QUANTUM PHYSICS

ATTEMPT OF A PUBLIC INTRODUCTION

Michael Spira (PSI)

I Special Relativity

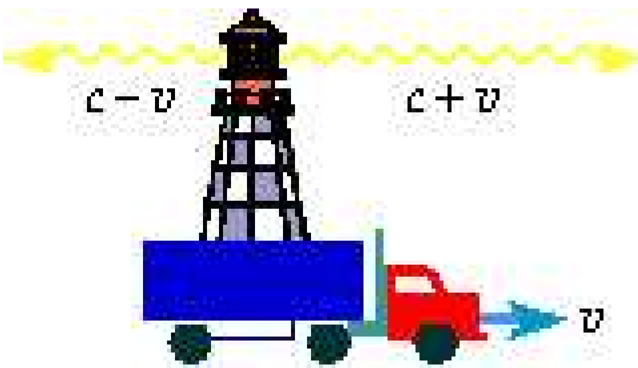
II General Relativity

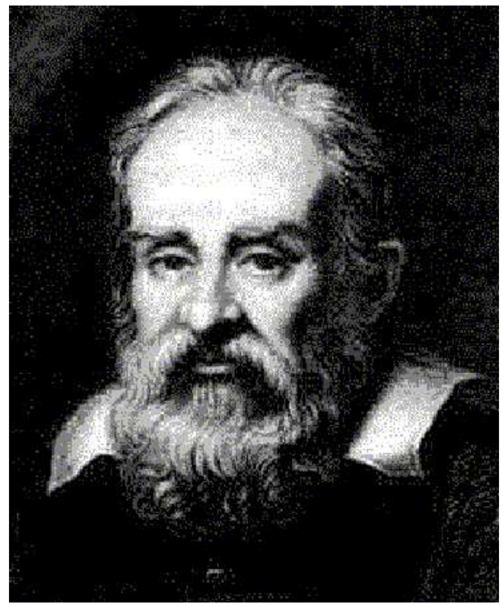
III Quantum Physics

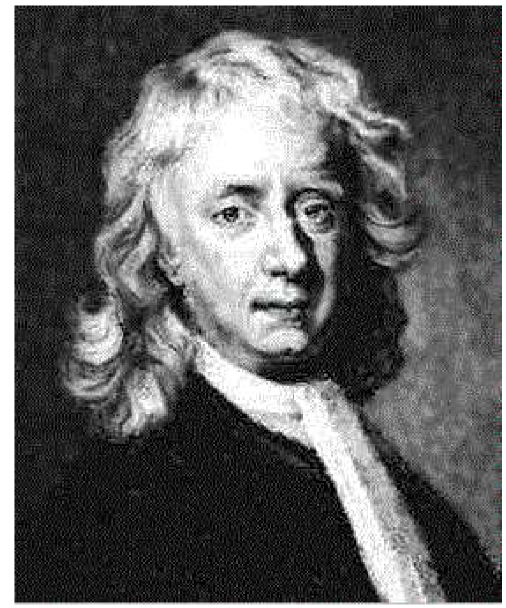
IV Elementary Particles (Quantum Field Theory)

I SPECIAL RELATIVITY

- Galilei (1636), Newton(1687): physics equivalent in all intertial frames [systems moving with respect to each other with a constant speed (not excluding a speed of zero)]

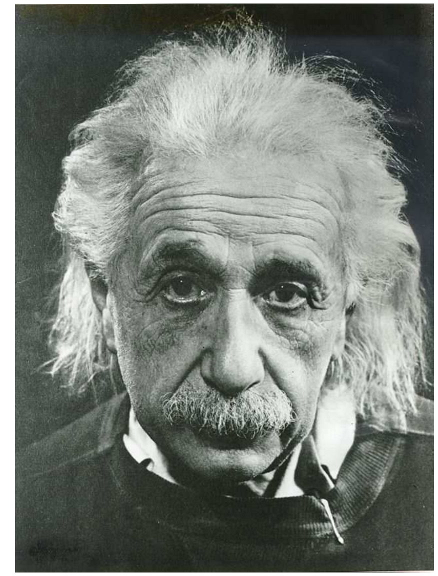






- common believe: light propagates through ether with speed c

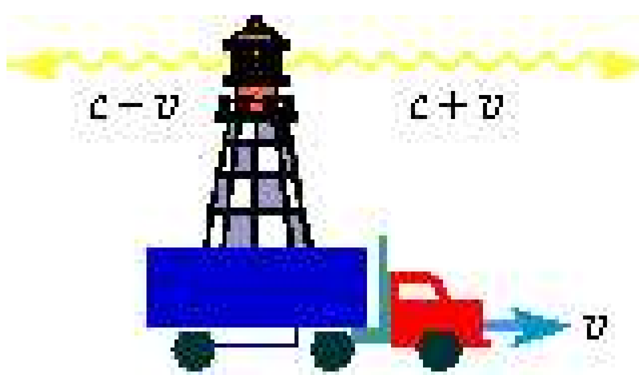
Einstein (1905):



1.) Any two inertial systems of reference are equivalent. In other words, all the physical laws must have the same form in every inertial system.

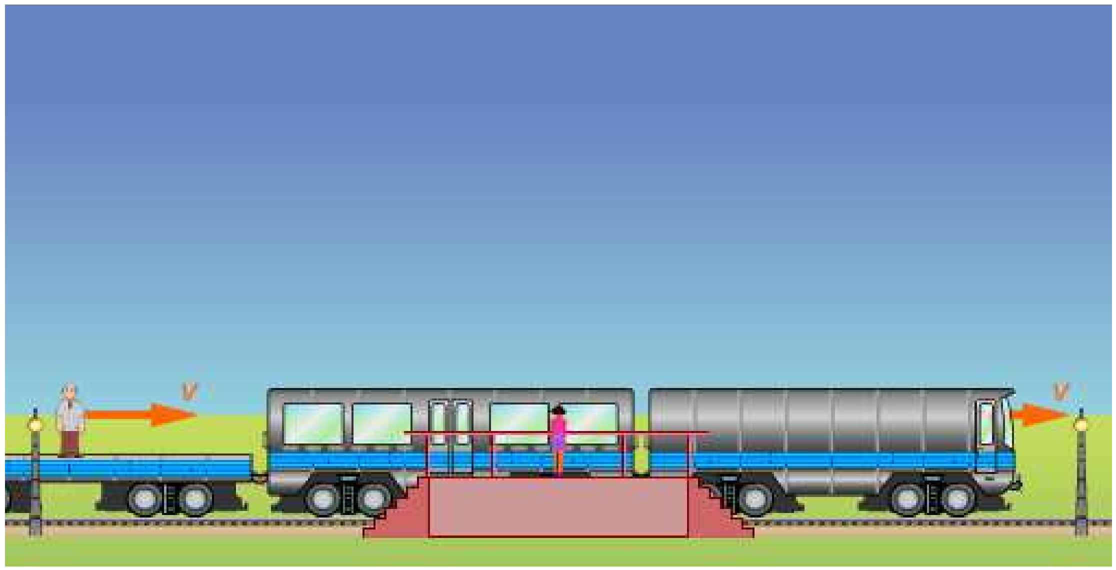
2.) The speed of light in a vacuum is the highest possible speed by which information can be exchanged between two events. Its value is independent of the inertial system (no ether!).

