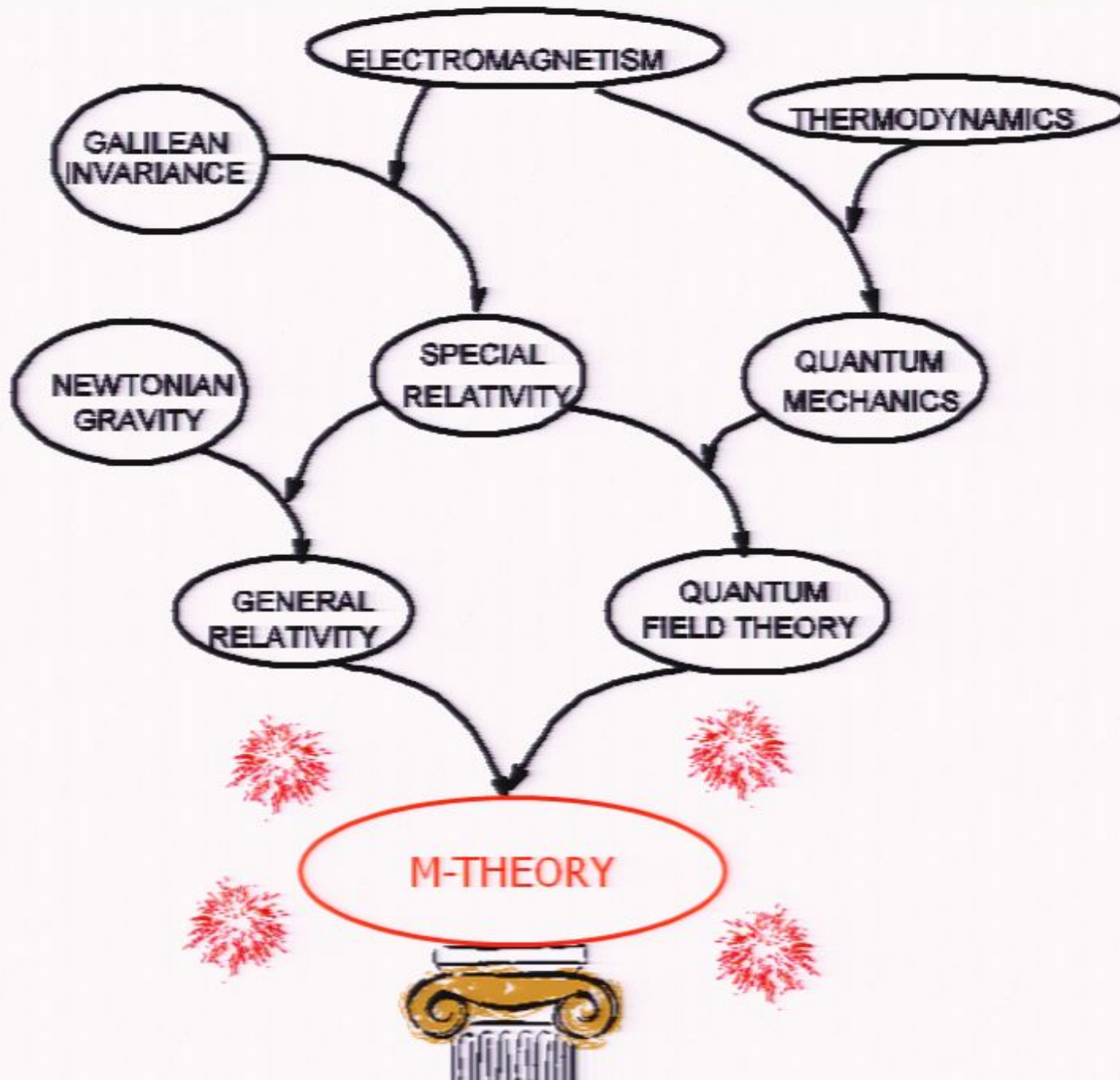
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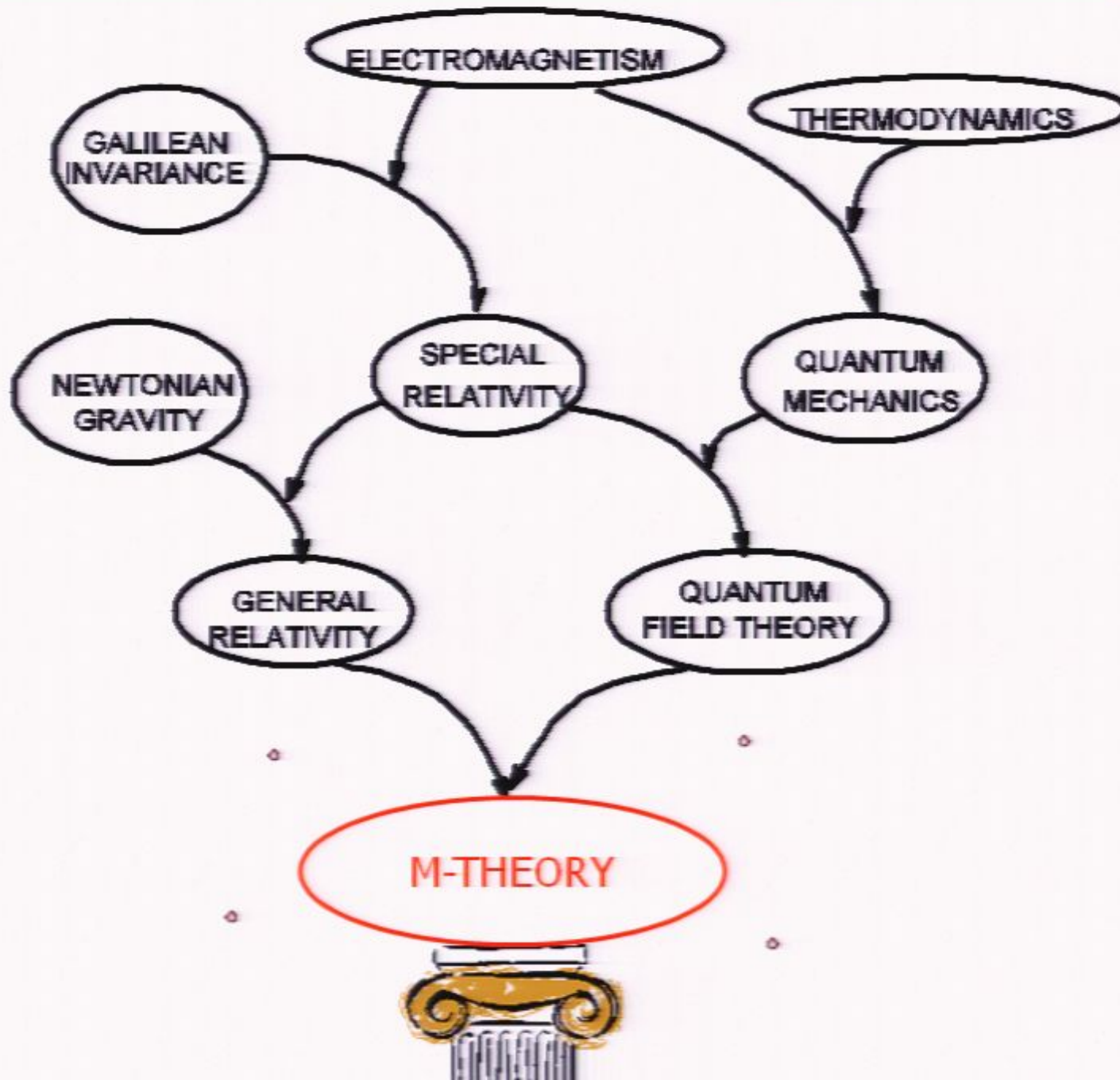
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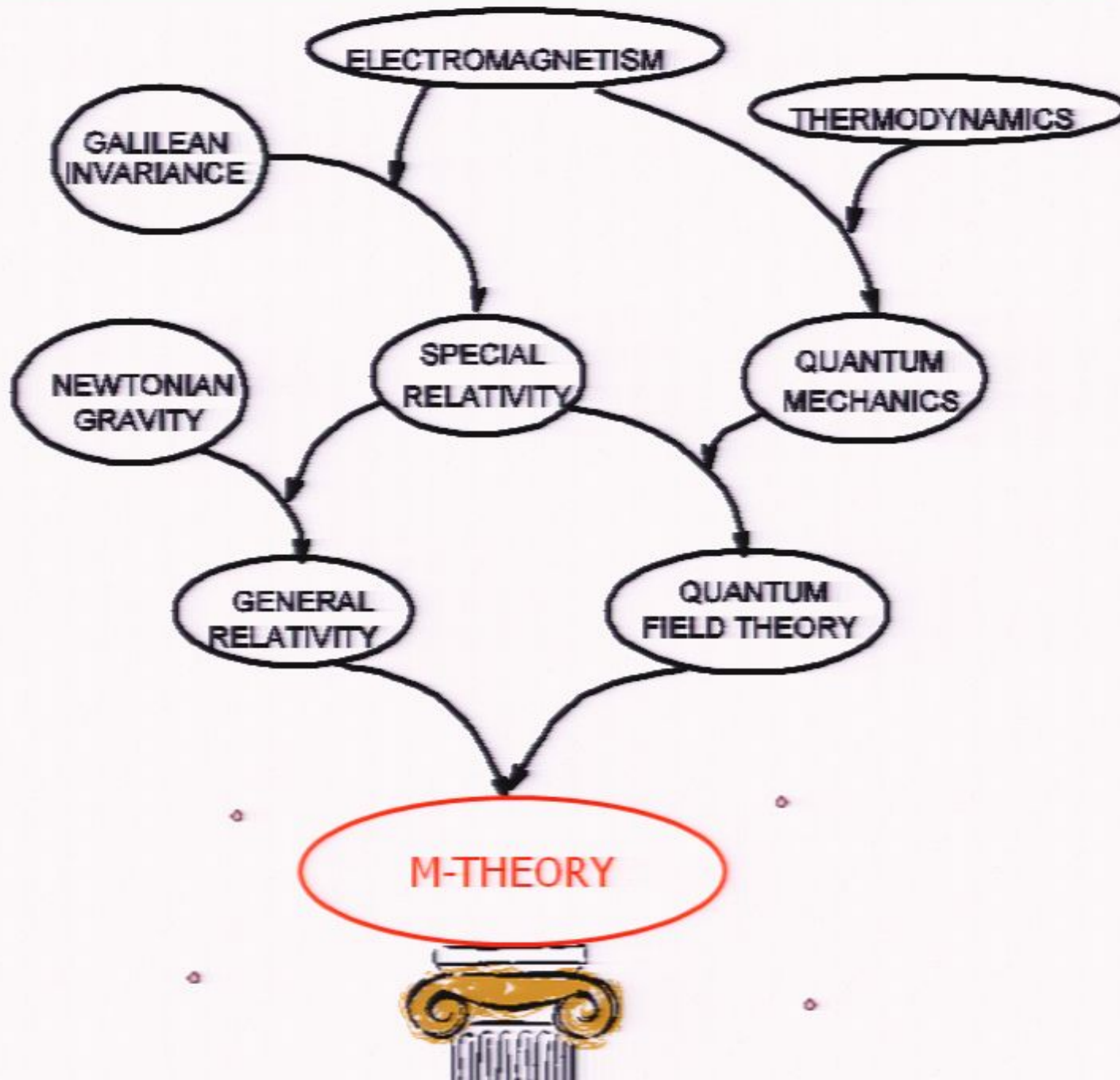
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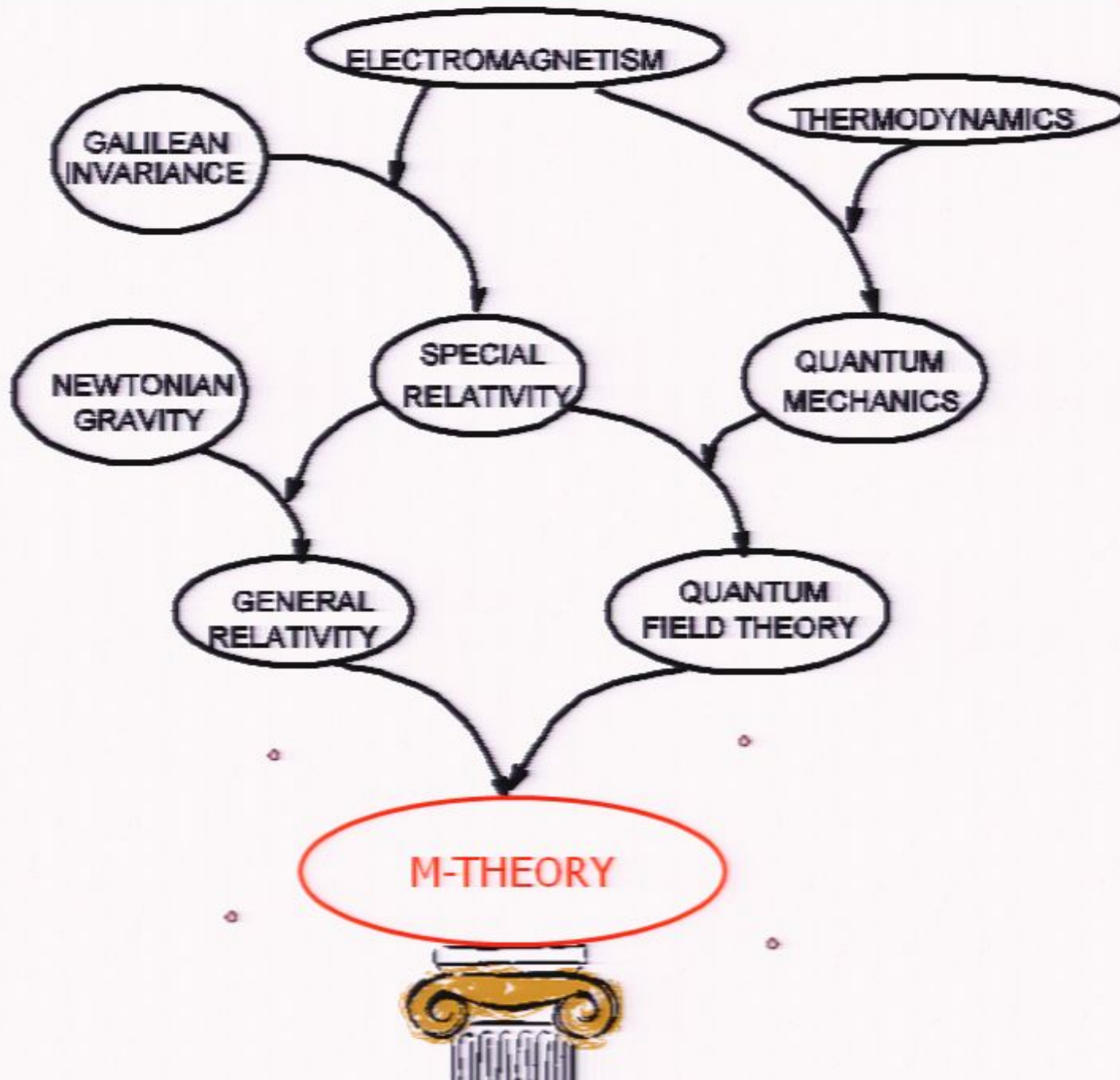
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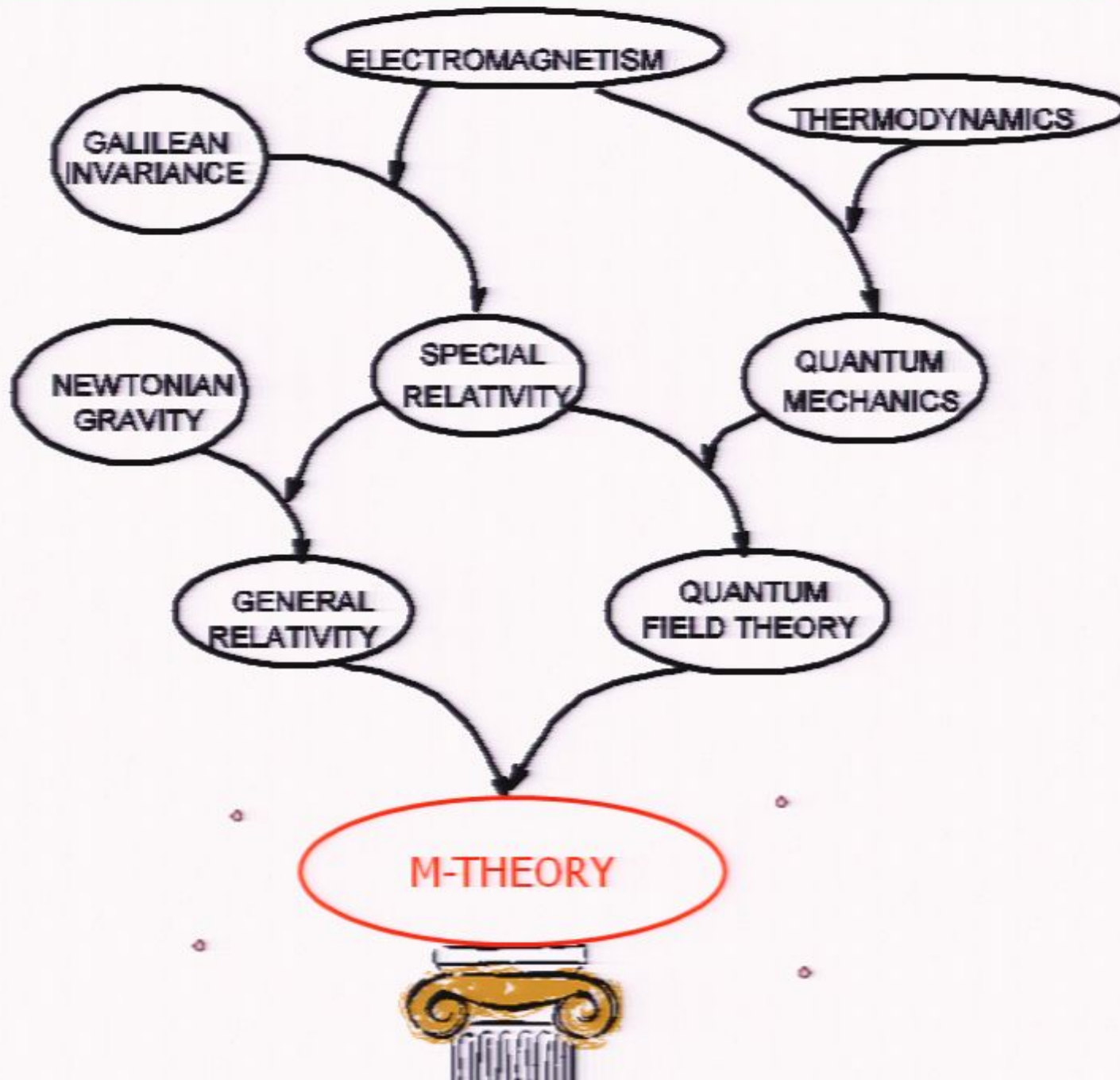
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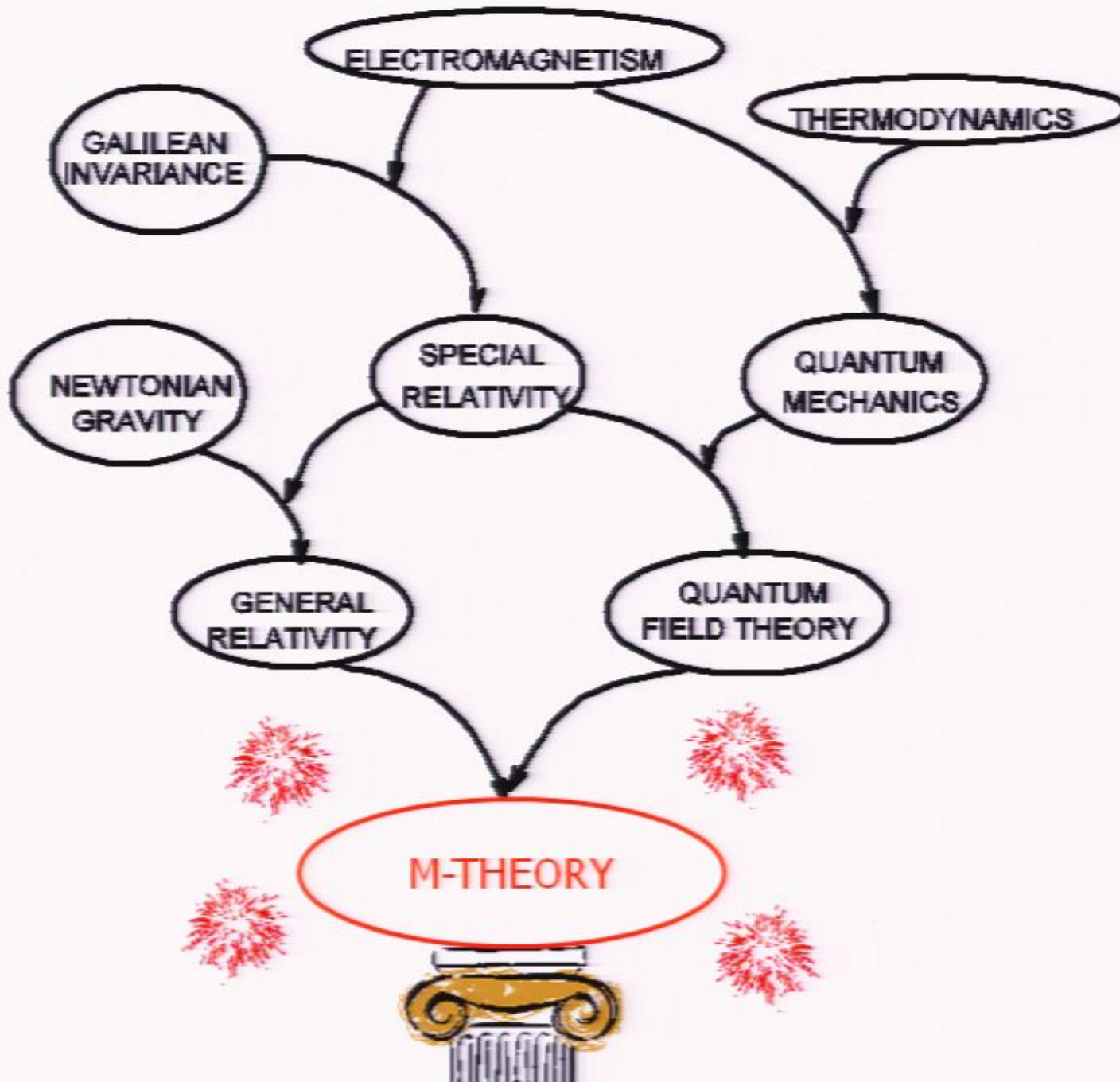
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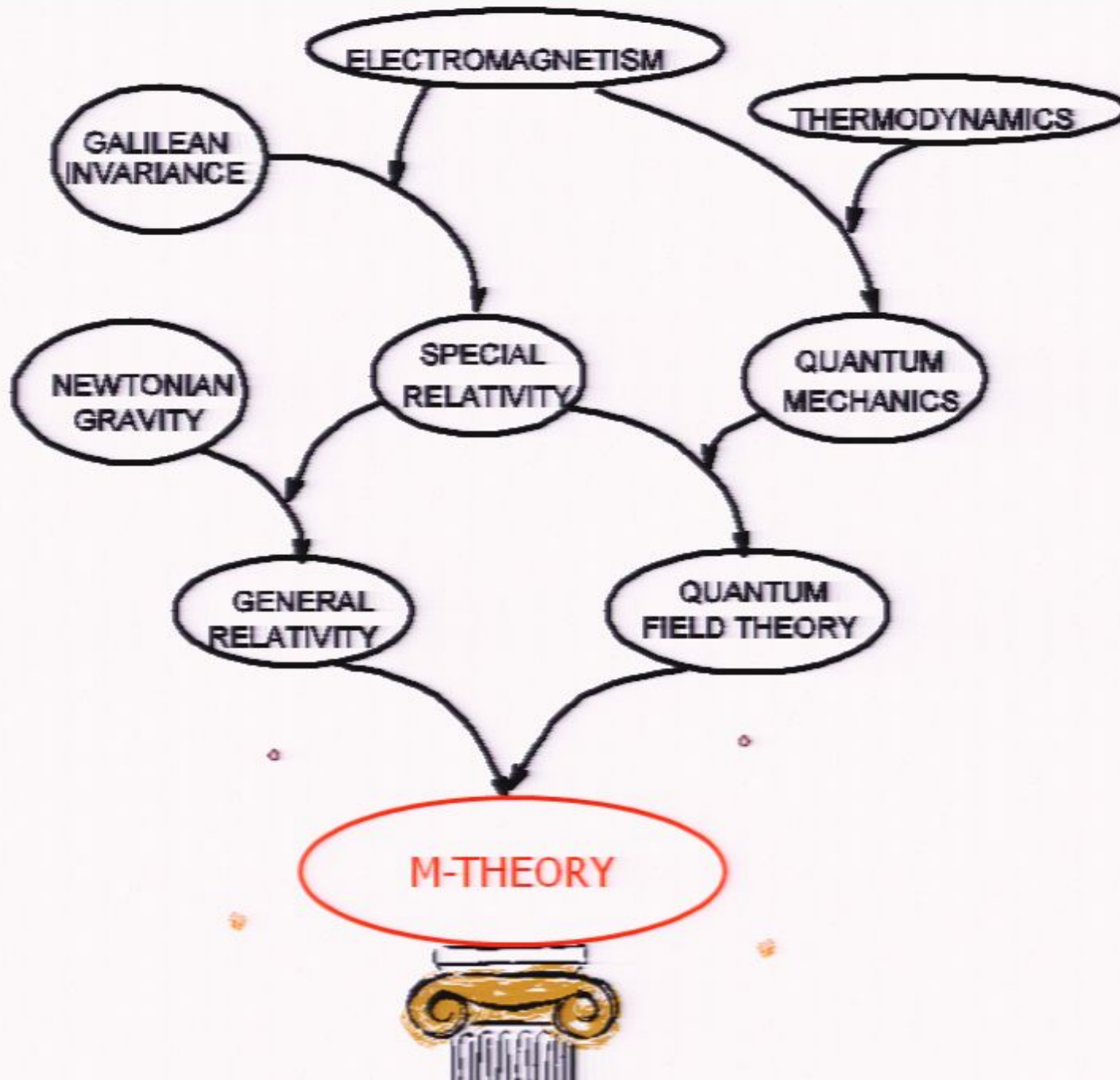
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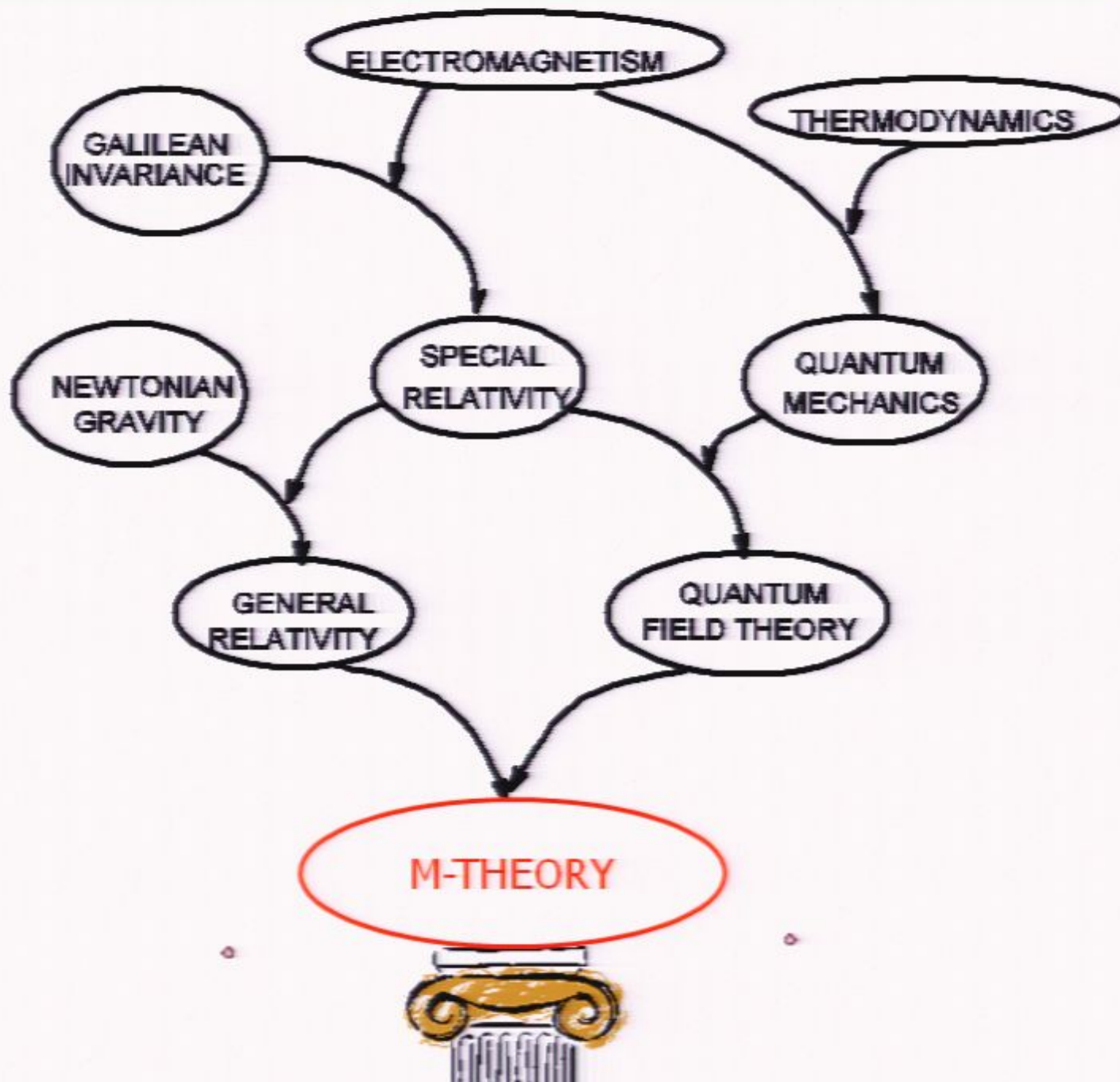
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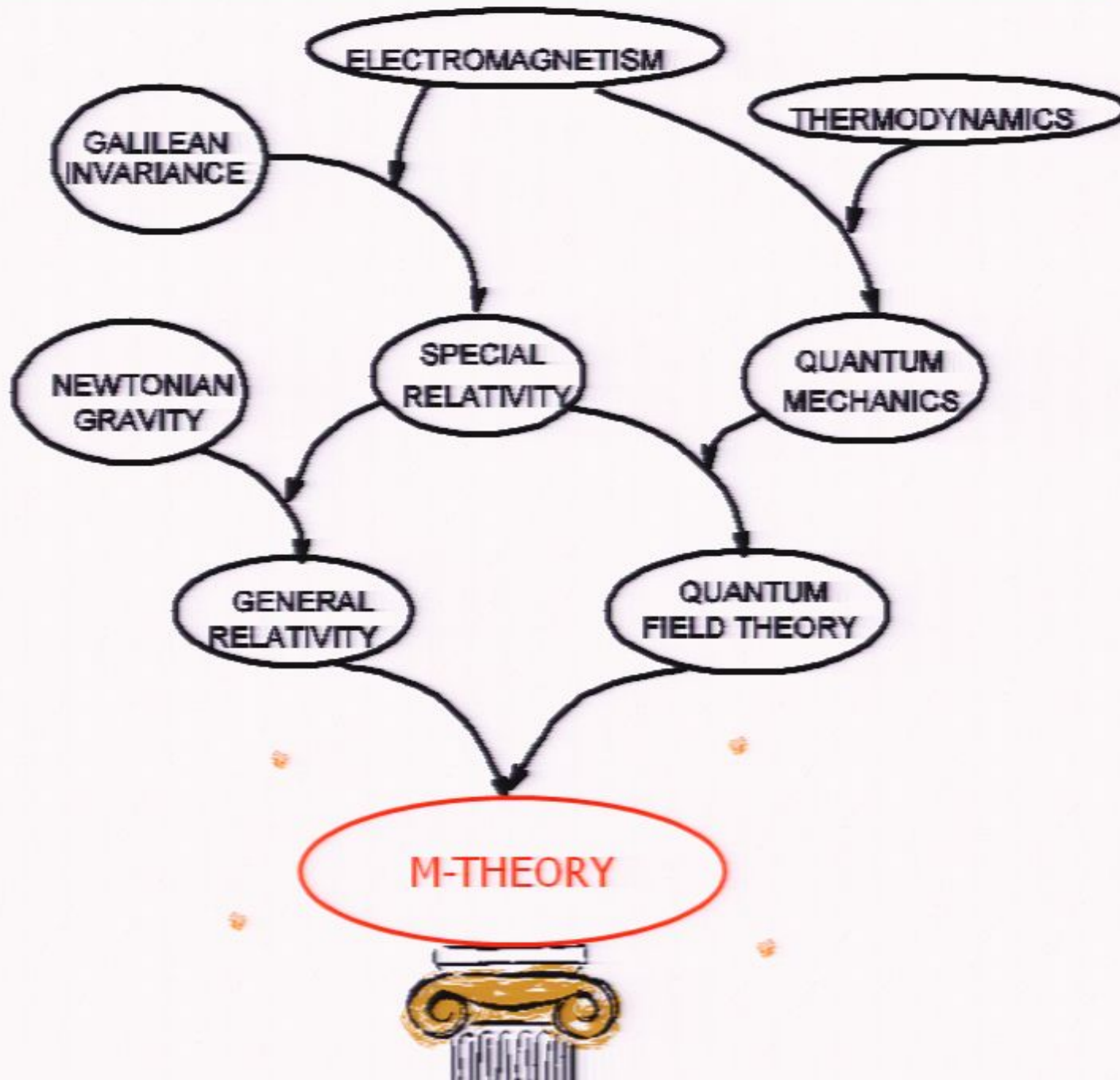
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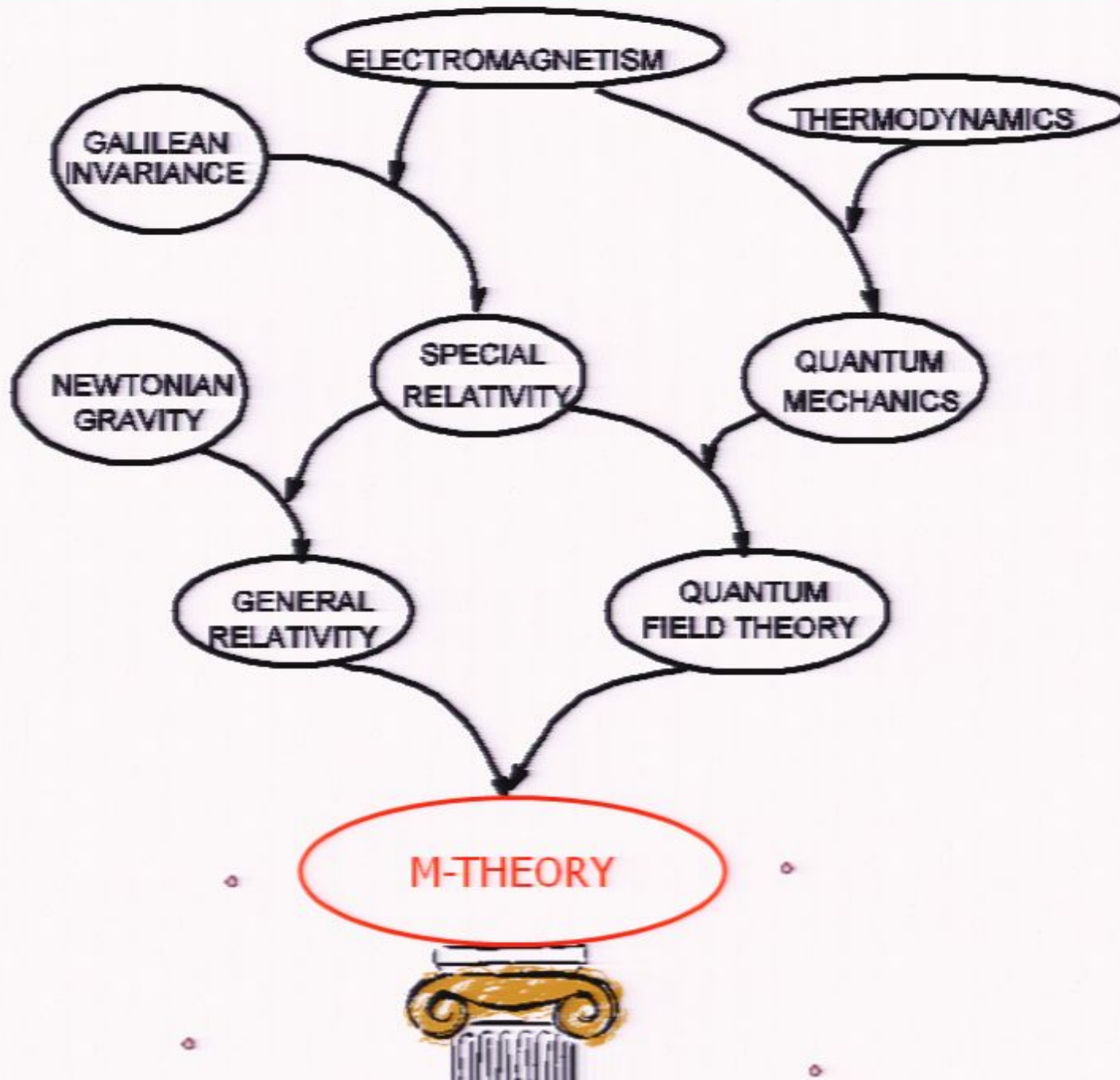
