Kick-off meeting of the Brout-Englert-Lemaître Centre

From the scientific revolution towards the understanding of nature

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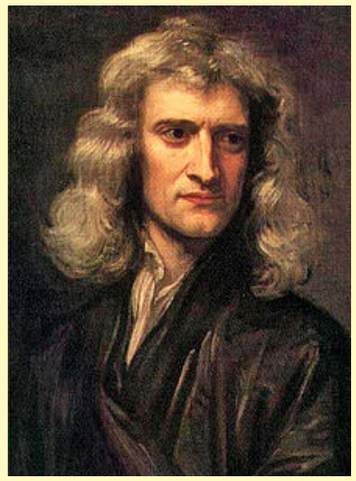
I From the inertial principle to gravity and electromagnetism

Galileo Galilei
(1564-1642)

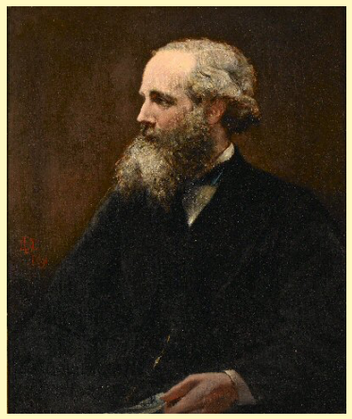
The inertia principle



Isaac Newton (1643-1727)

gravitation

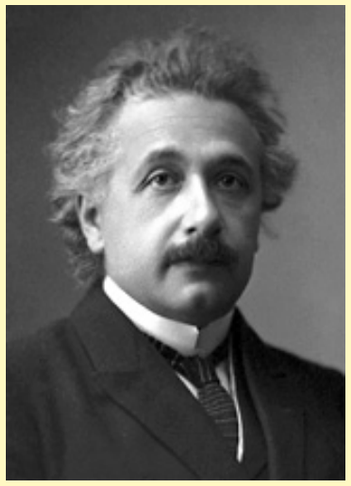
the notion of particle



James Clerk Maxwell (1831-1879)

electromagnetism

the notion of field



Albert Einstein (1879 - 1955)

special relativity *(new inertia principle)*

general relativity *(new theory of gravitation)*

the photon

quantum physics ⟶ quantum electrodynamics

Planck, Einstein, Bohr… Heisenberg, Schrodinger, Dirac, …

Special relativity

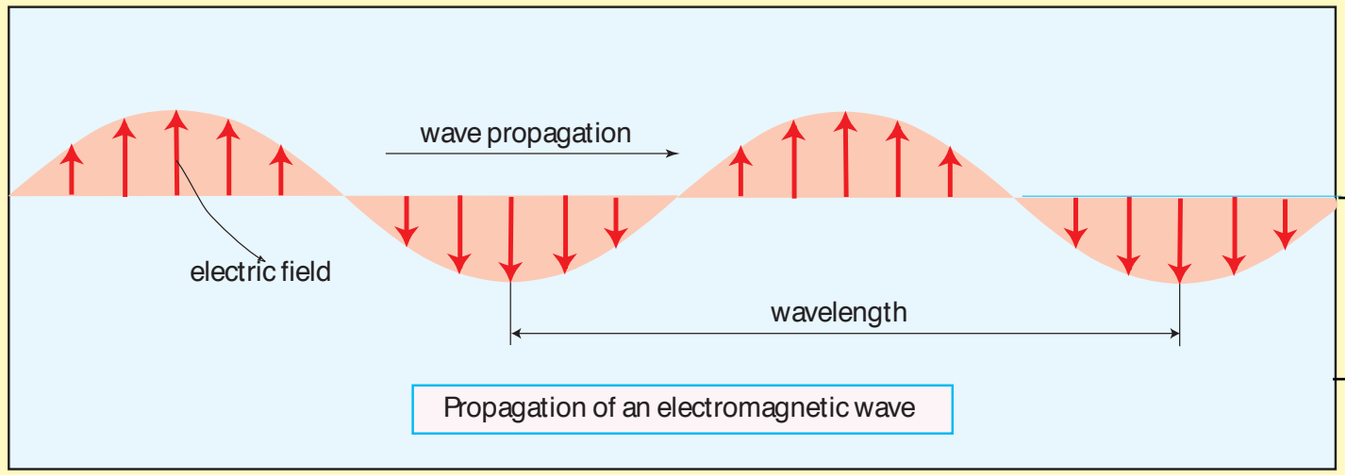
The velocity of light is the maximal velocity of the propagation of a signal