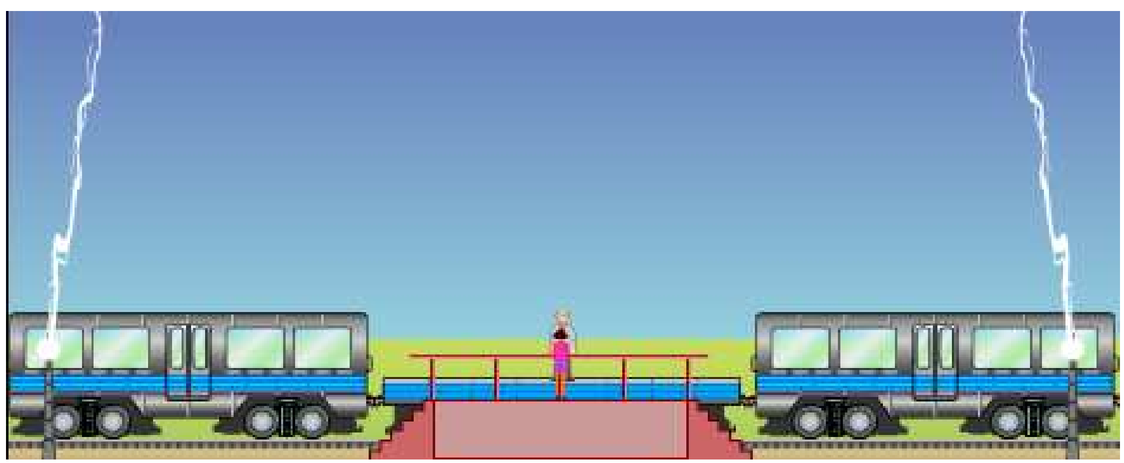
$$\boxed{c = 299792.458 \text{ km/s}}$$



???

PROBLEM OF SIMULTANEITY





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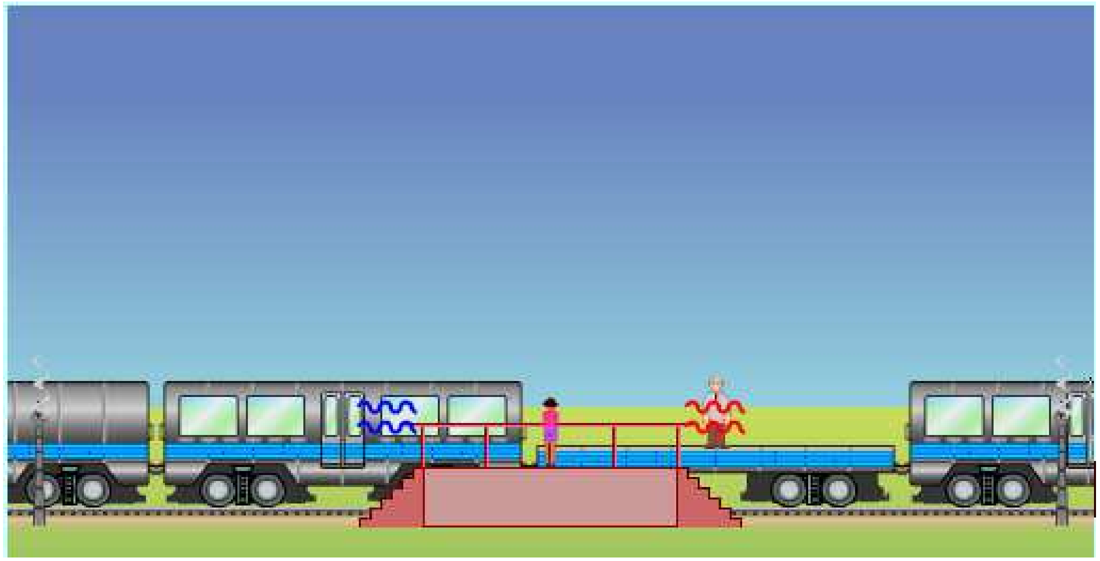
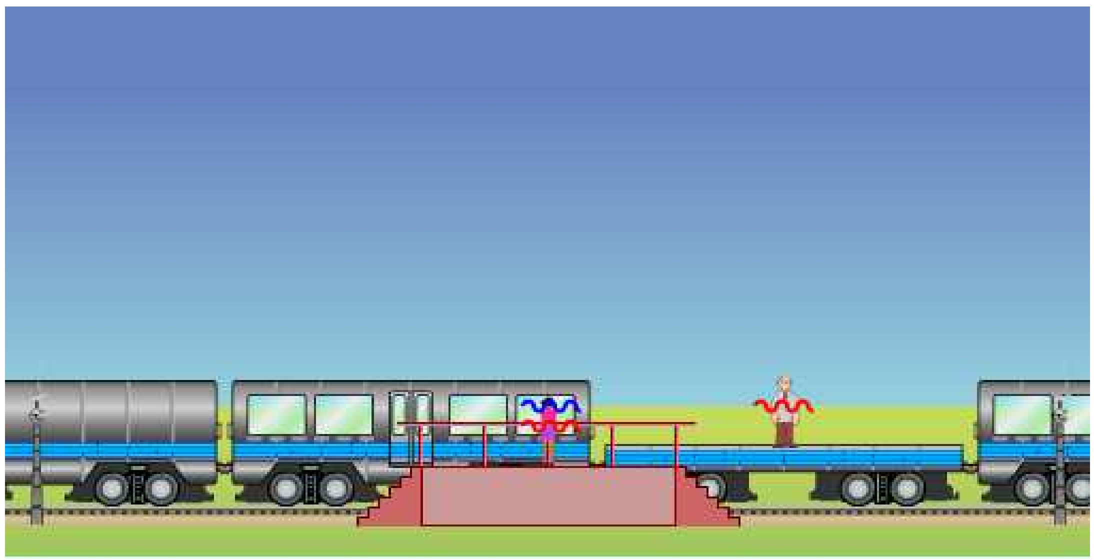
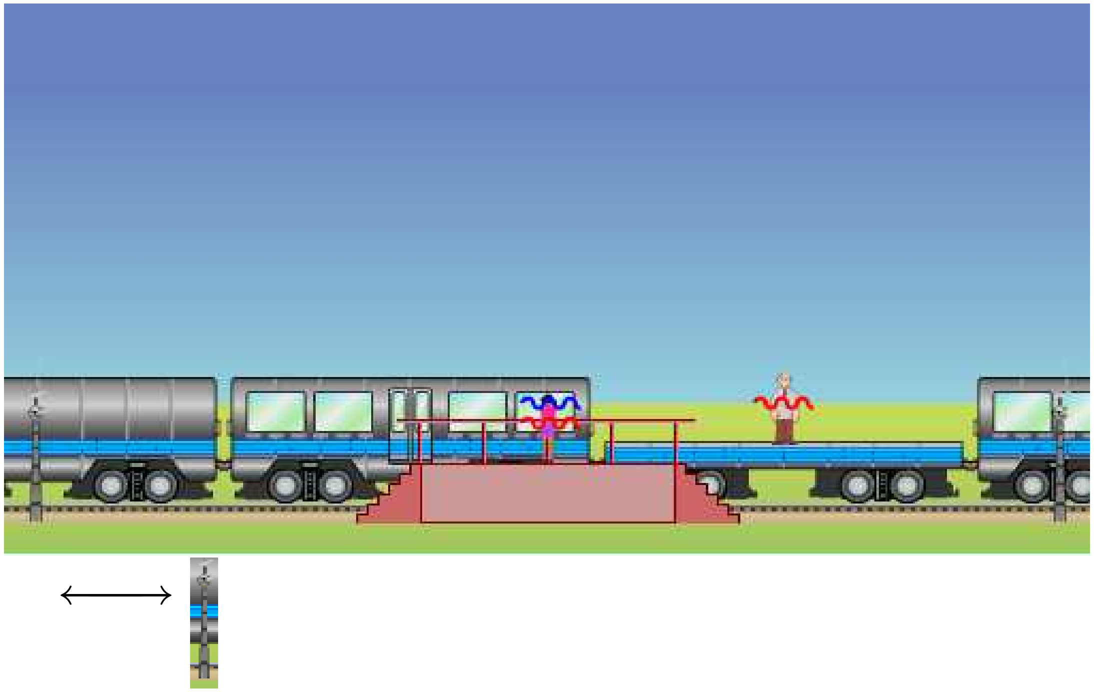
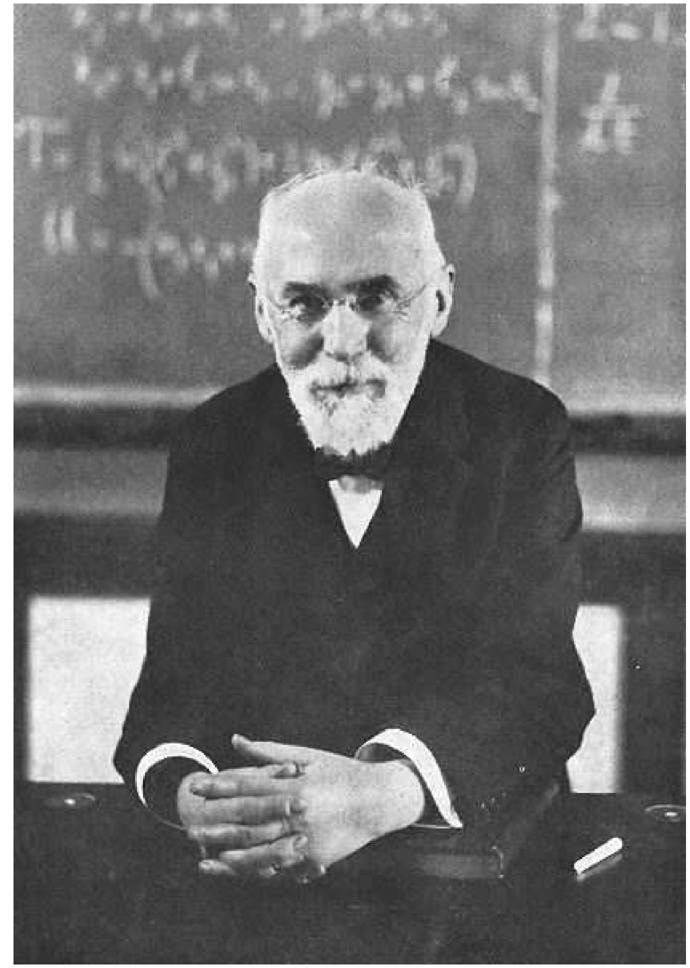