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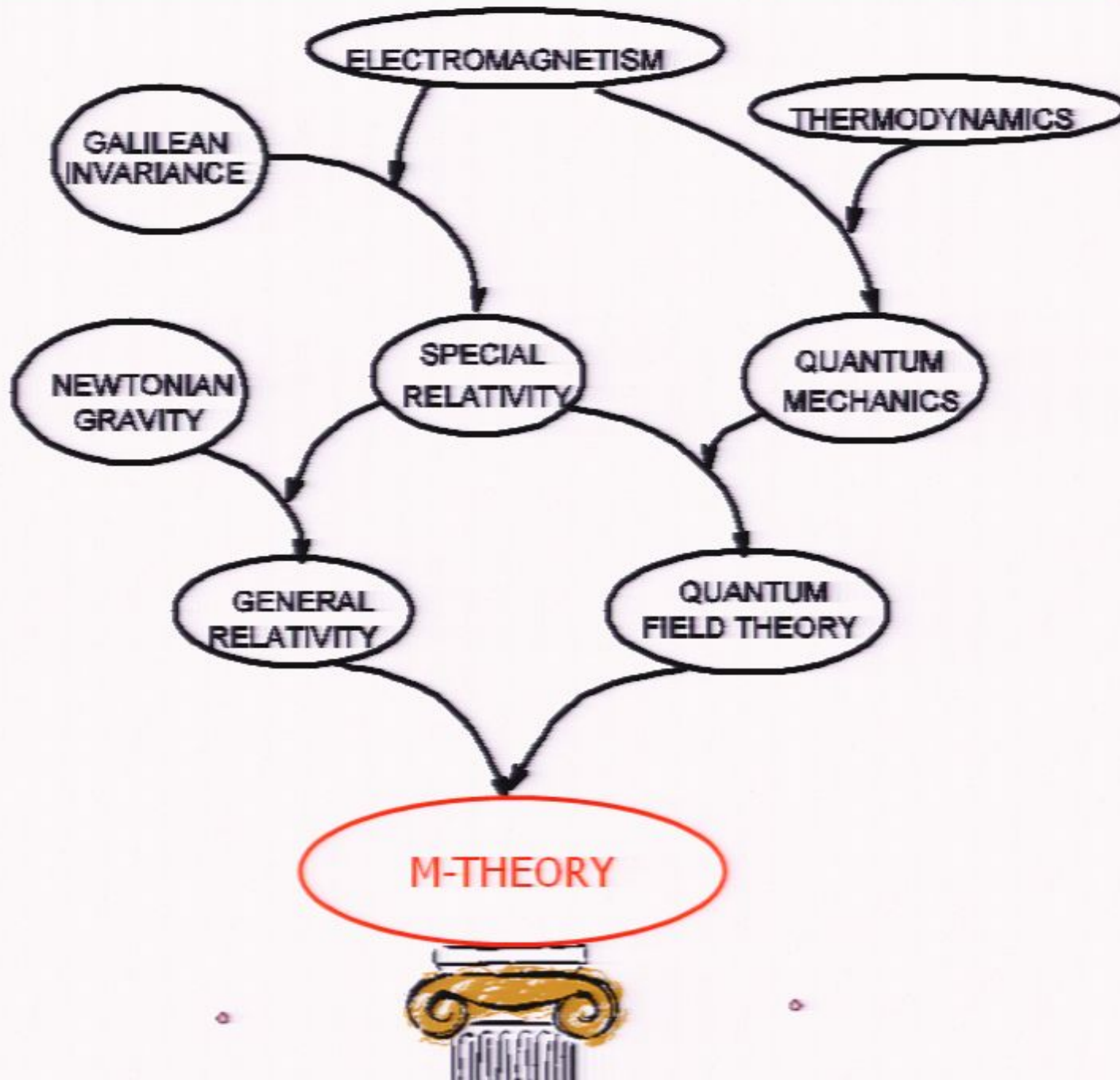
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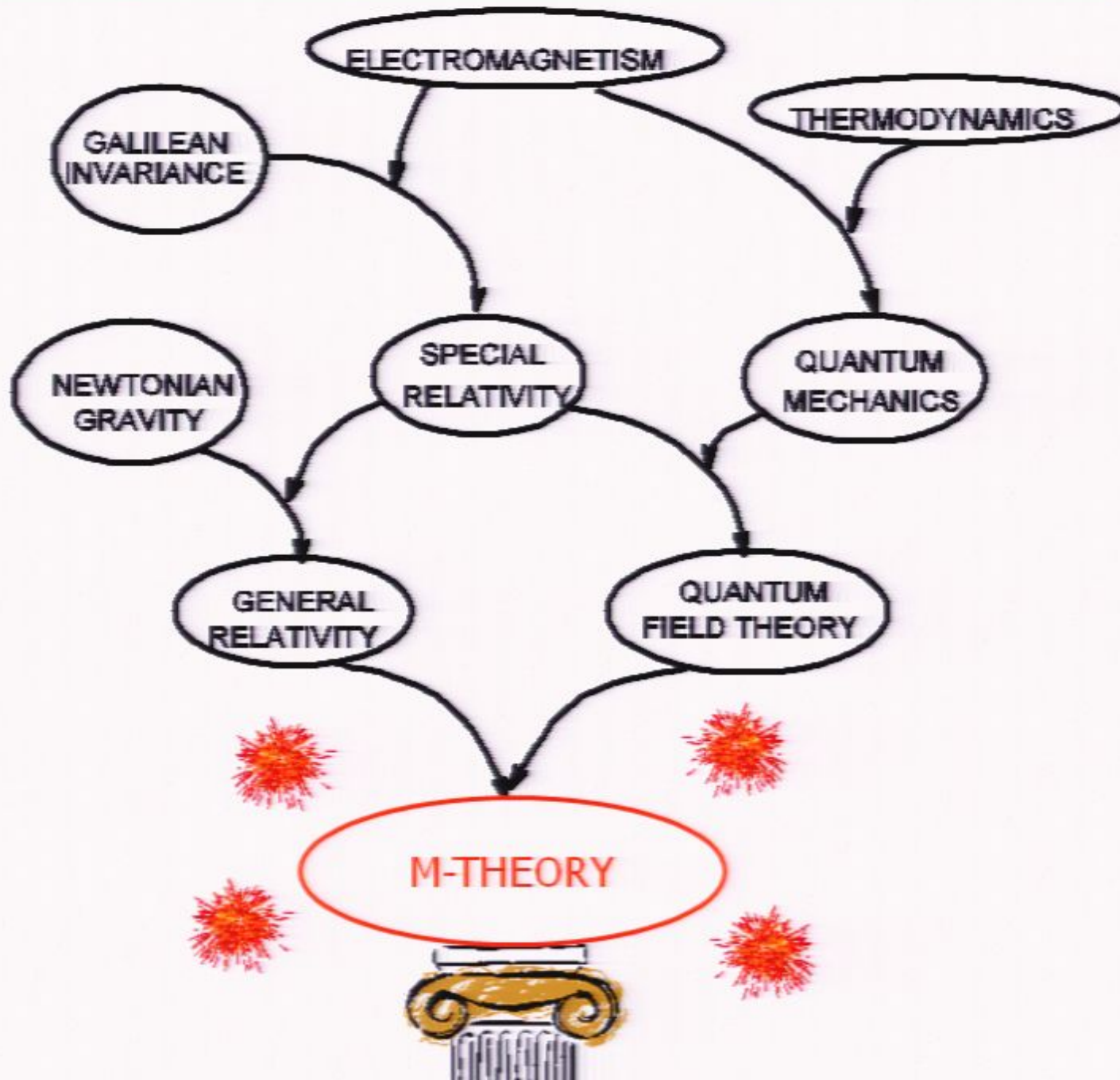
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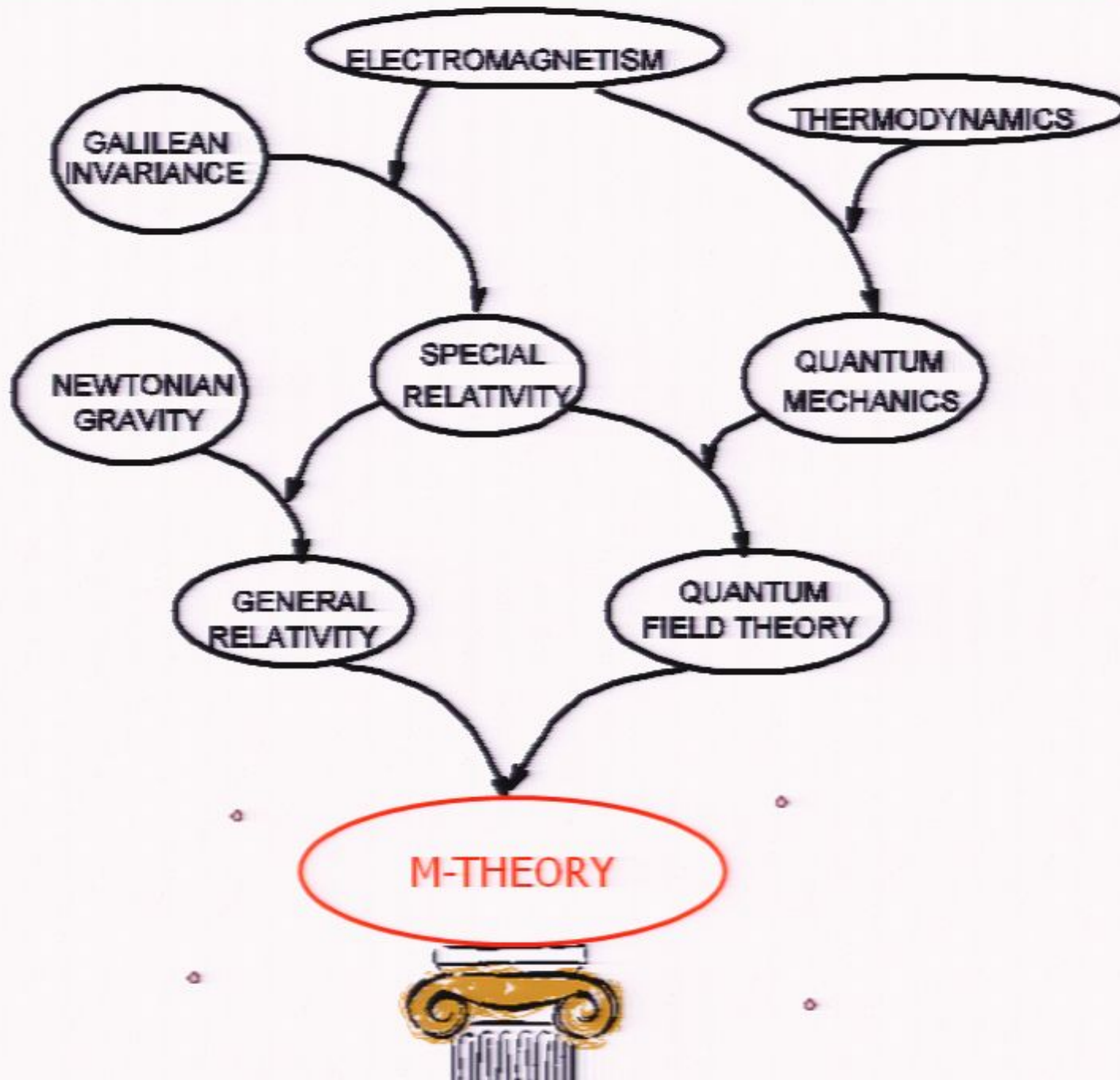
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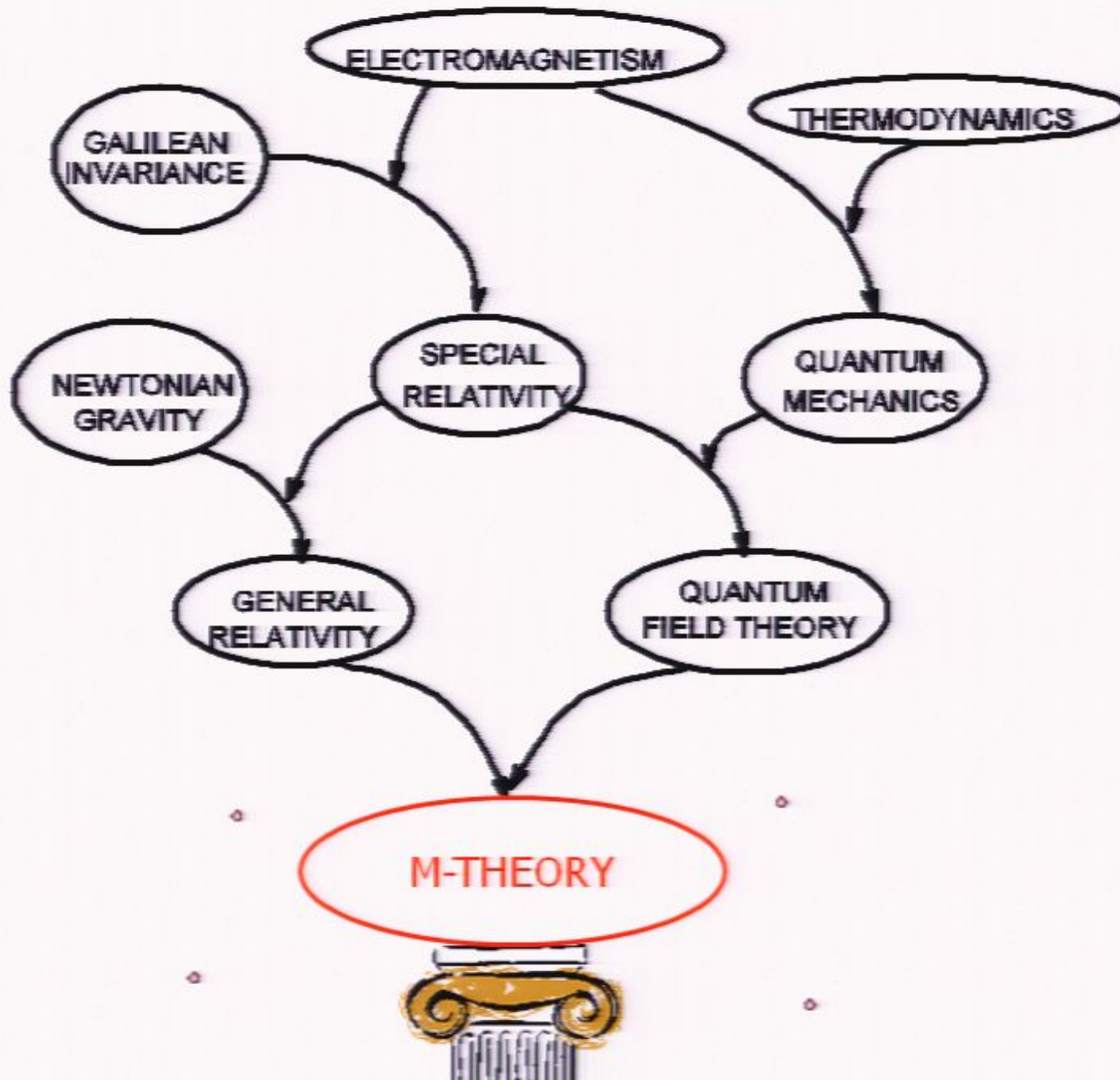
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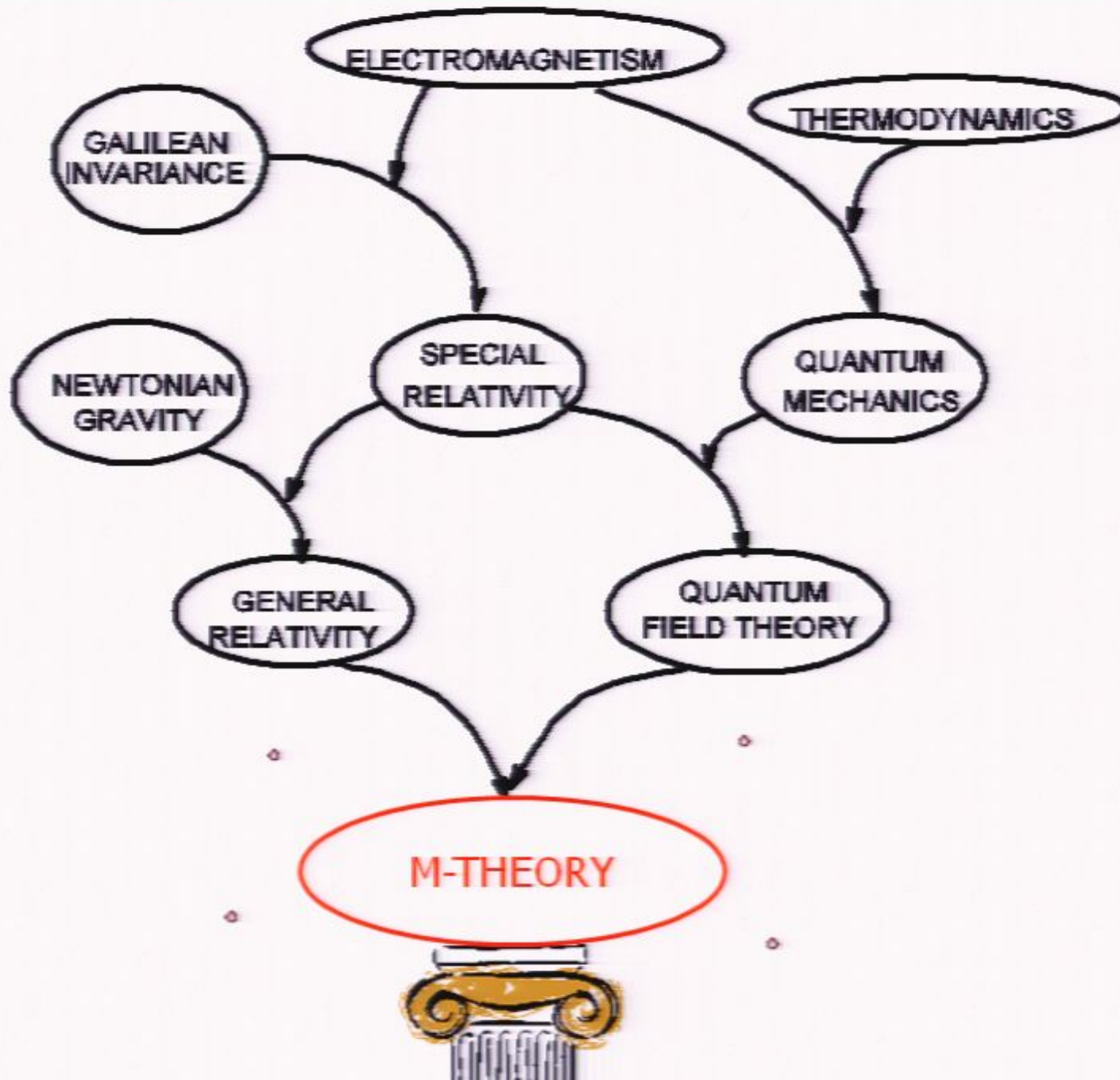
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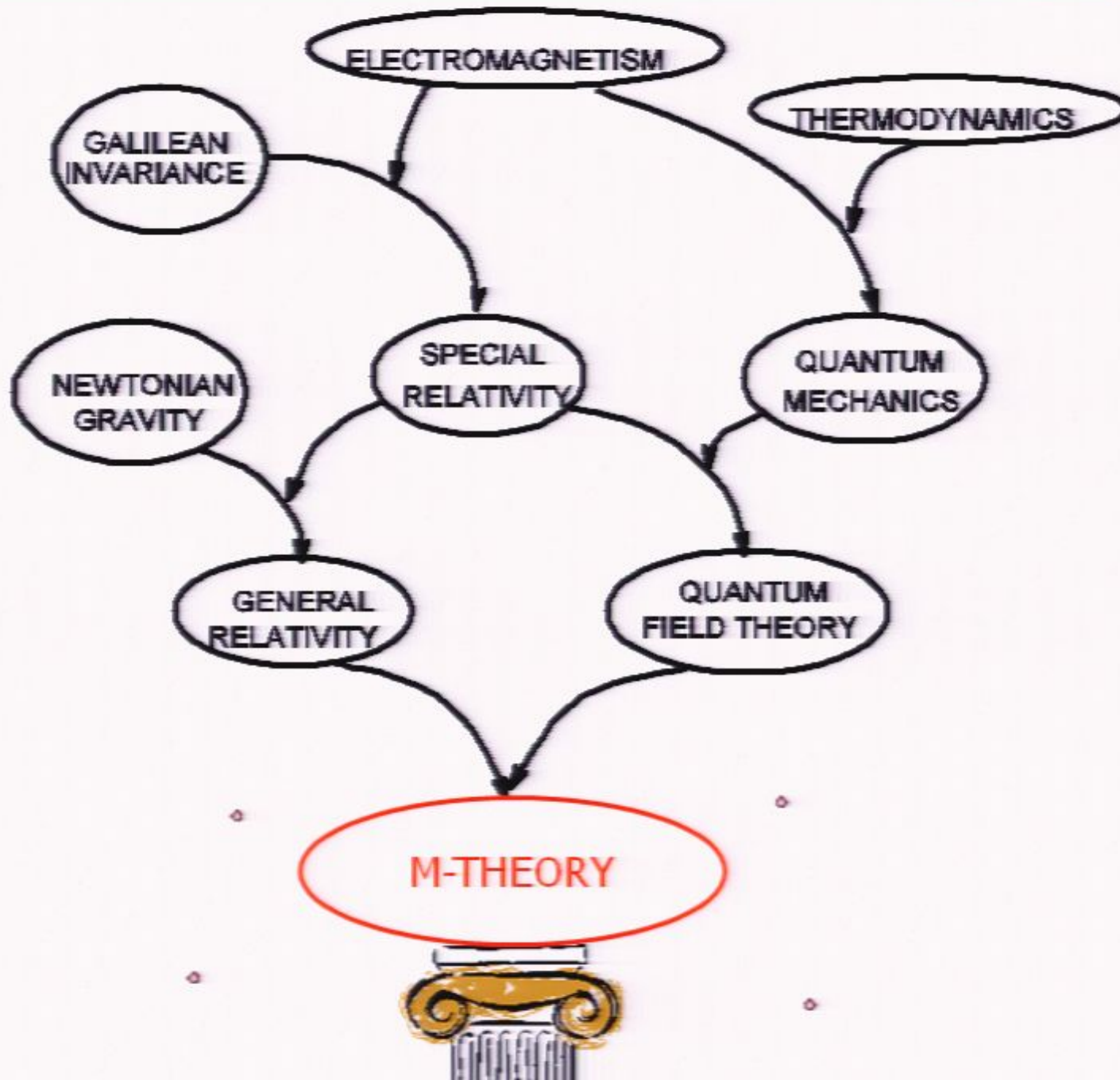
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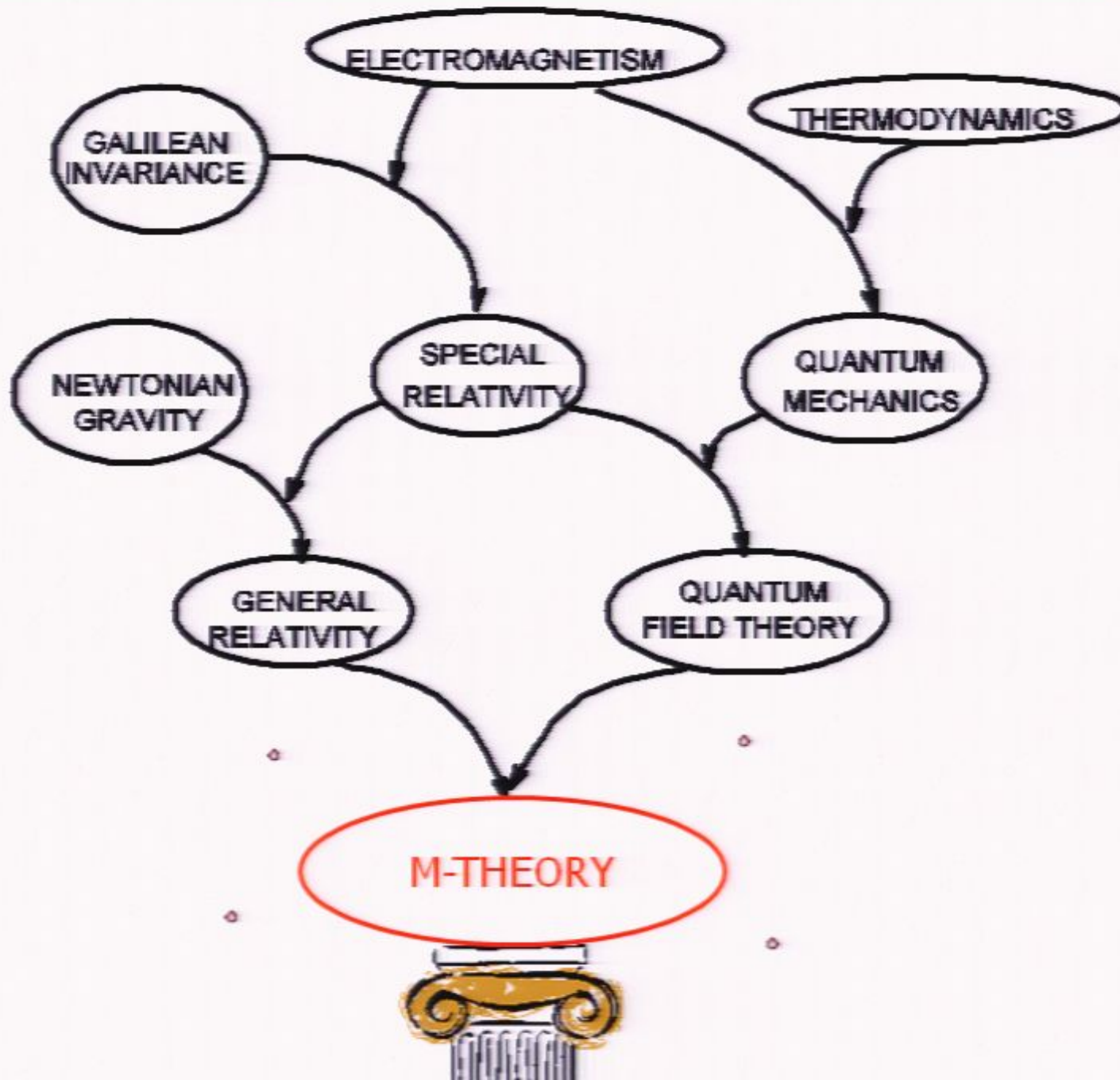
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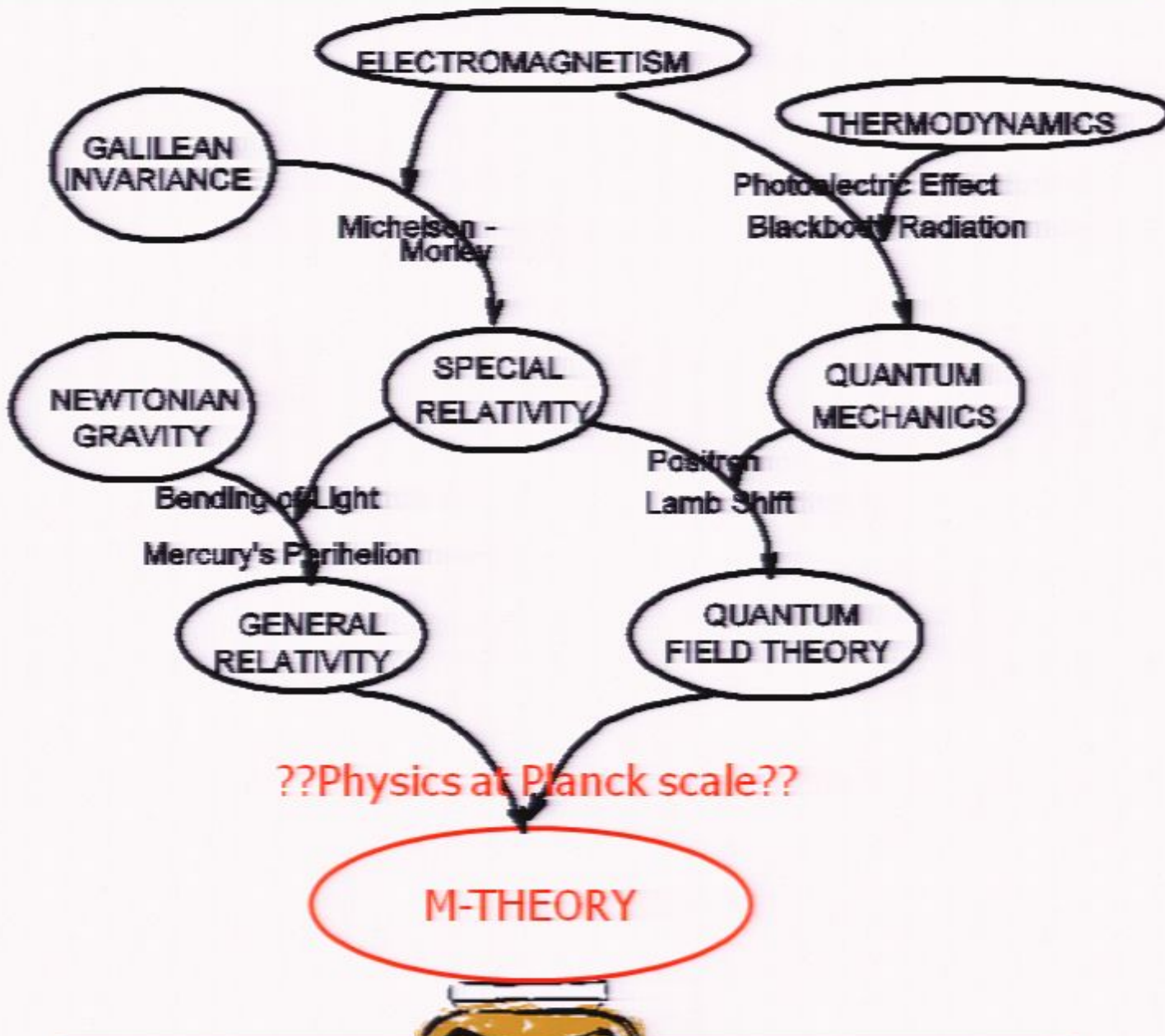
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STRING THEORY SUMMARIZED:

I JUST HAD AN AWESOME IDEA.
SUPPOSE ALL MATTER AND ENERGY
IS MADE OF TINY, VIBRATING "STRINGS."

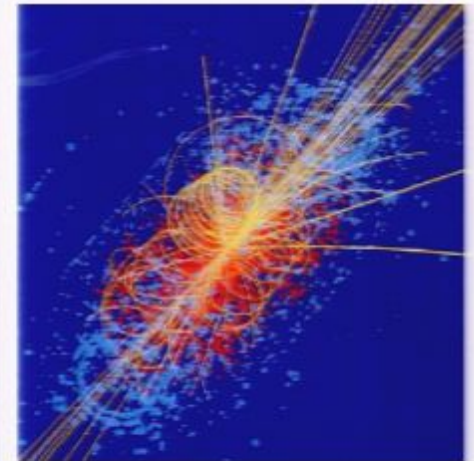
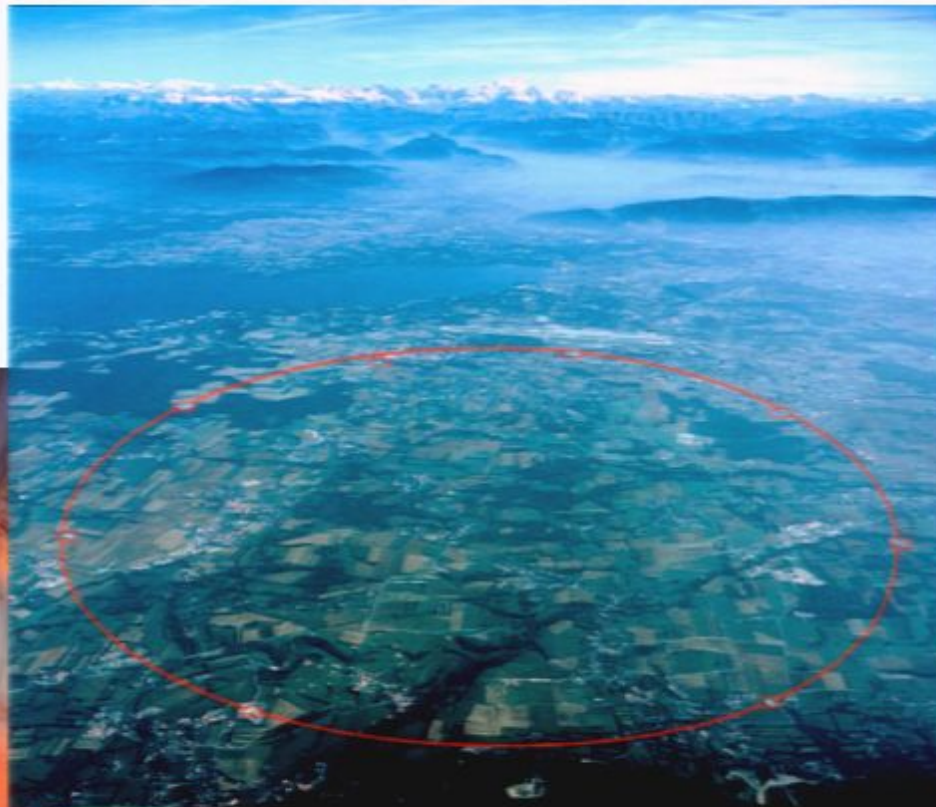
OKAY. WHAT WOULD
THAT IMPLY?