The mass m of a particle whose rest-mass is m_0 increases with its velocity

$m_0 \neq 0$ *the particle never reaches the velocity of light*

$m_0 = 0$ *the particle always travels with the velocity of light*

Quantum theory



particles are "carried" by fields

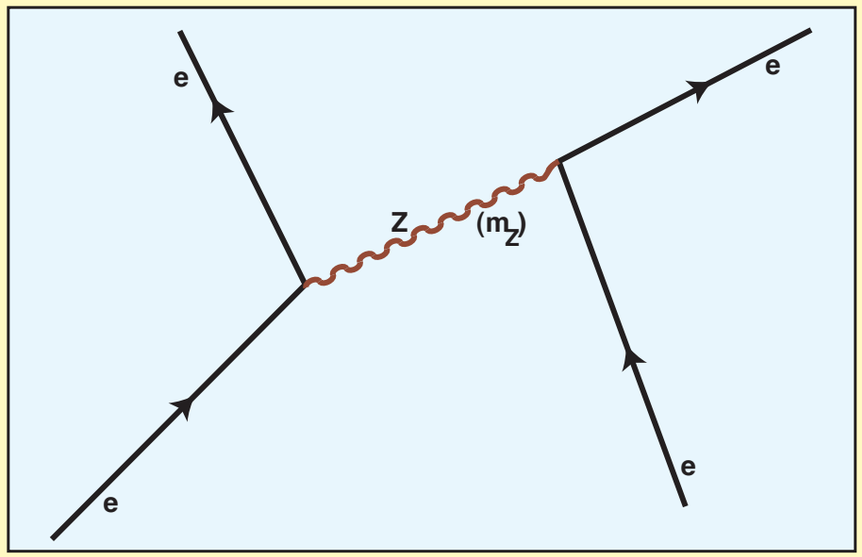
probabilities

$m_0 = 0$ *two polarisations*

$m_0 \neq 0$ *three polarisations*

Bosons and Fermions

Interactions between particles result from particle exchange



Exchange of massless particles $\longrightarrow$ *long range*

Exchange of massive particles $\longrightarrow$ *short range*

II. Short range fundamental interactions and the BEH mechanism

F. Englert and R. Brout, Phys. Rev. Lett. 13 (1964) 321
P.W. Higgs, Phys. Rev. Lett. 13 (1964) 508.

[1964] F. Englert, P. Higgs (Nobel Prize 2013)

Quantum electrodynamics is a consistent quantum theory

↓ ***Hypothesis***

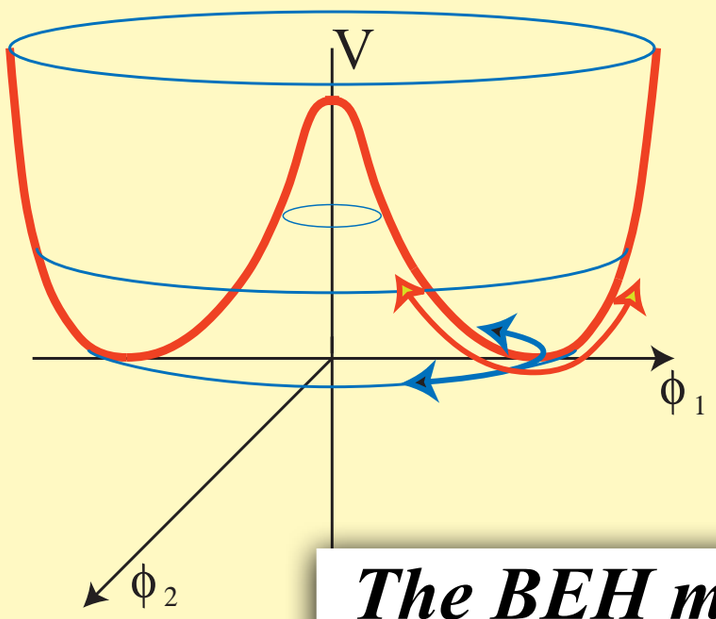
Fundamental short range interactions are mediated by generalised photons (Yang-Mills fields)

How to remove the lock against mass ?