LORENTZ CONTRACTION





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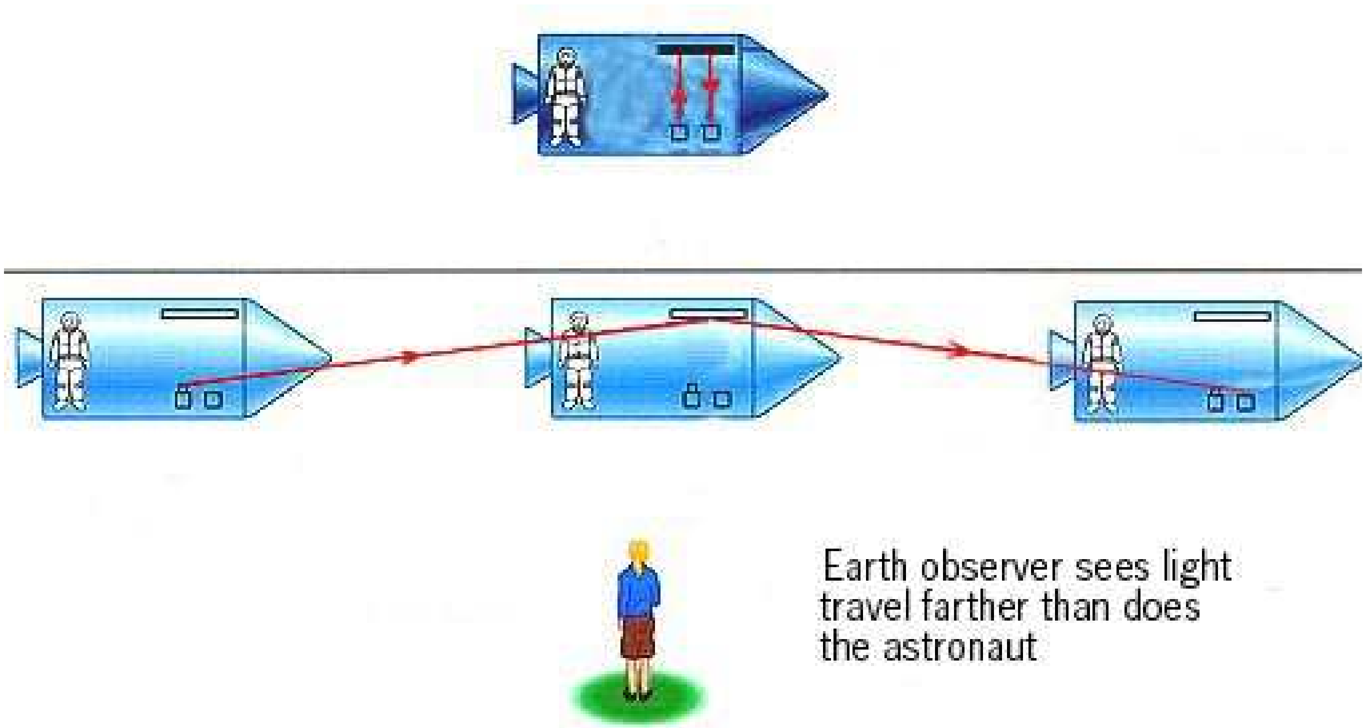
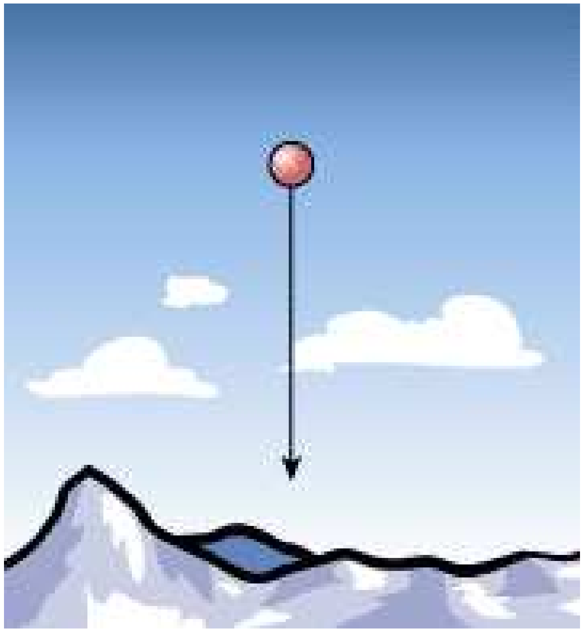
TIME DILATATION