I DUNNO.



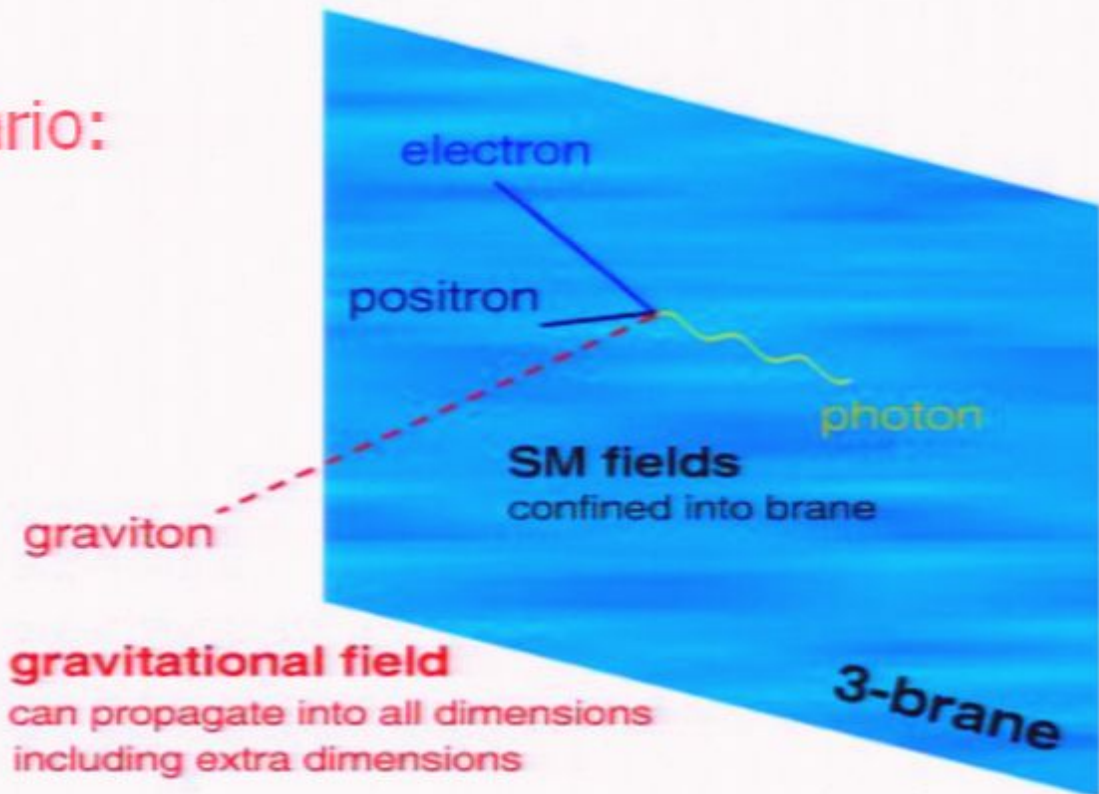
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accelerator experiments: probe 10^{12} eV and beyond
Tevatron, Large Hadron Collider,



How far away is the Planck scale really?