How to generate the third polarisation?

Spontaneous symmetry "breaking"

Example: Add to electromagnetism two scalar fields interacting through a potential



$$\phi_2 = \varphi_2$$

massless scalar field coupled to YM → 3rd polarisation

$$\phi_1 = \langle\phi_1\rangle + \varphi_1$$

condensate ***massive BEH scalar***

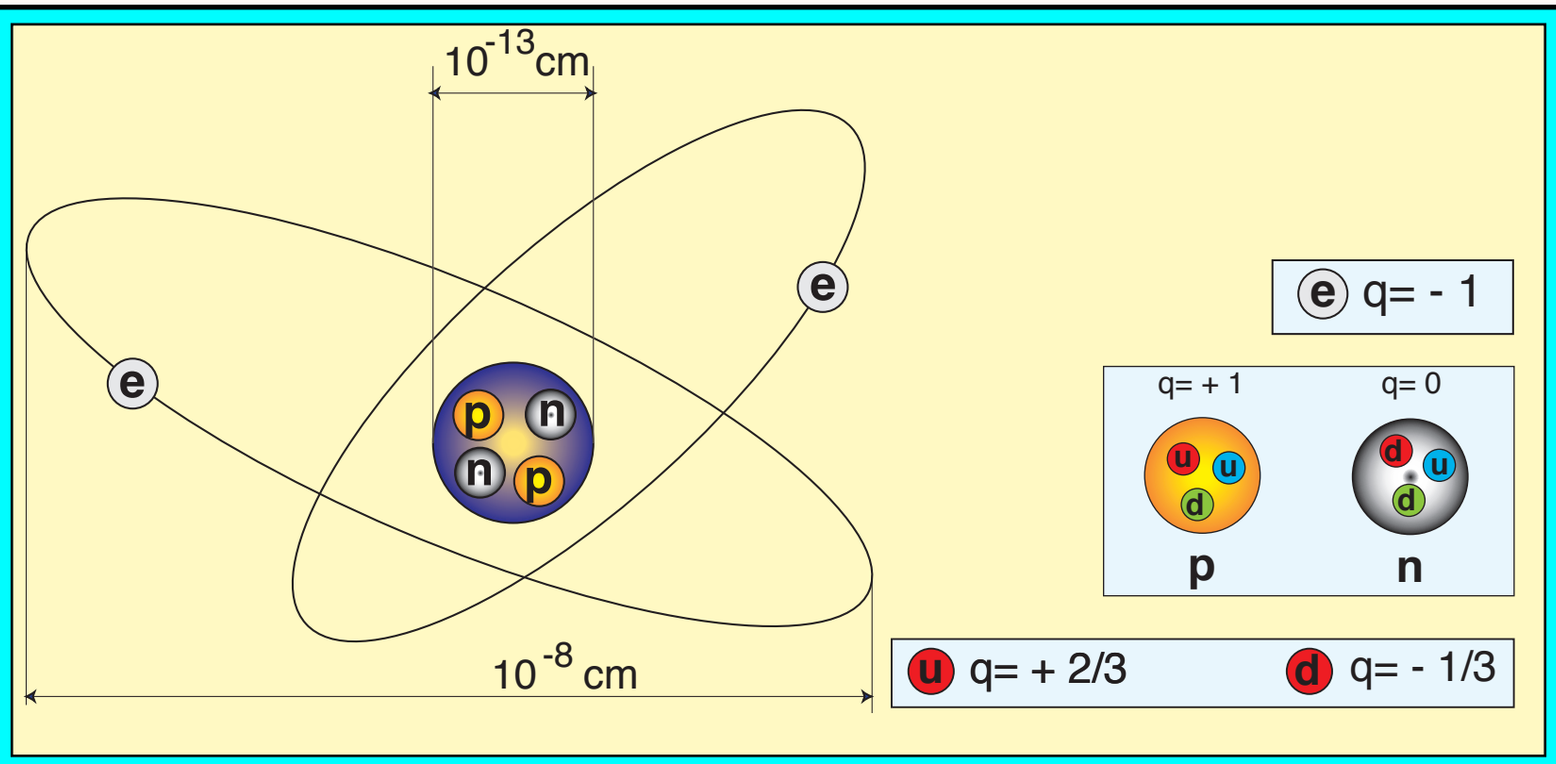
massive Y.M. field: $M_V^2 = e^2\langle\phi_1\rangle^2$