ATMOSPHERIC MUONS

Life time 2.2 $\mu s \Rightarrow$ L $\sim$ 700 m
Atmosphere: 10 km ???



ATMOSPHERIC MUONS

Life time 2.2 $\mu s \Rightarrow$ L $\sim$ 700 m
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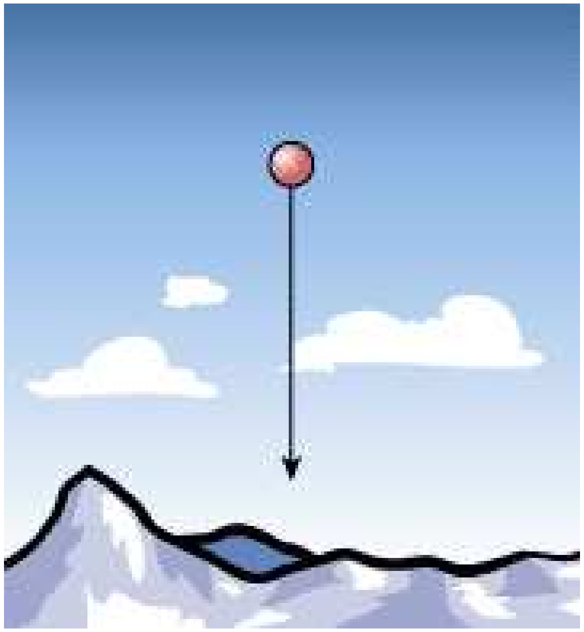
earth: time dilatation 50 $\mu s \Rightarrow$ L $\sim$ 15 km

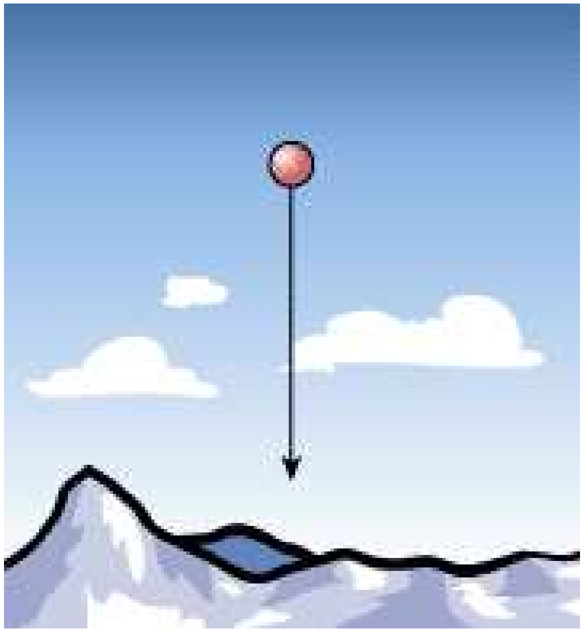


ATMOSPHERIC MUONS

Life time 2.2 μs $\Rightarrow$ L $\sim$ 700 m
Atmosphere: 10 km ???