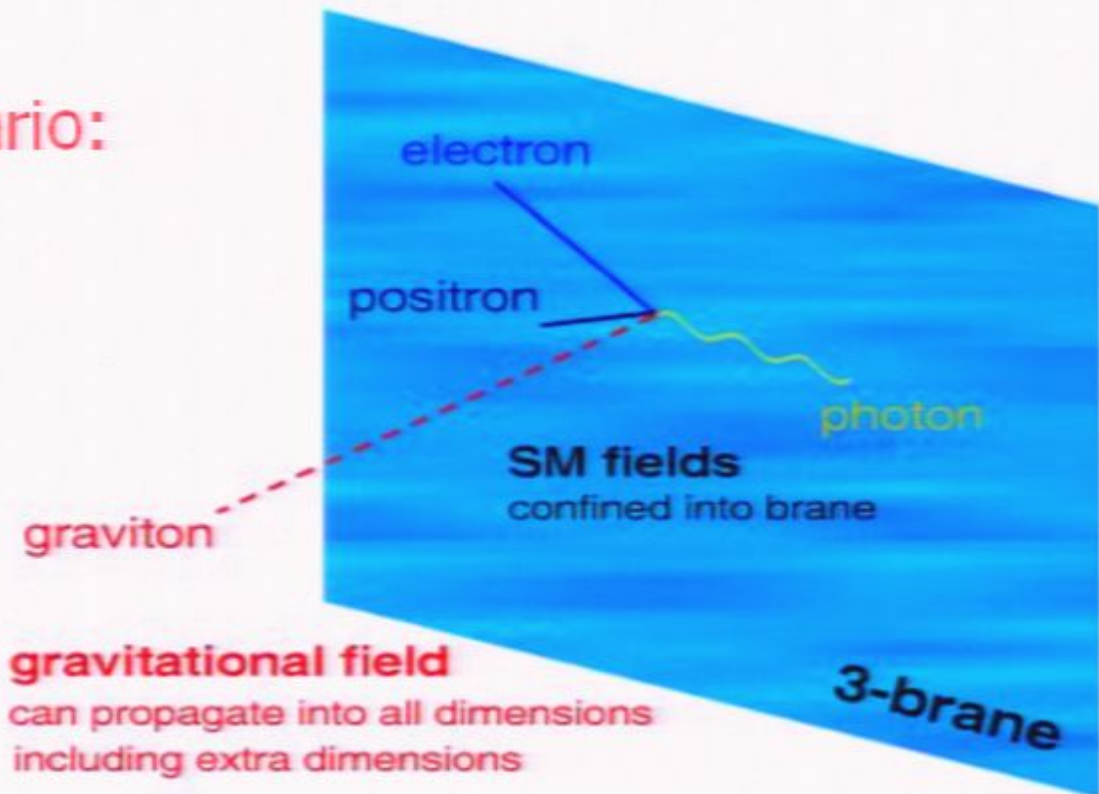
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(Some) Extra dimensions may be **very** large!

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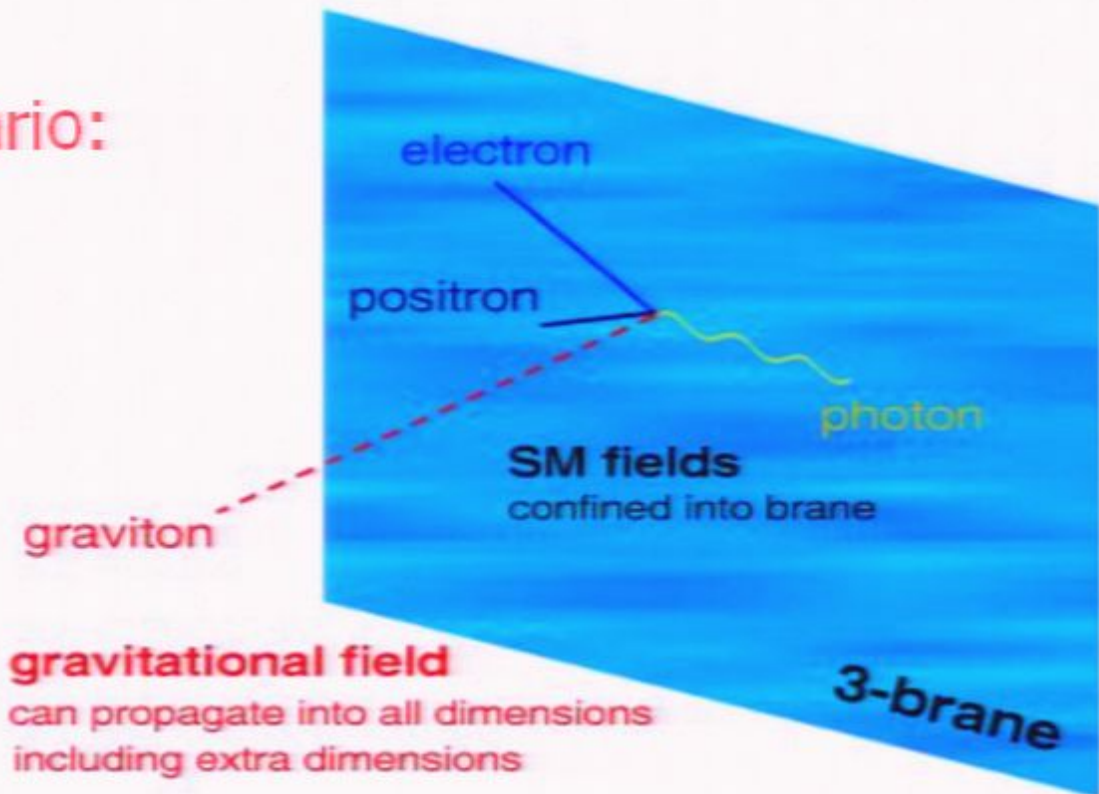


(Some) Extra dimensions may be **very** large!

Advantage: $G_4 = G_{10}/V_6$

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Advantage: $\ell_{P,10}^8 = V_6 \ell_{P,4}^2$

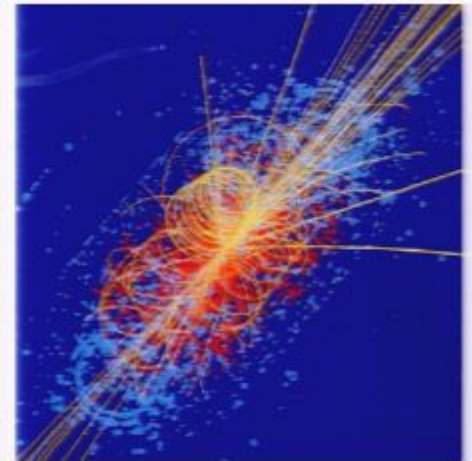
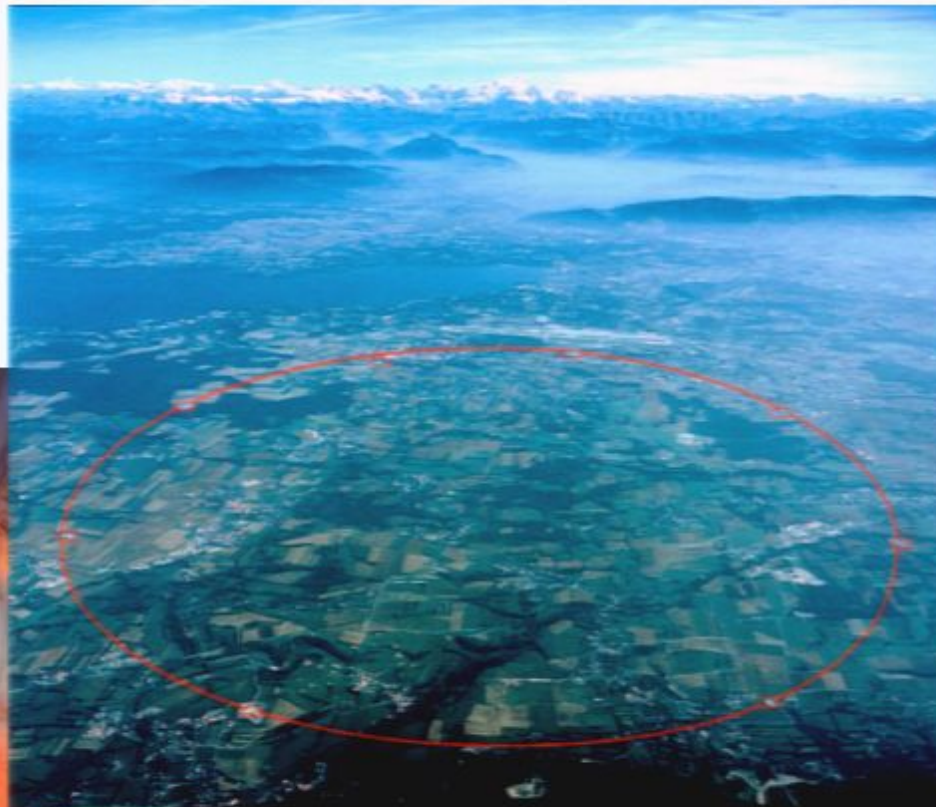
Pirsa: 08070002

Planck scale may be
within reach!!

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Superstring theory: a theory looking for a good experiment

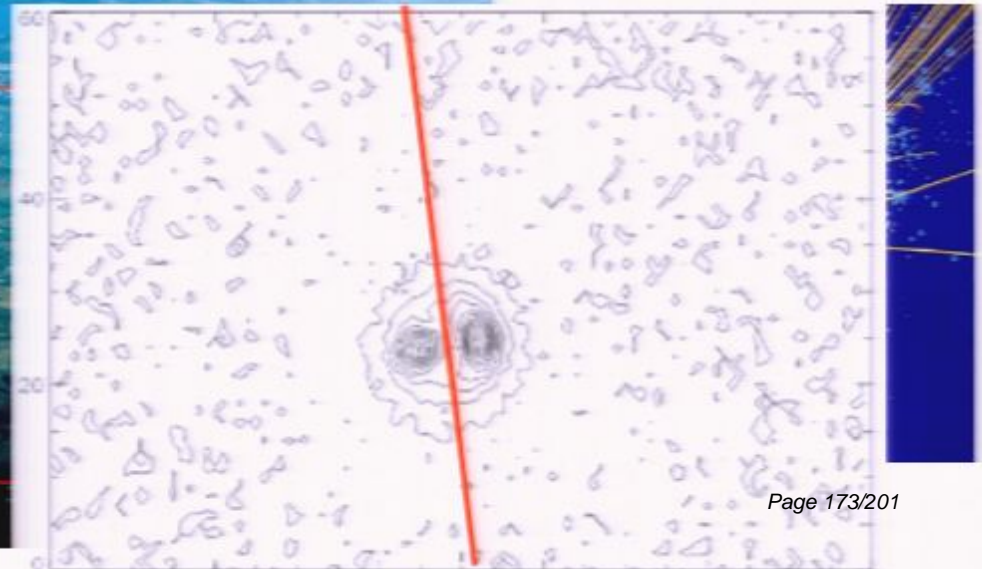
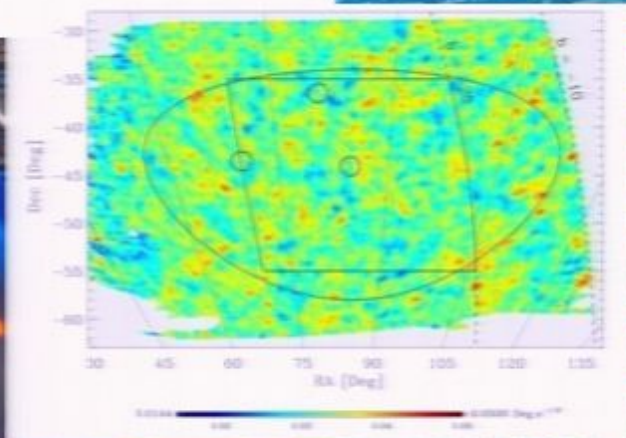
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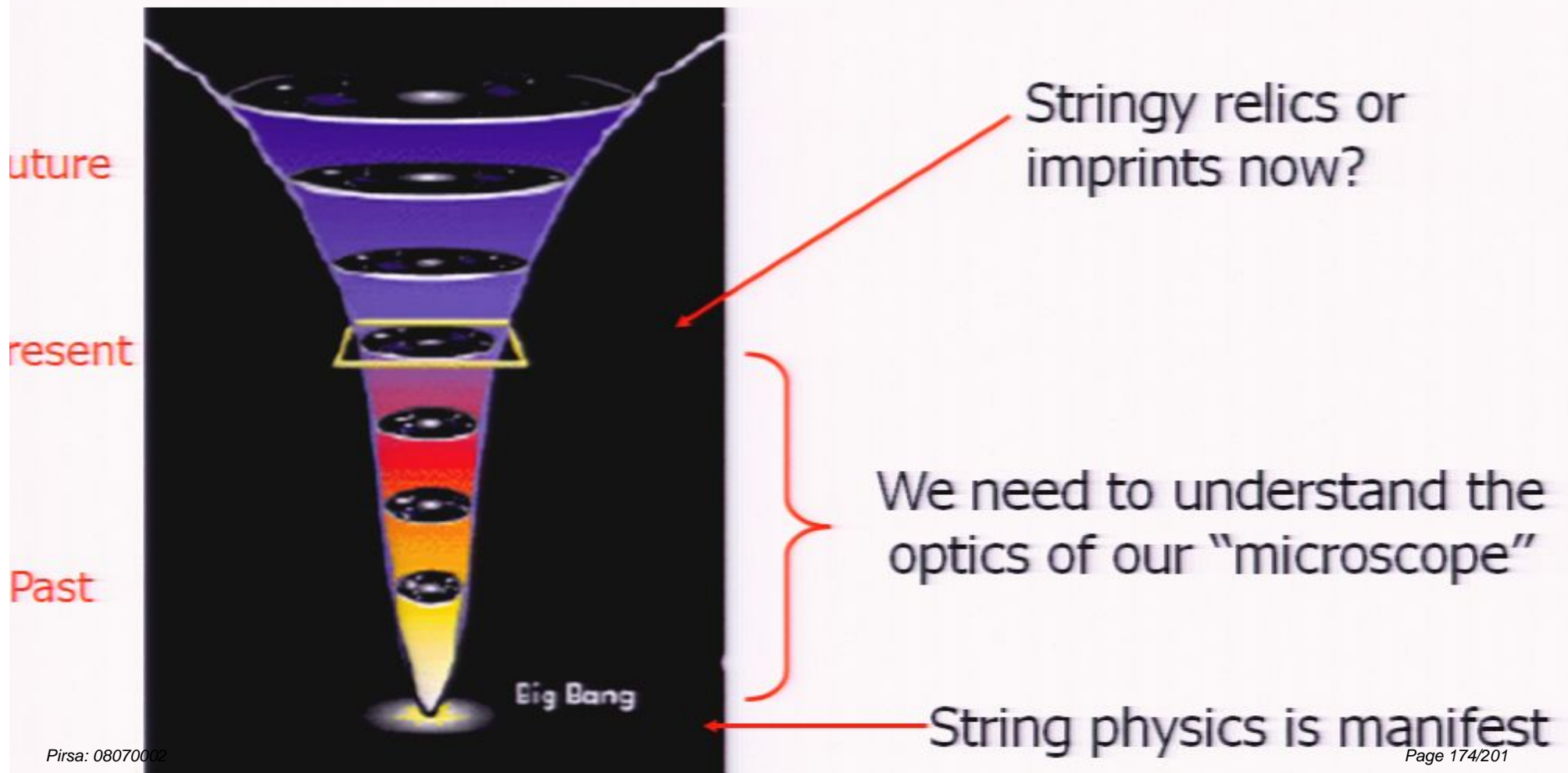
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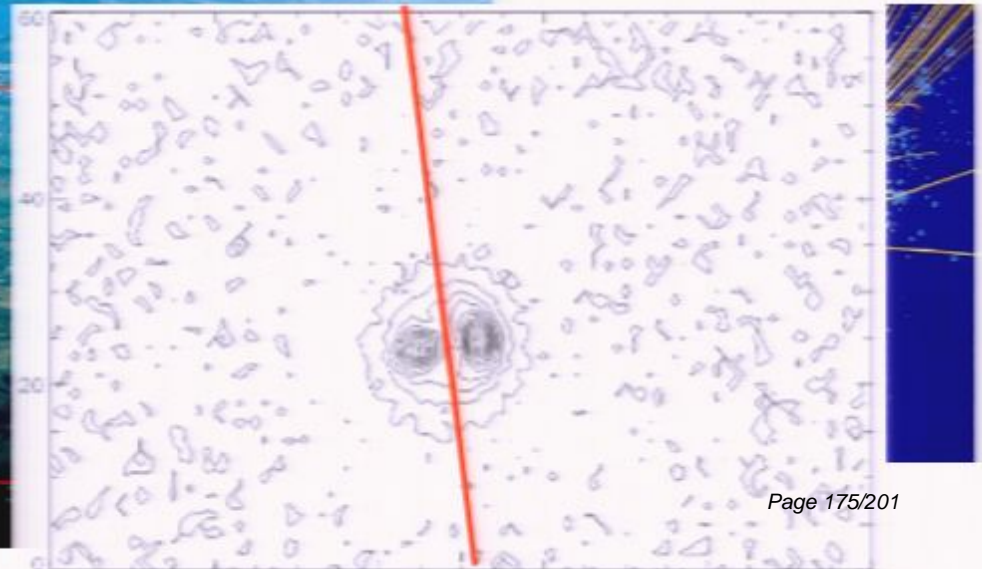
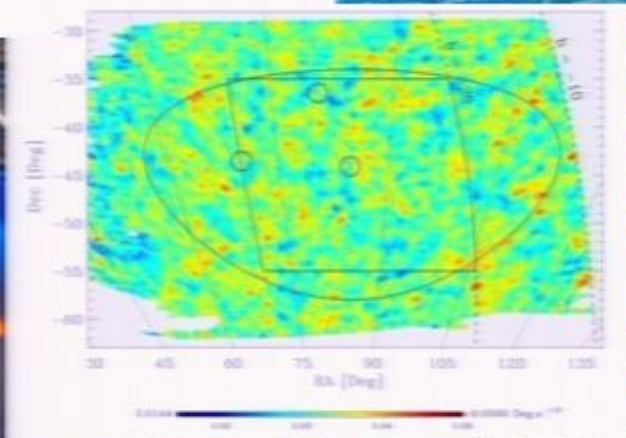
Cosmology: extreme conditions of early universe give a window on small scales and high energies



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a mathematical model of our physical universe