The BEH mechanism is consistent with quantum theory

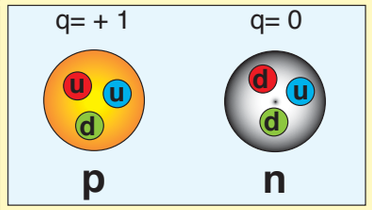
F. Englert, Proceedings of the 1967 Solvay Conference, p.18.

[1971] G.'t Hooft, M. Veltman (Nobel Prize 1999)

III. The Standard Model of elementary particles



particles (charge) [fermions]	
$e\ (-1)$ $\quad \nu_e\ (0)$	$u\,u\,u\ (\frac{2}{3})$ $\quad d\,d\,d\ (-\frac{1}{3})$
$\mu\ (-1)$ $\quad \nu_\mu\ (0)$	$c\,c\,c\ (\frac{2}{3})$ $\quad s\,s\,s\ (-\frac{1}{3})$
$\tau\ (-1)$ $\quad \nu_\tau\ (0)$	$t\,t\,t\ (\frac{2}{3})$ $\quad b\,b\,b\ (-\frac{1}{3})$



+ antiparticles

[1967] S. L. Glashow, A. Salam, S. Weinberg (Nobel Prize 1979)

interaction	range	elementary particles [bosons]
gravitation (1687) - (1915)	∞	graviton (?)
electromagnetism (1864 —)	∞	photon
weak interactions (1967) -(1971)	$\sim 10^{-16}$ cm	$W^+\ W^-\ Z$
strong interactions ($\sim$ 1970)	$\sim 10^{-13}$ cm	8 gluons

The BEH boson (1964 → 2012)

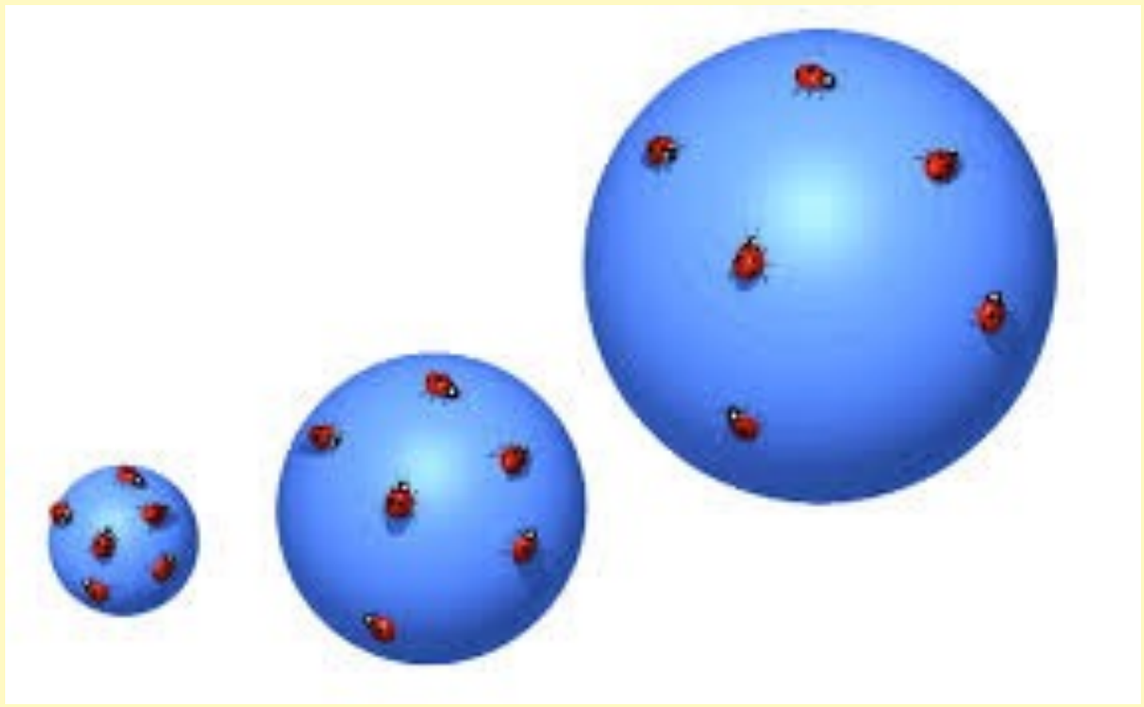
-The BEH mechanism generates all the masses of the elementary objects and is consistent with quantum theory