earth: time dilatation 50 μs $\Rightarrow$ L $\sim$ 15 km

muons: Lorentz contraction L $\sim$ 450 m



TWIN PARADOX

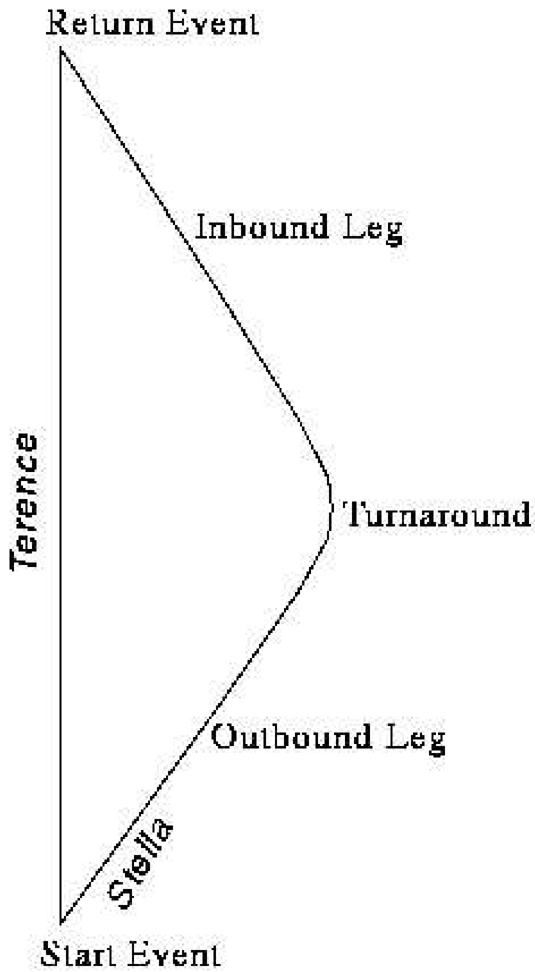


Figure 1: The Twin's Worldlines

TWIN PARADOX

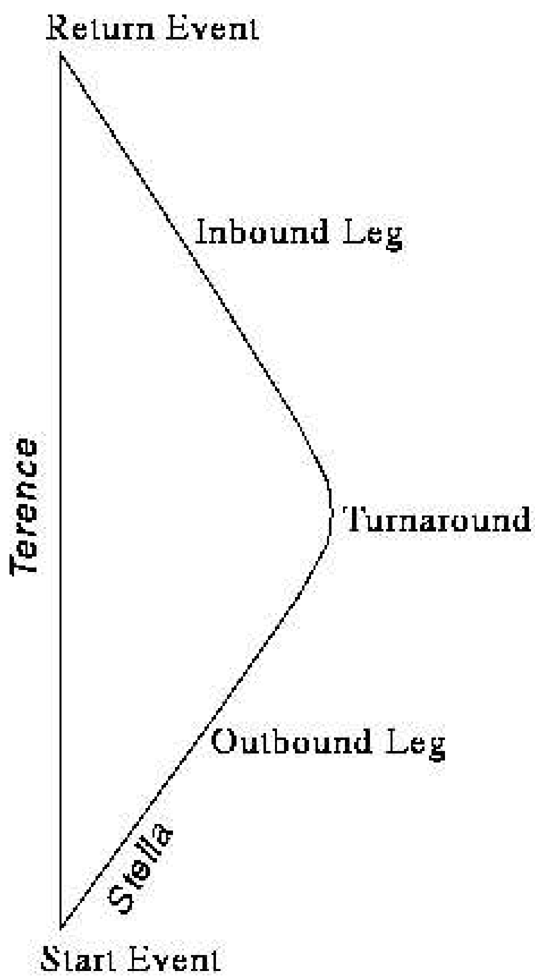


Figure 1: The Twin's Worldlines

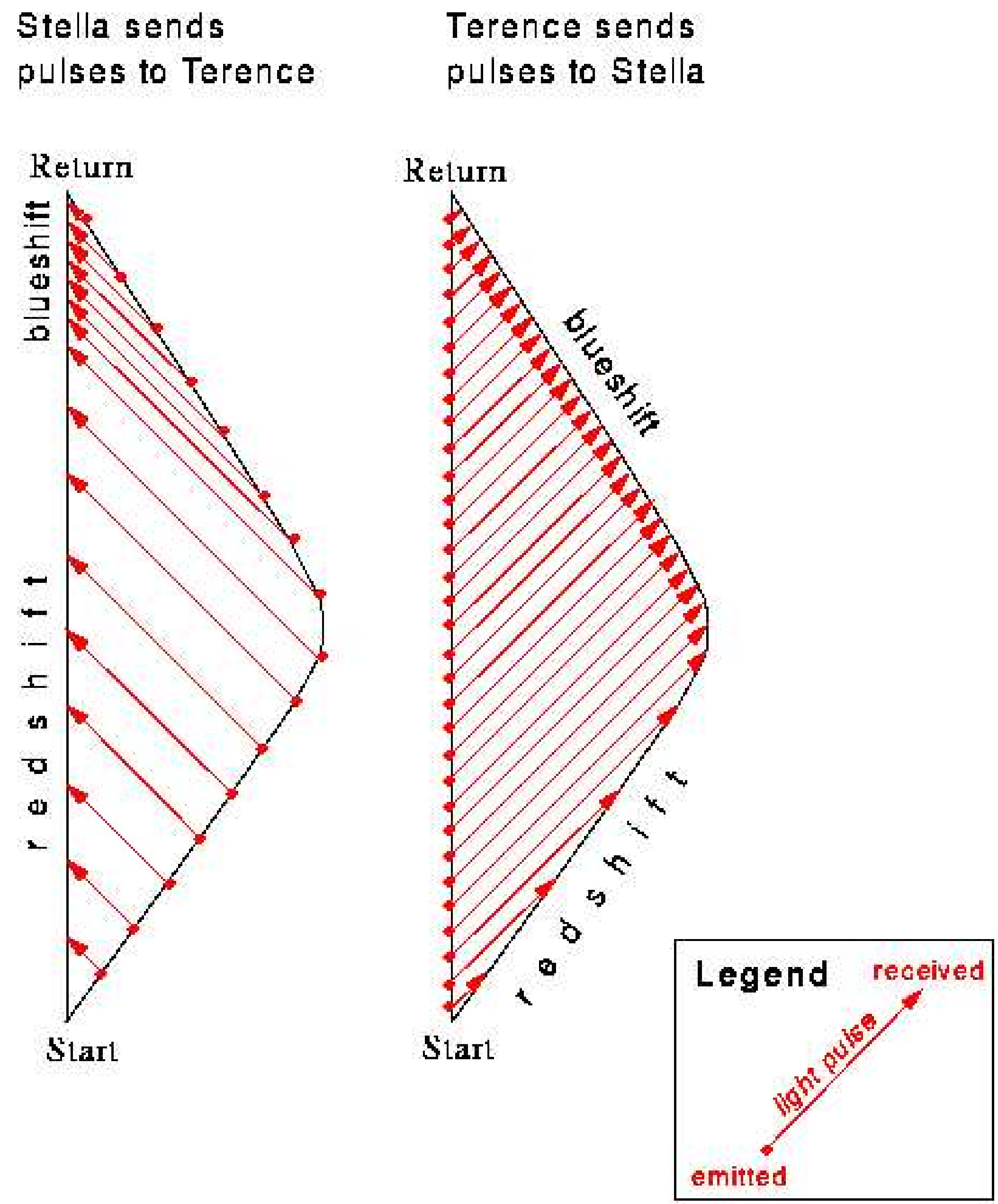
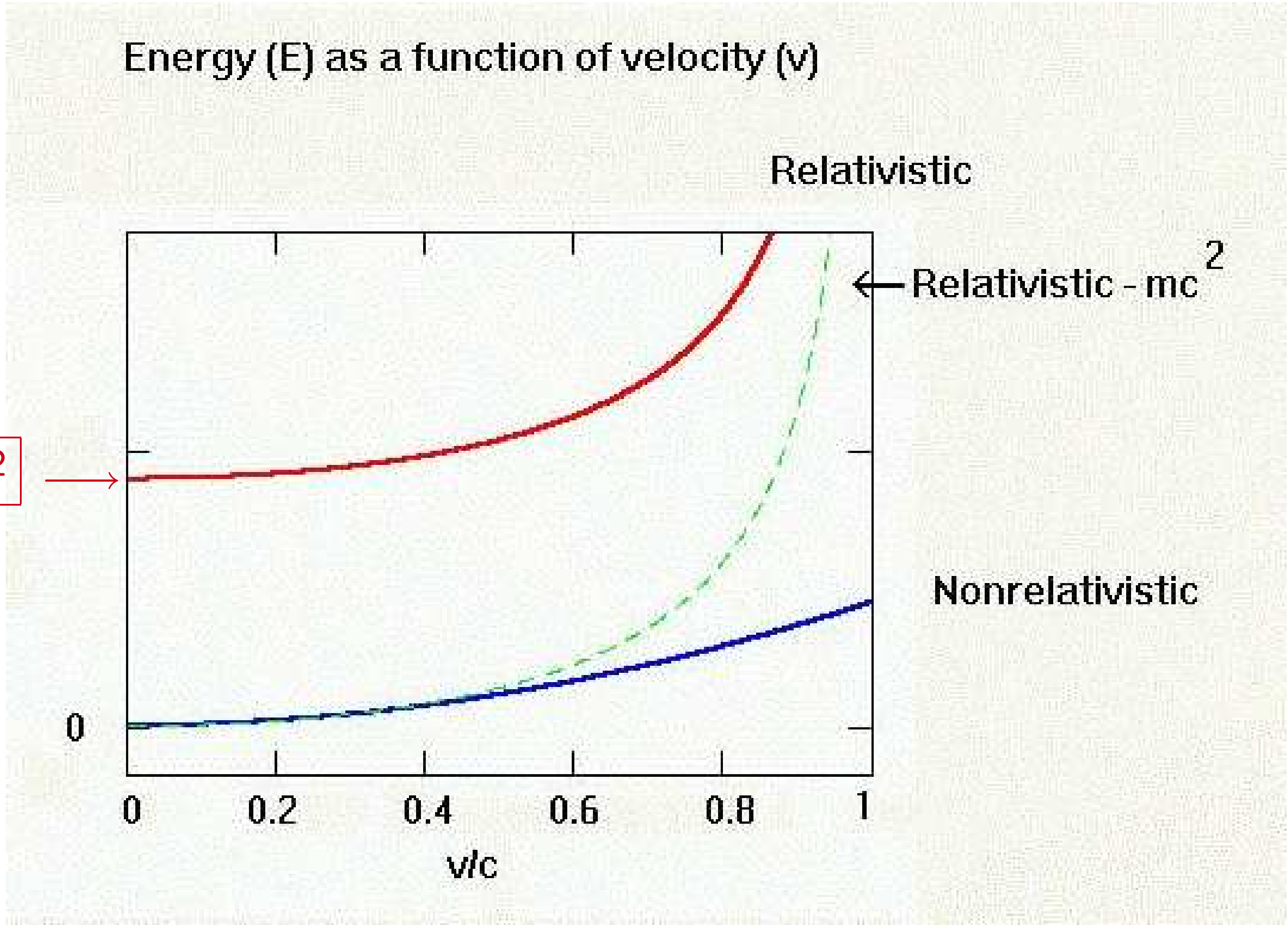