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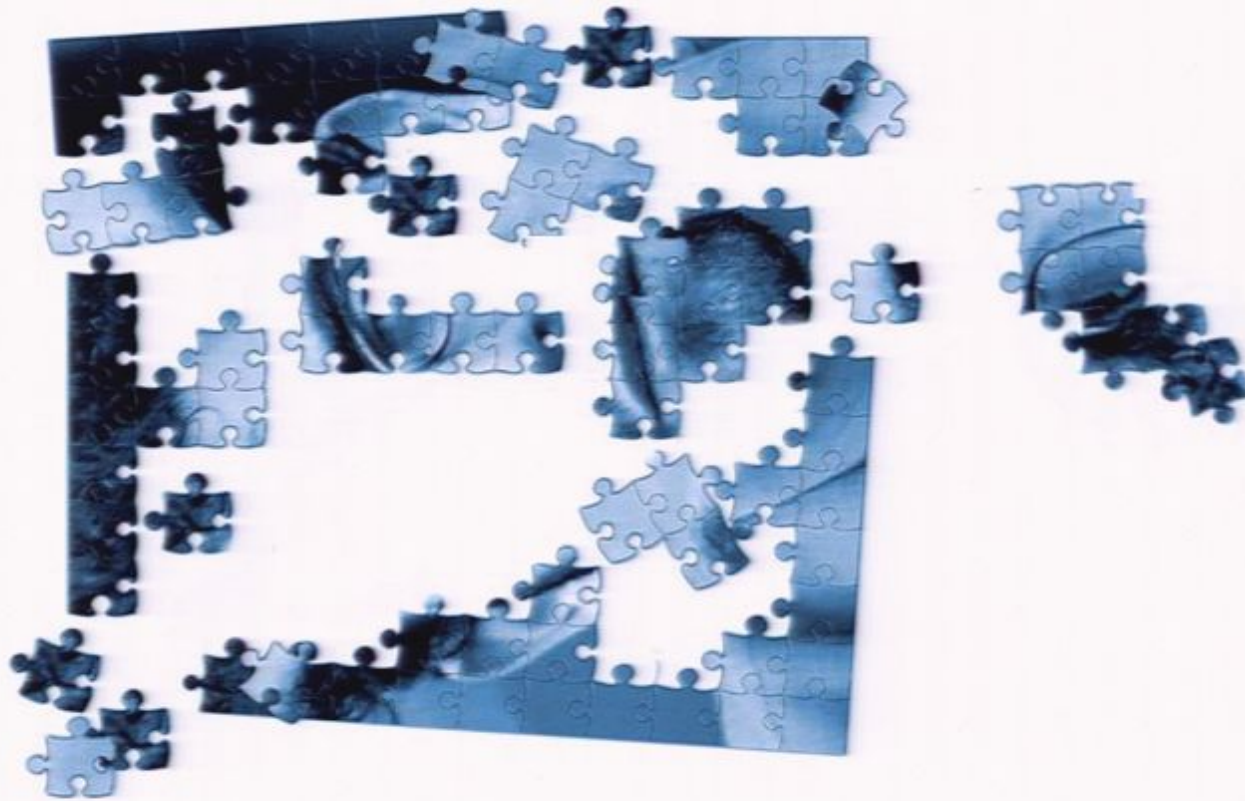
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***We are still groping for
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***We are still searching for
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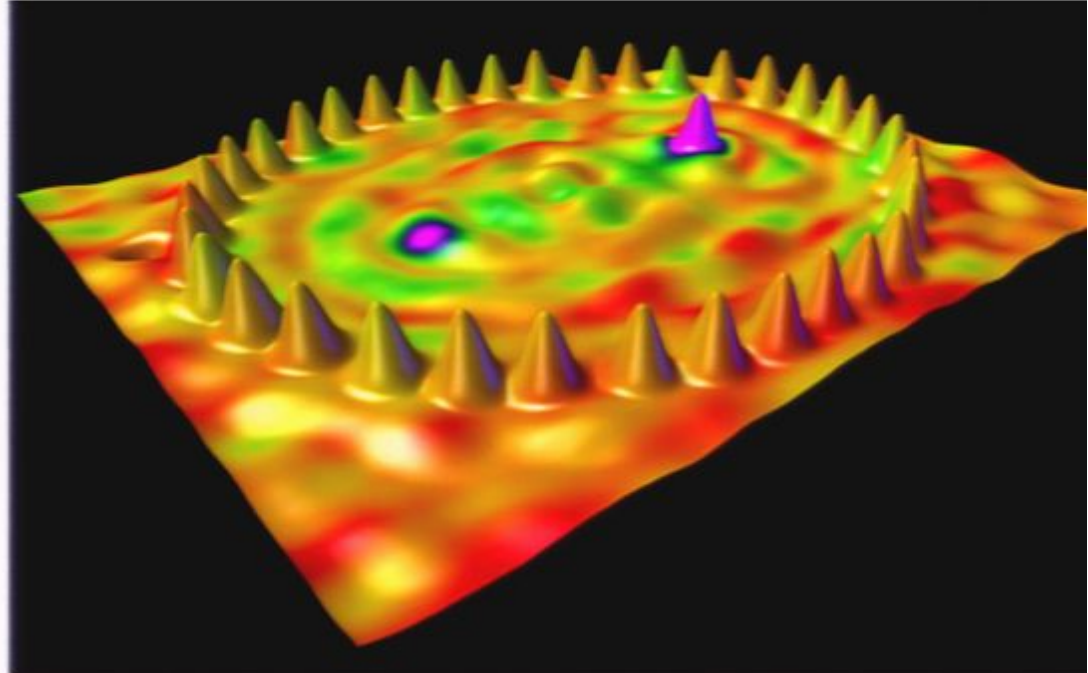


early 1900's —

Ernst Mach: “atoms are physically unverifiable entities”

early 1990's —

individual atoms are
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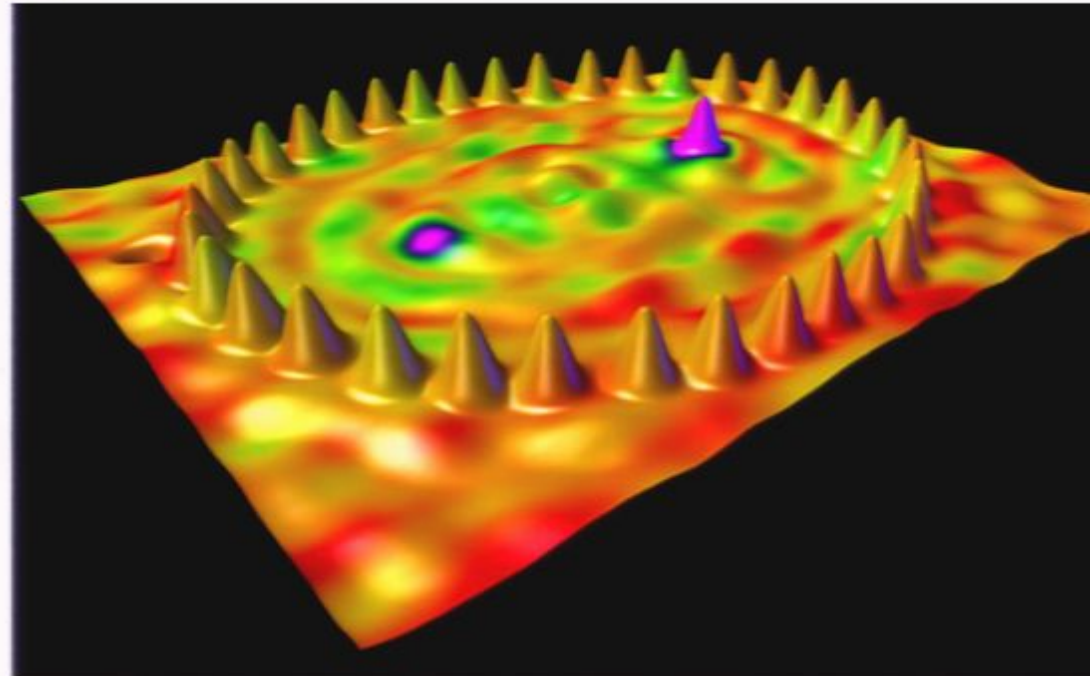


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For superstrings,
the adventure is still only beginning!

More strings on the web:

“The Elegant Universe”

Brian Greene

<http://www.pbs.org/wgbh/nova/elegant/>

Superstrings!

<http://www.sukidog.com/jpierre/strings/>

The Official String Theory Web Site:

<http://superstringtheory.com/>

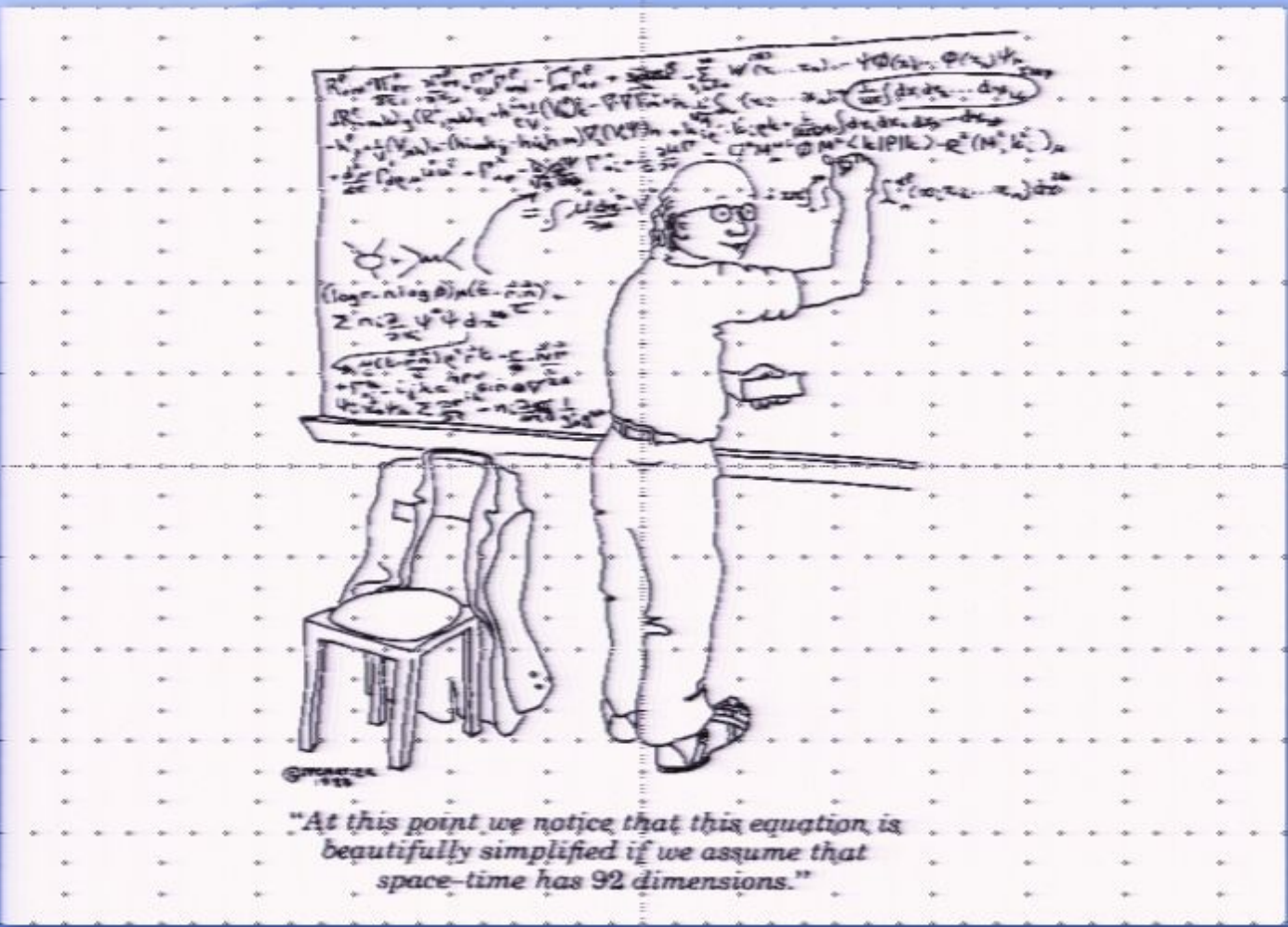
***“It’s the 21st century –
time to feed your brain!”***

Font Paragraph Drawing Editing

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Shape Fill - Shape Outline - Shape Effects - Shapes - Arrange - Quick Styles - Find - Replace - Select - Editing