-The Standard Model contains all presently known elementary particles and all laws governing their behaviour.

IV. The Universe and the merging of the two "infinities"

The hot expanding Universe

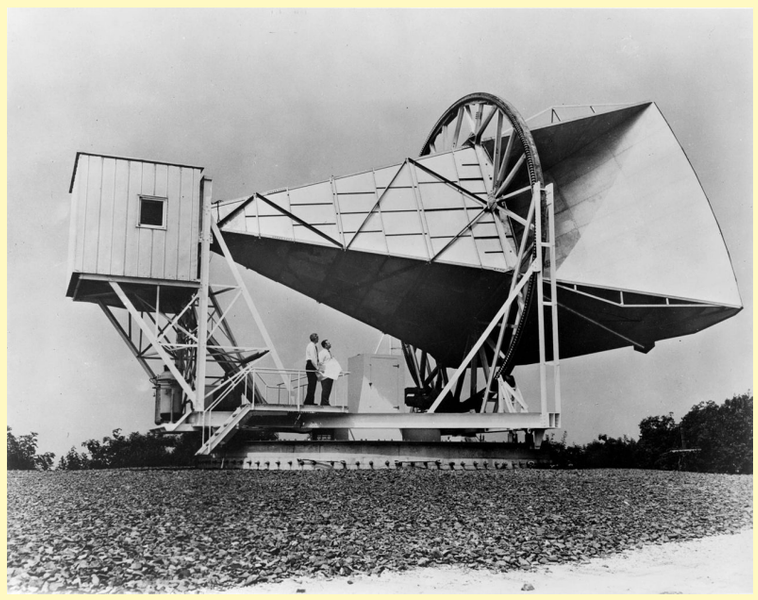
The Lemaître-Hubble expansion (1927-1929)



The Hubble "constant" is now

70 (km/sec)/Mps

The Cosmic Microwave Radiation (CMB)



1965

The Universe had a beginning and was primordially hot

Towards the merging of the two "infinities"