Figure 2: The Doppler Shift Explanation

ENERGY AND MASS

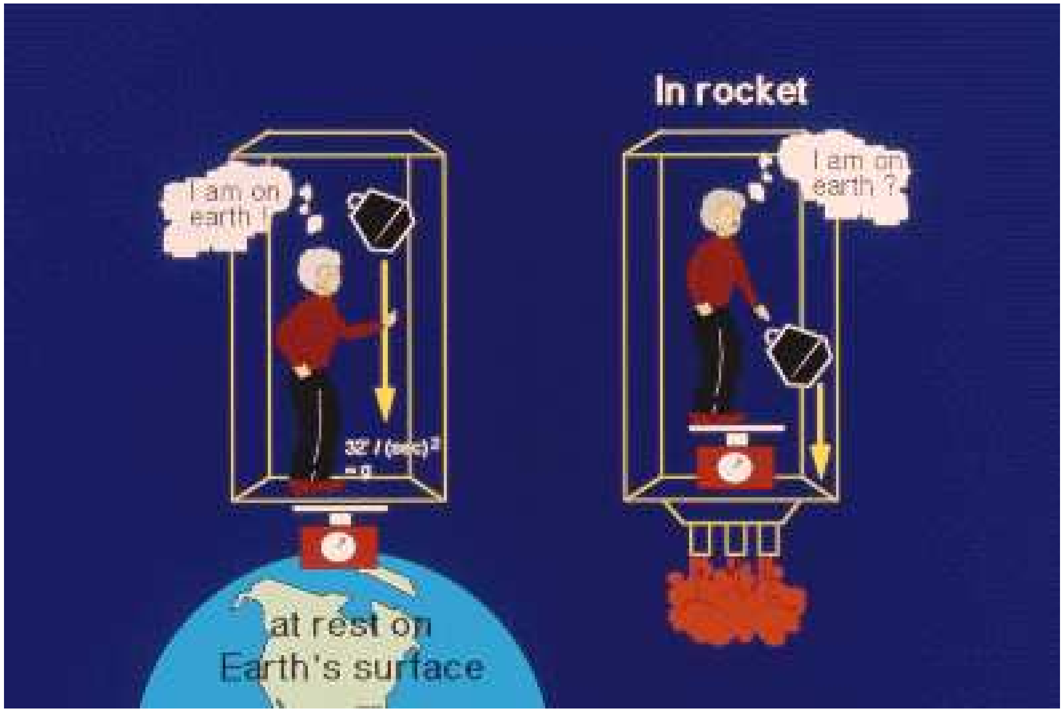


$E = mc^2$ $\longrightarrow$

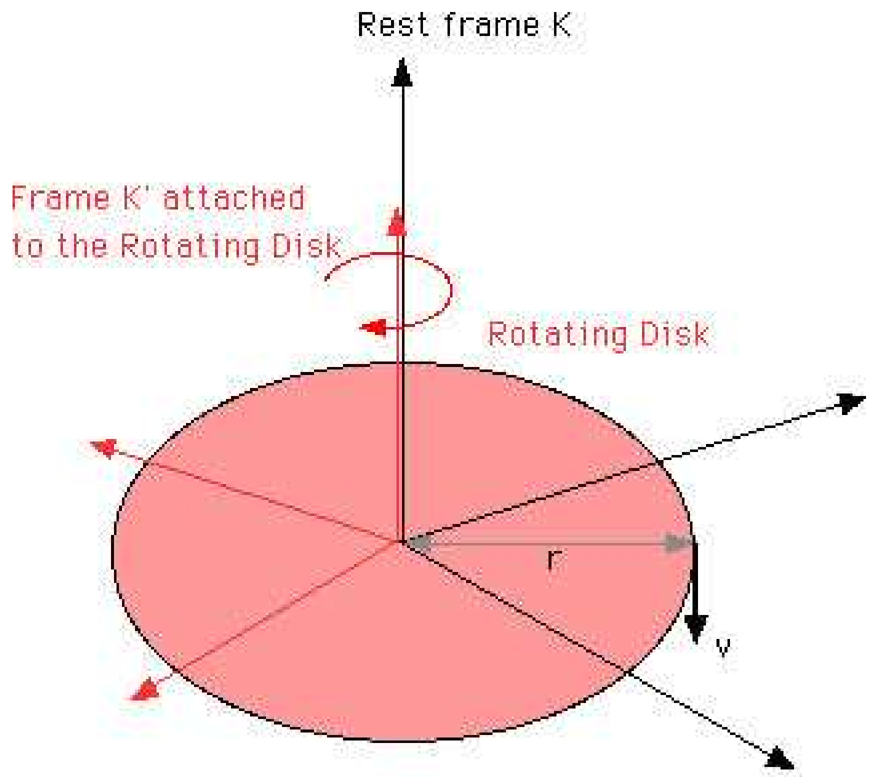
- Energy weighs!!