Outline

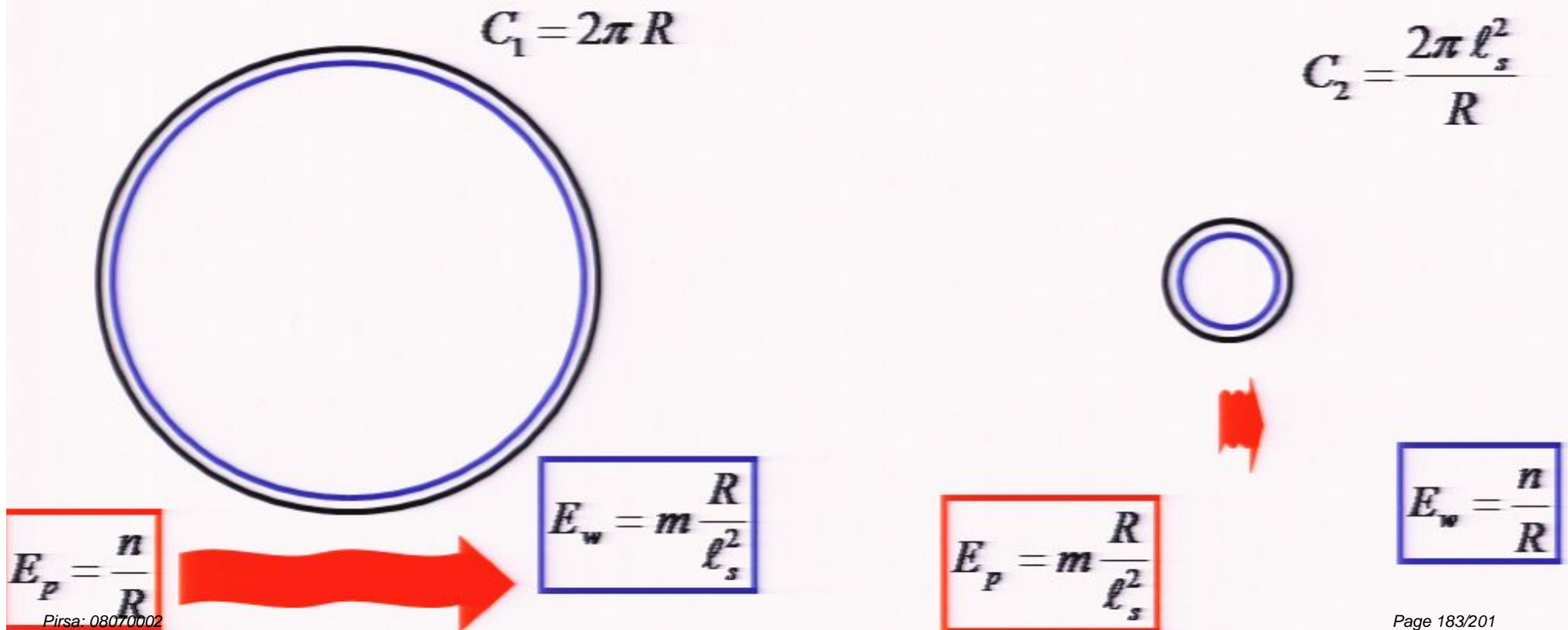


Click to add notes

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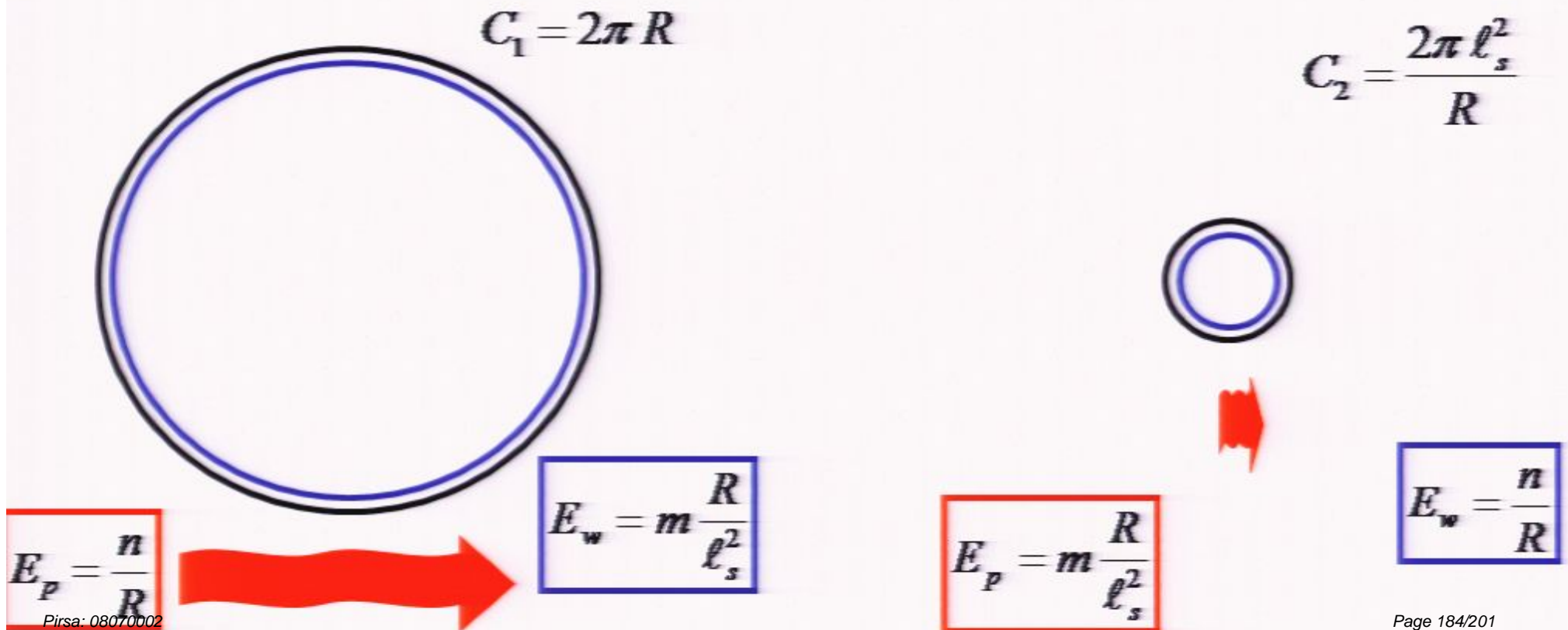
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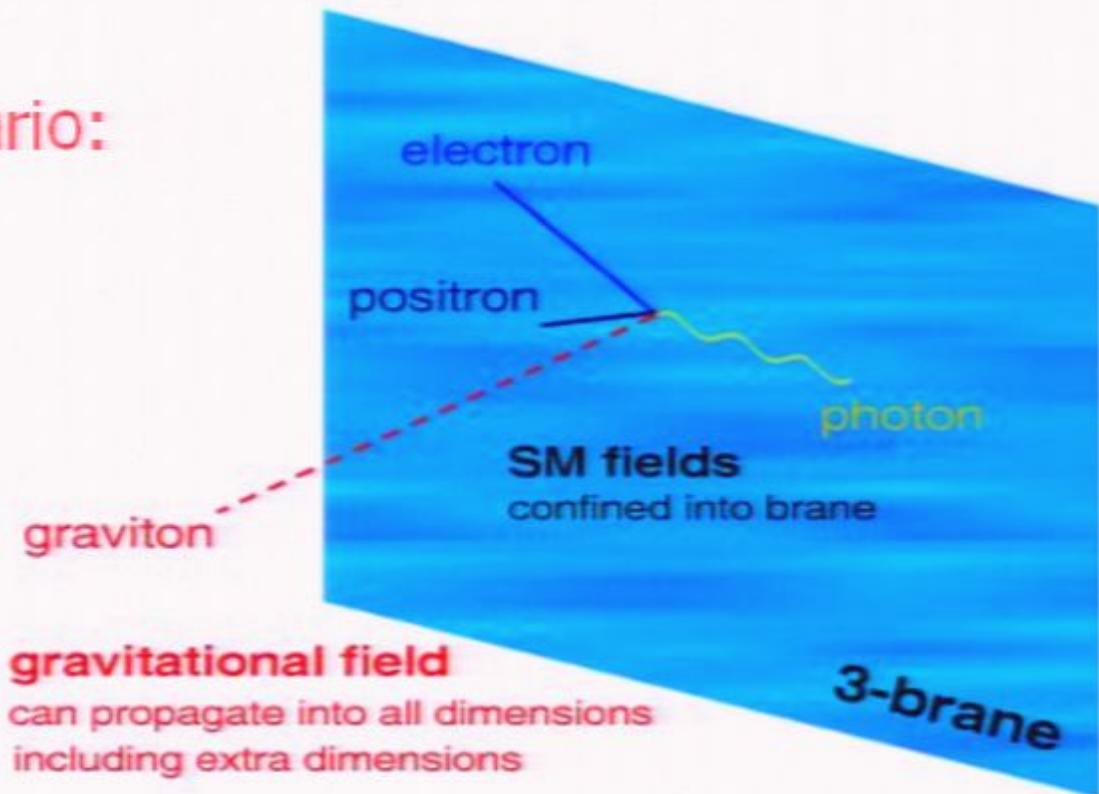
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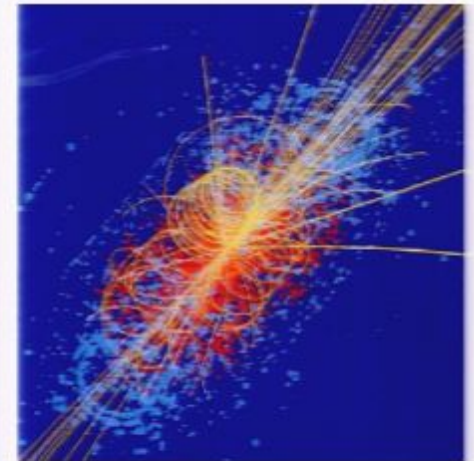
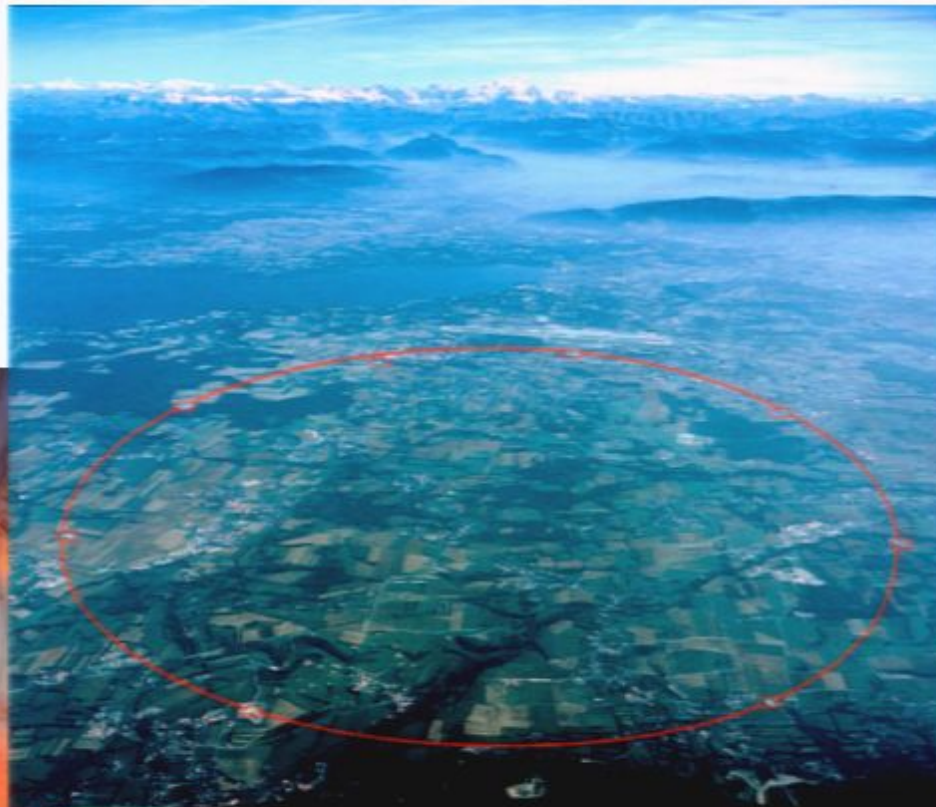
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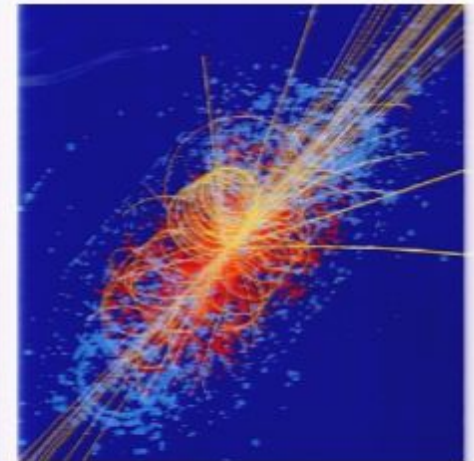
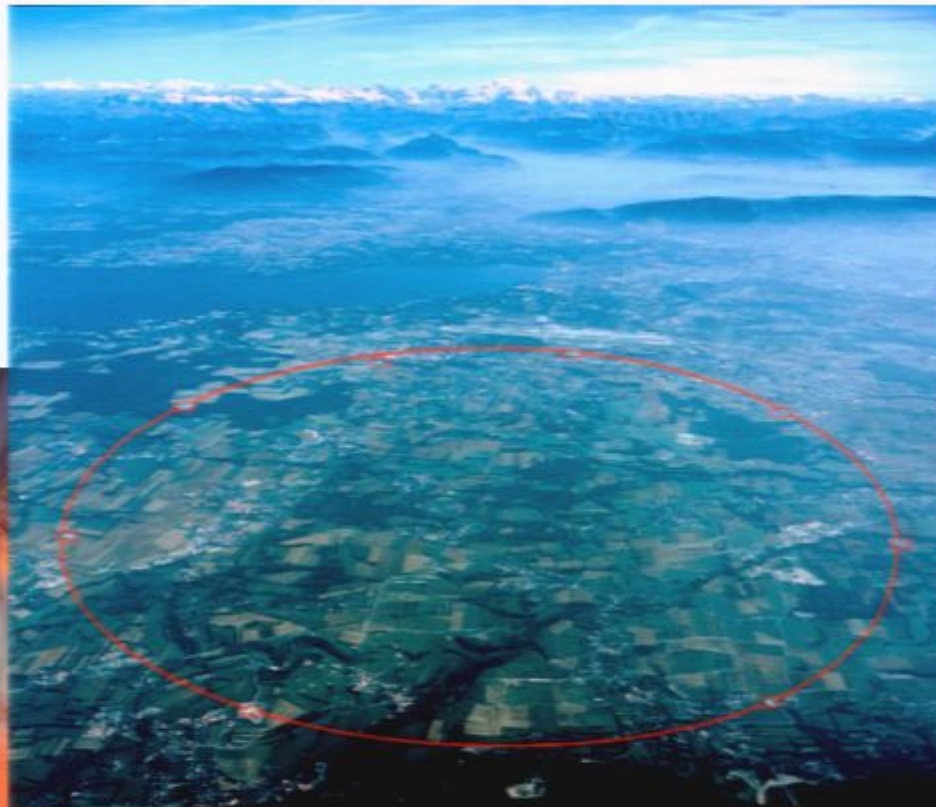
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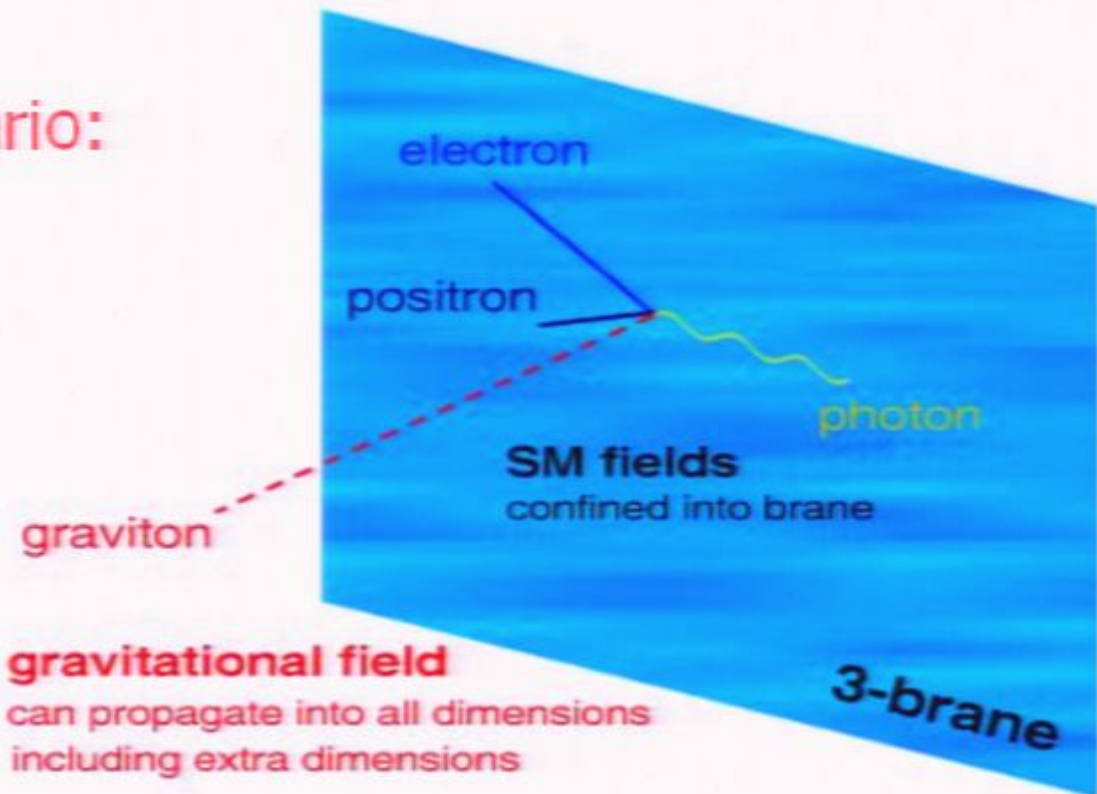
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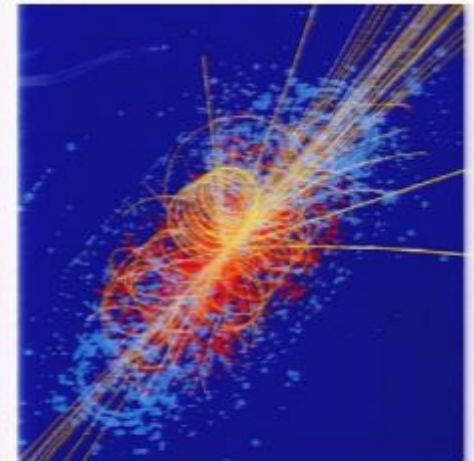
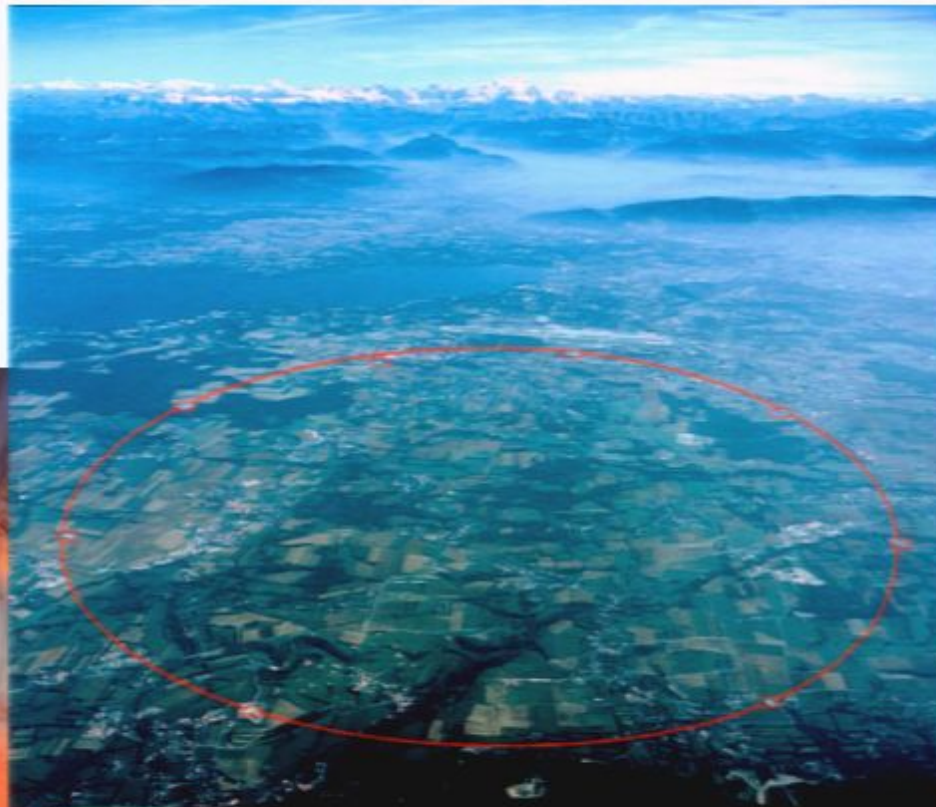
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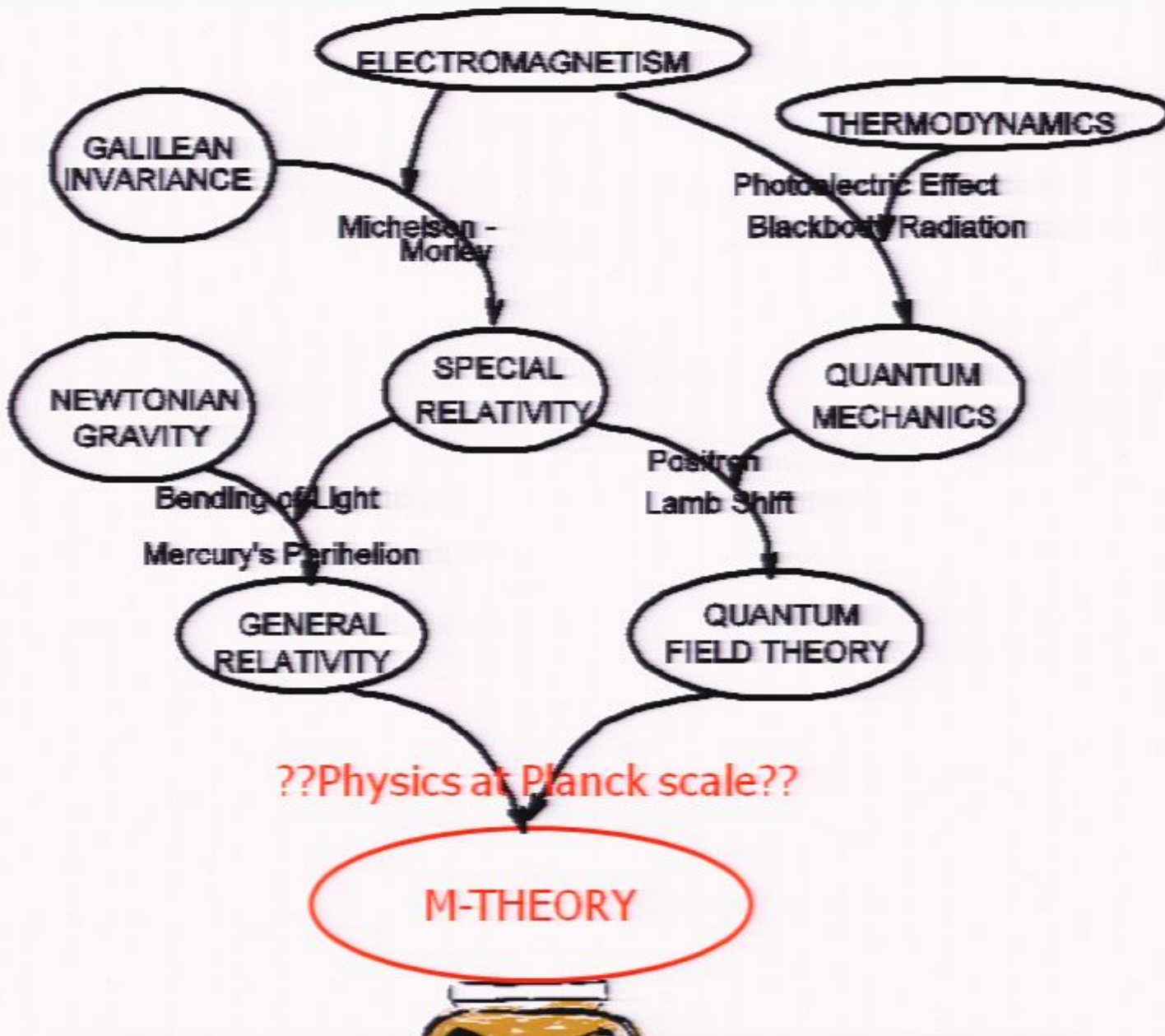
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Superstring theory: a theory looking for a good experiment