Baryonic matter 4% ***Dark matter 26%*** ***Dark energy 70%***

Large scale structures

V. Mukhanov and G. Chibisov, JETP. Lett. 33 (1981) 532.

Quantum fluctuations

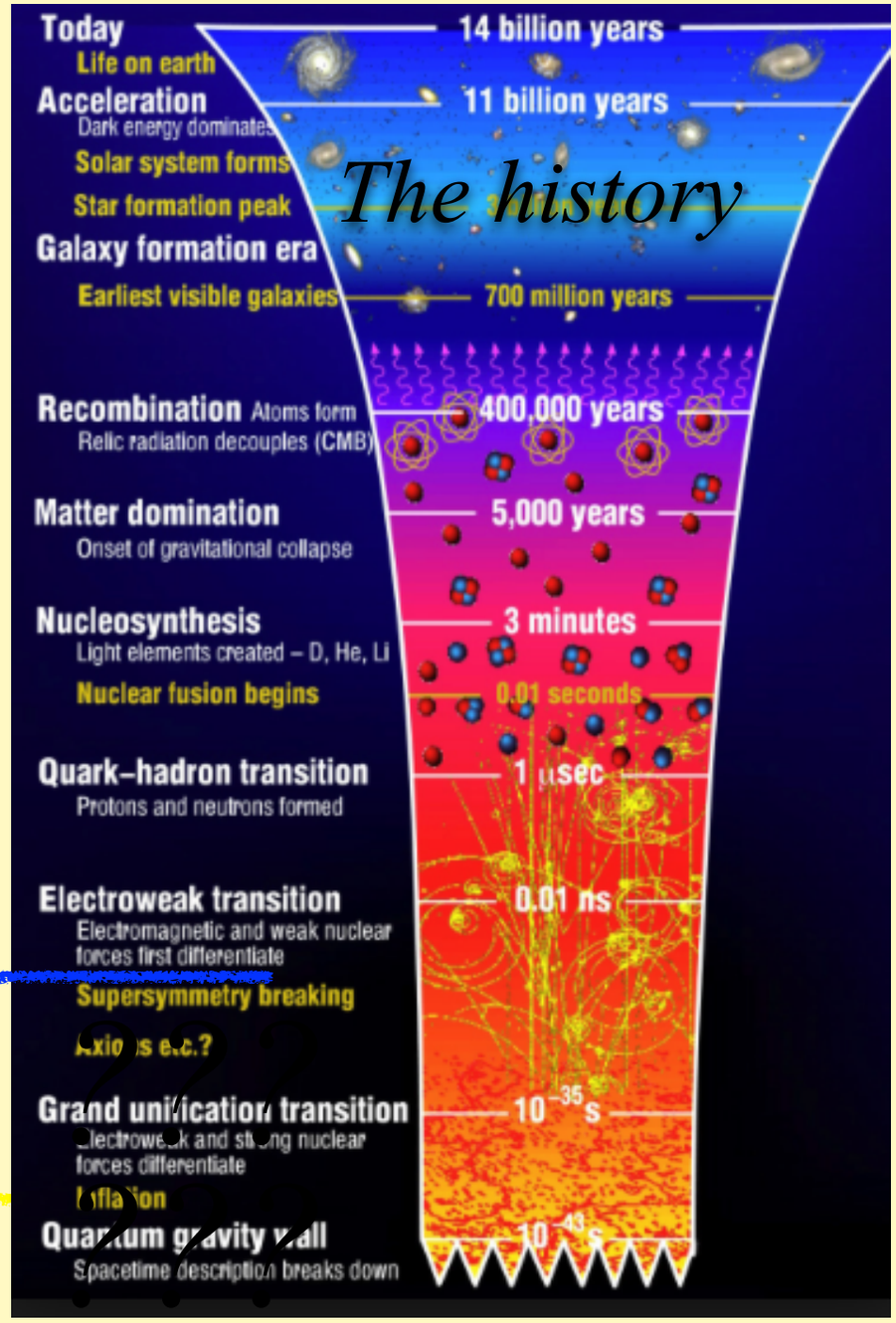
Quantum birth of the Universe

E.P. Tryon, Nature 246 (1973) 396.

G. Lemaître, Nature 127 (1931) 706.

Inflation

The Standard Model of elementary particle + General Relativity



Quantum gravity ?

Quantum birth of the universe from exponential expansion

R. Brout, F. Englert, E. Gunzig, Ann. of Physics 115 (1978) 78, Gen. Rel. and Grav. 10 (1979) 1.
R. Brout, F. Englert, Ph. Spindel, Phys. Rev. Lett. 43 (1979) 417.
R. Brout, F. Englert, J-M. Frère, E. Gunzig, P. Nardone and C. Truffin, Nucl. Rhys. B170 [FS1] (1980) 228.