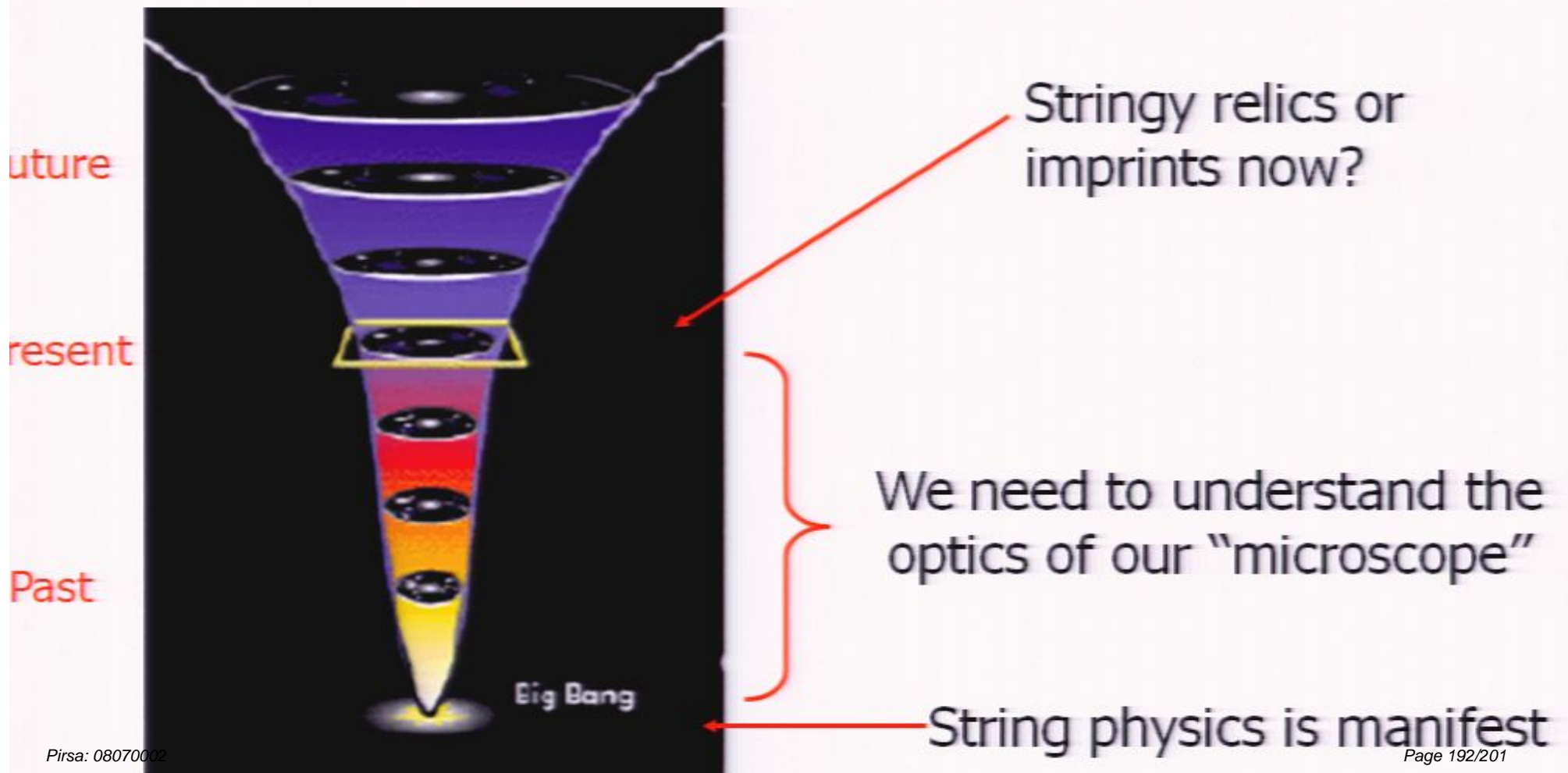
accelerator experiments: probe 10^{12} eV and beyond
Tevatron, Large Hadron Collider,



String/M-theory is a rich source of new ideas



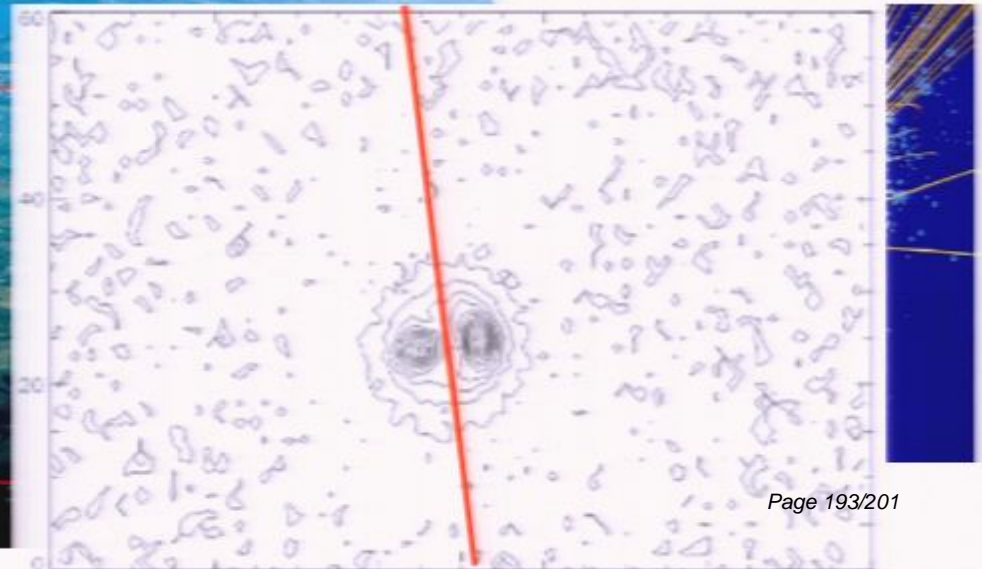
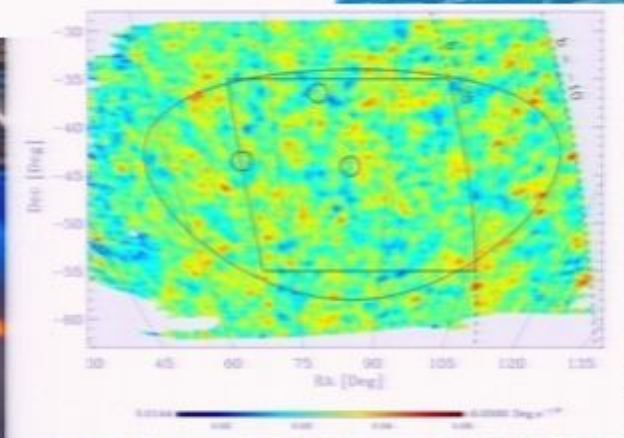
Cosmology: extreme conditions of early universe give a window on small scales and high energies



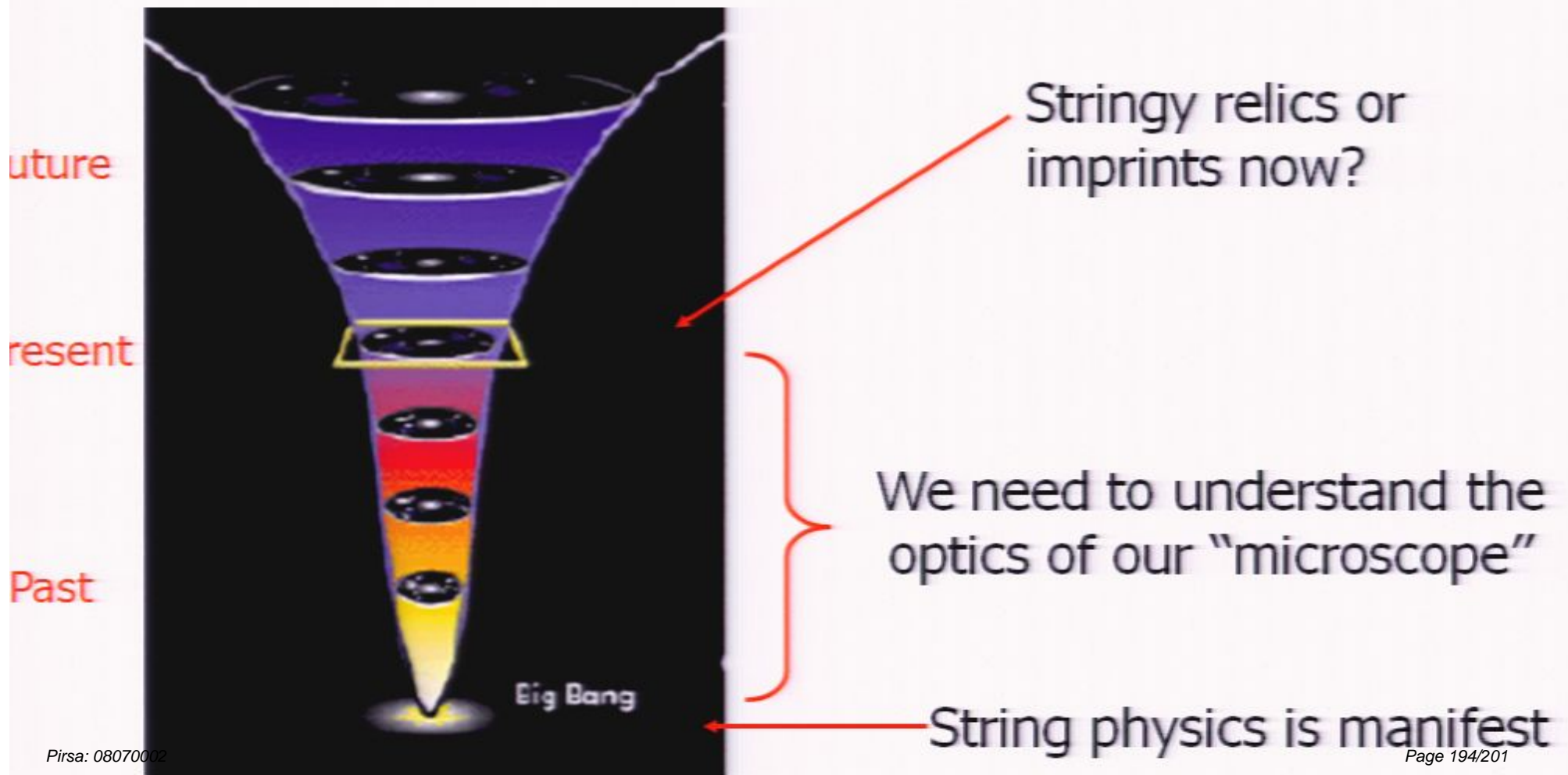
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cosmological experiments: extreme conditions of early universe may have left **stringy** imprints

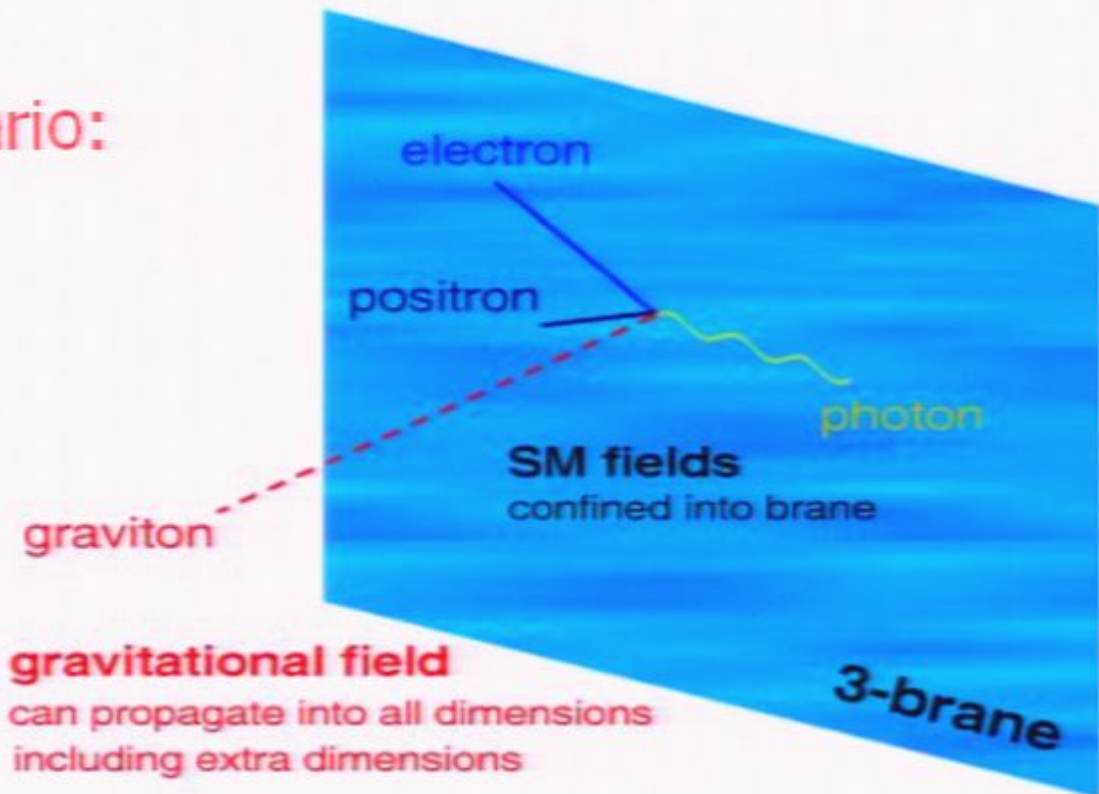


Cosmology: extreme conditions of early universe give a window on small scales and high energies



How far away is the Planck scale really?

Brane-world scenario:



(Some) Extra dimensions may be **very** large!

Advantage: $G_4 = G_{10}/V_6$

$$2d = n\lambda$$

$$\cancel{d = n\lambda}$$

λ $\frac{d}{2}$ $\frac{d}{2}$ d
 -1 $+1$ $+1$ -1

$$2d \sin \theta = n\lambda$$

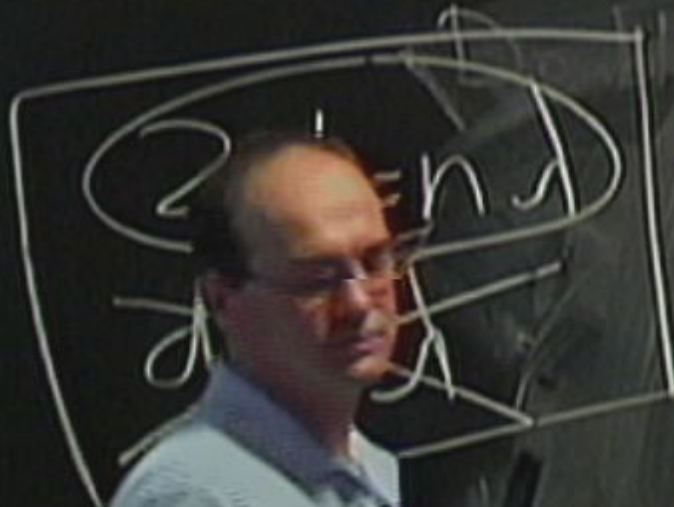
$$\lambda = 4$$

$$2d = 4\lambda$$

$$\lambda = \frac{2d}{4} = \frac{d}{2}$$

atom 1

atom



$\frac{1}{2}$ $\frac{1}{3}$ $\frac{1}{4}$ $\frac{1}{5}$
 $\frac{1}{2}$ $\frac{1}{3}$ $\frac{1}{4}$ $\frac{1}{5}$

$$2d = n \lambda$$

let $n=4$

$$2d = 4 \lambda$$

$$\lambda = \frac{2d}{4} = \frac{d}{2}$$

atom 1

$\lambda = -1$ $\lambda = \frac{1}{2}$ $\lambda = \frac{1}{3}$

$2d = n \cdot \lambda$

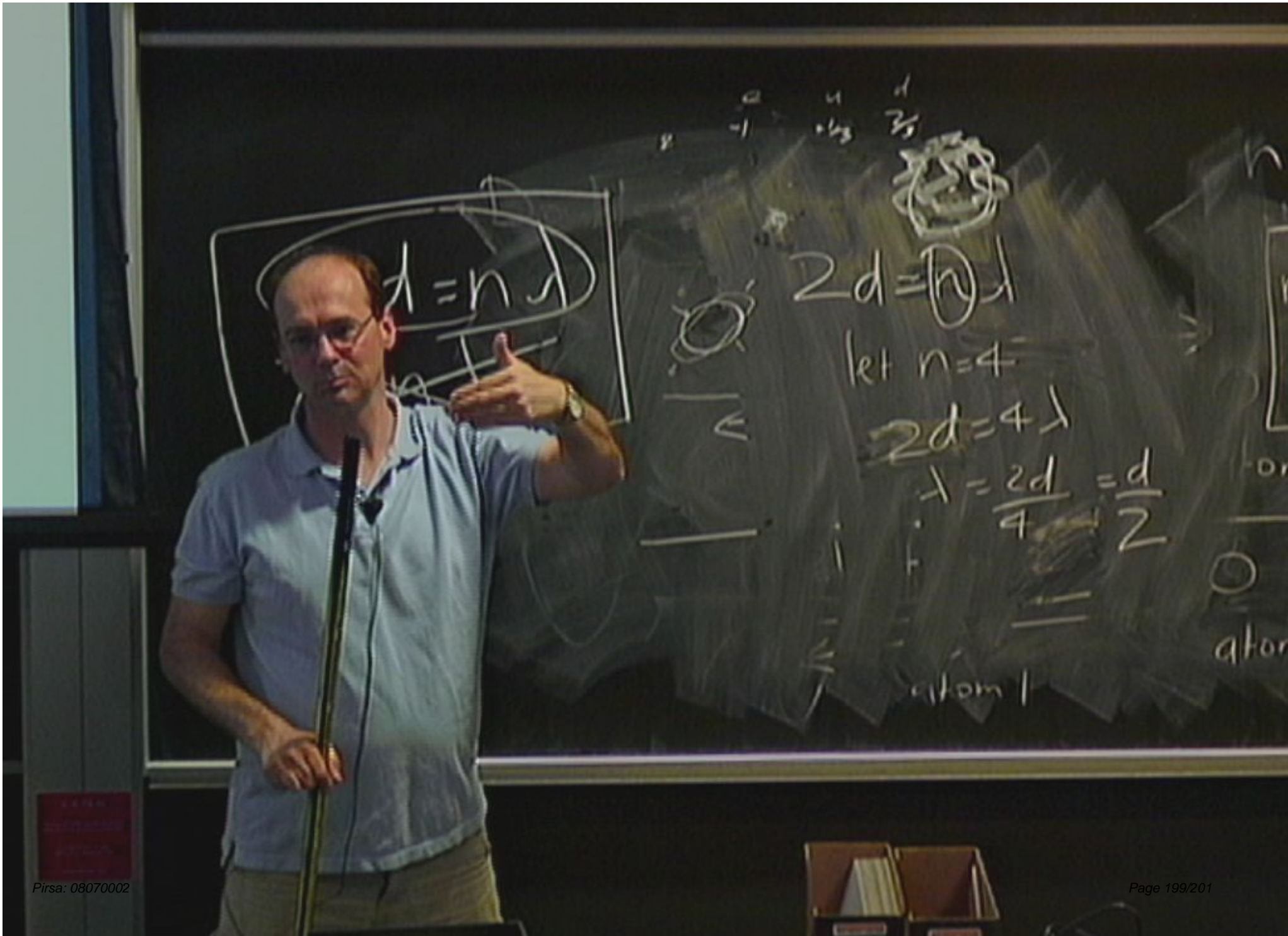
let $n=4$

$2d = 4 \cdot \lambda$

$\lambda = \frac{2d}{4} = \frac{d}{2}$

atom

atom



String/M-theory is a rich source of new ideas