V. The Unknown

With the Standard Model of elementary particules, and the measured values of cosmological parameters, we may reasonably reconstruct the history of the universe and its particle content up to 10^{-11}s after its birth.

Beyond the Standard Model, Neutrinos, Parameters,

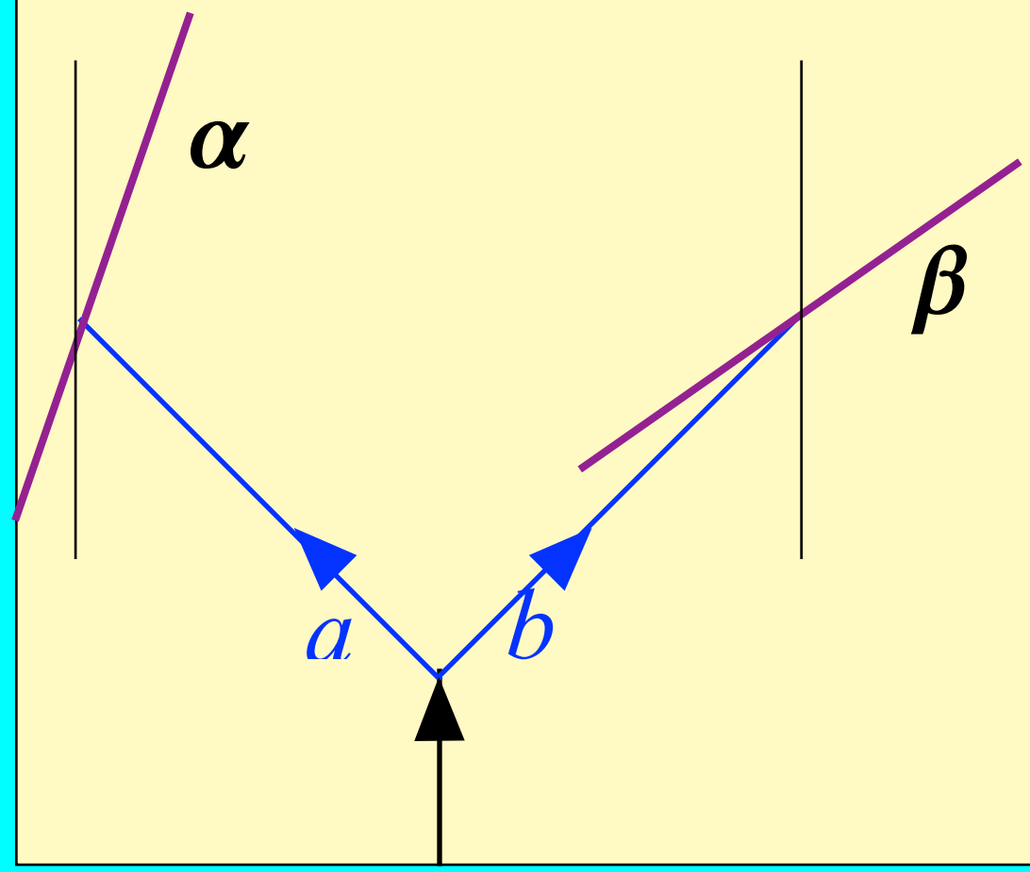
Dark Matter (25%), Dark energy (70%)

The complexity issue ***Quantum gravity*** ***Quantum theory***

The quantum puzzle

Quantum theory is remarkably verified as a theory predicting the outcome of an experiment in terms of probabilities.

What underlies the probability ?



The result indicates that the detected photons have well defined parallel polarisations after a measurement

Is quantum theory incomplete ?

Are there underlying "classical" variables?

No way to construct hidden local classical variables : Bell's theorem

Bell's theorem excluding local hidden variables assumes that the settings of the polarisers can be freely chosen without altering past events (=free will)

Hidden variables are not excluded if they underly everything

Complete determinism would invalidate Bell's theorem