II GENERAL RELATIVITY

Einstein (1916): physics equivalent in **all** frames



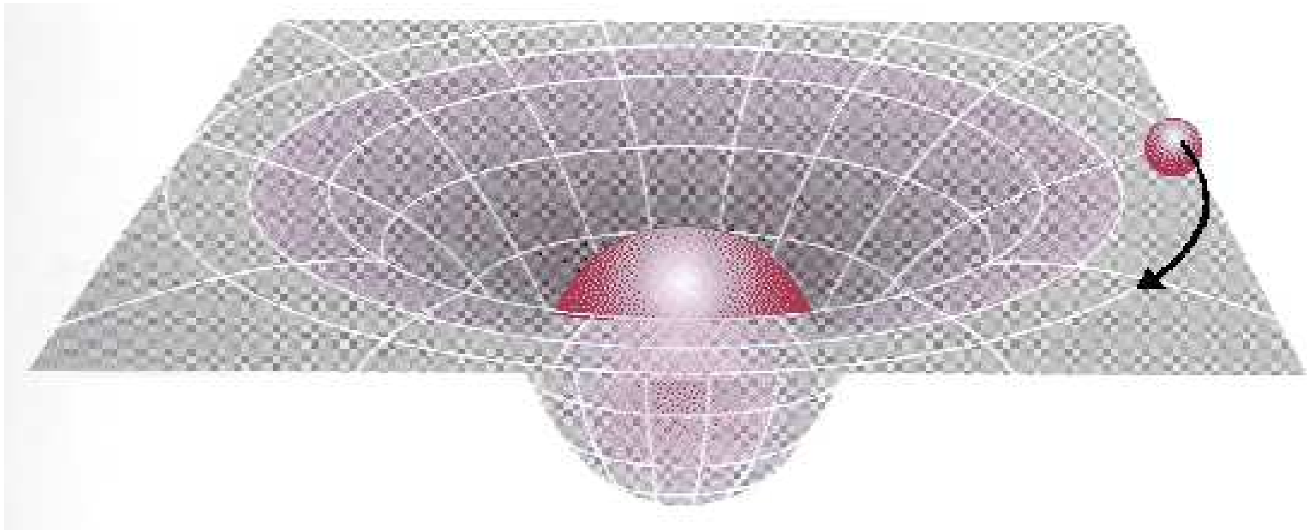
acceleration = gravitational field

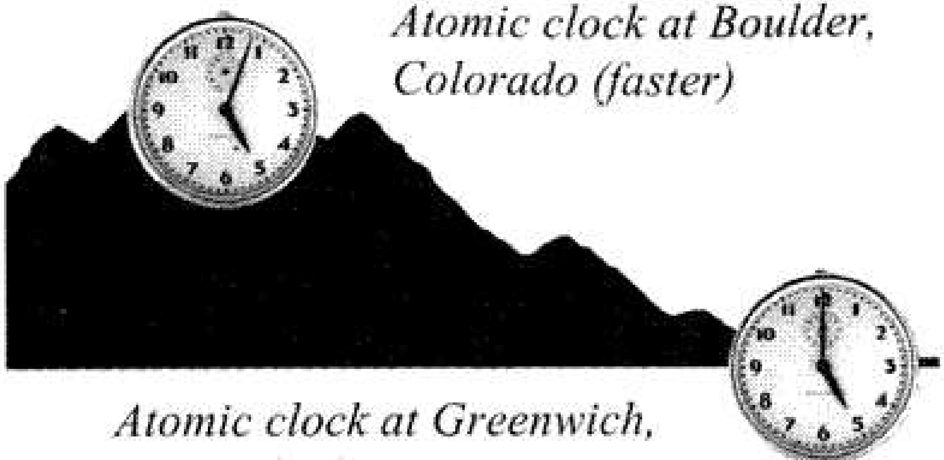


Centrifugal force = gravitational force

Lorentz contraction $\Rightarrow$ Circumference/diameter $< \pi$

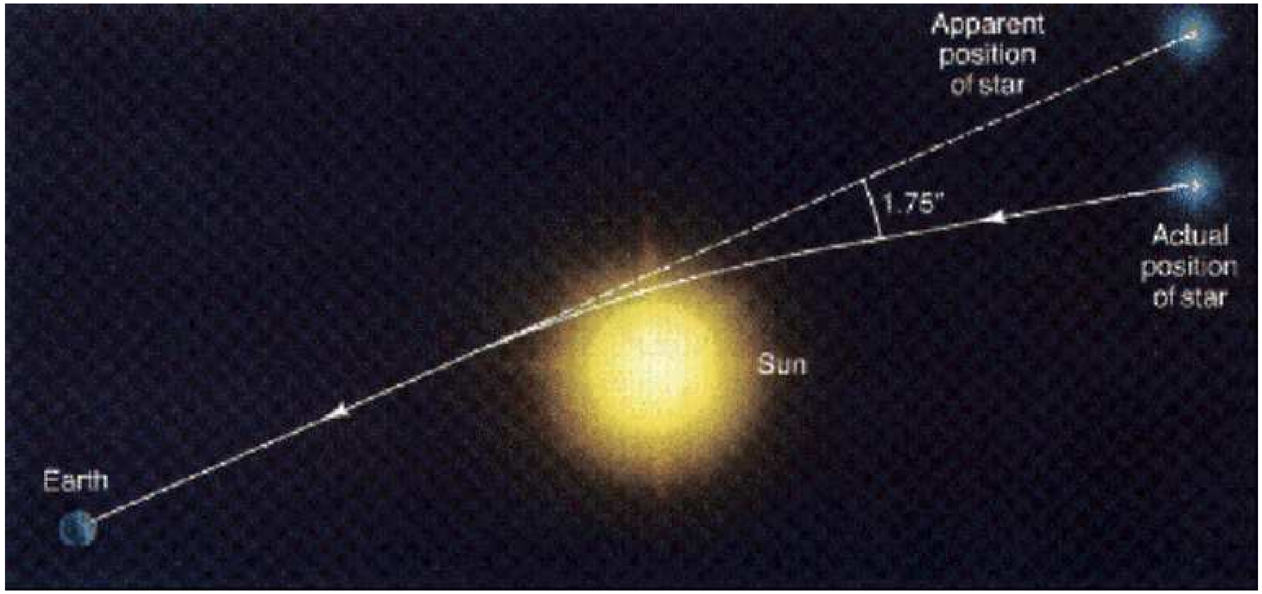
$\Rightarrow$ $\boxed{\text{disc is curved}}$



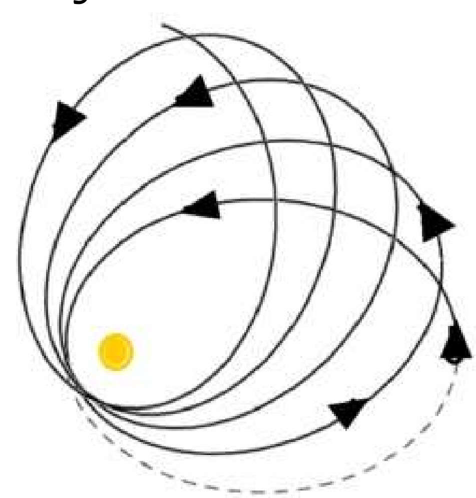


Gravitational Time Dilation: *The rate at which an atomic clock records time is diminished as gravity increases.*

light aberration in gravitational field of sun:

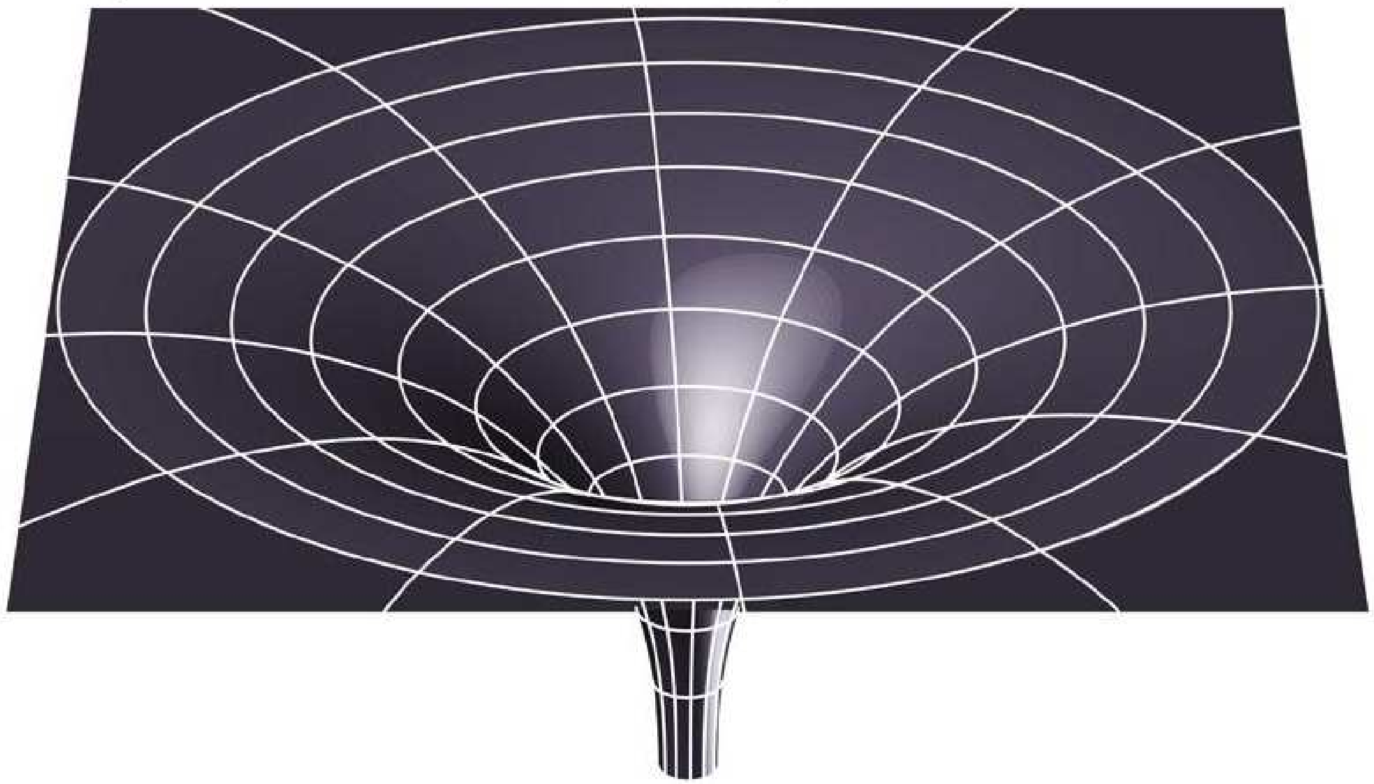


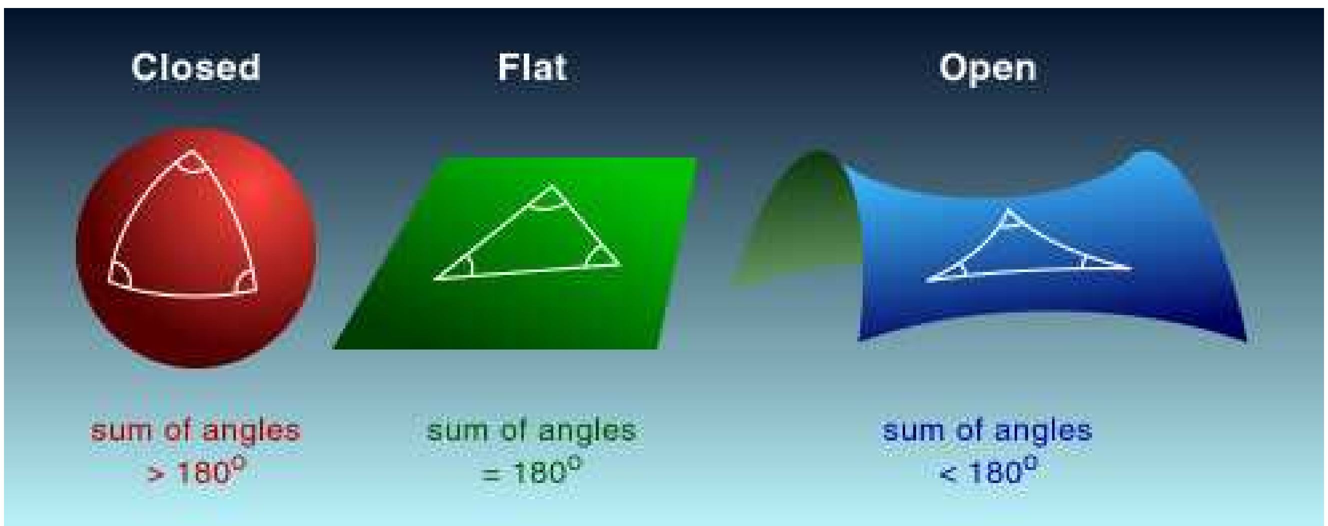
perihel movement of Mercury: 43"/century



Precession of the Perihelion of Mercury
The dashed line is the orbit in Newtonian theory.

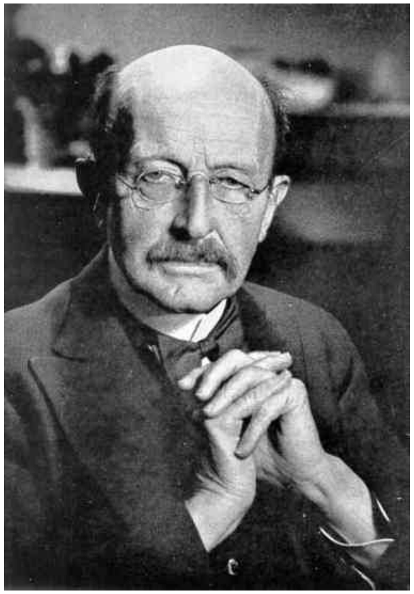
spacetime around the Sun compressed to a black hole

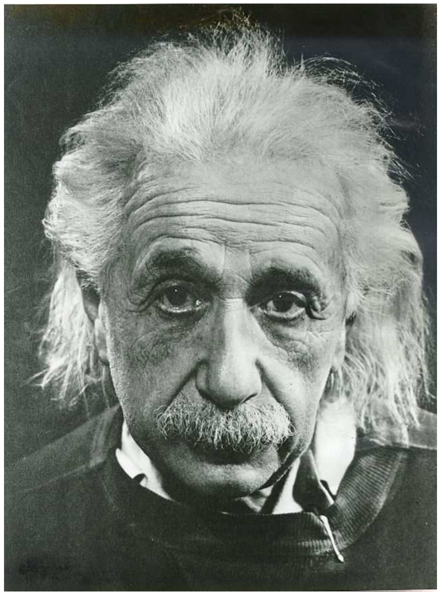




III QUANTUM PHYSICS

Planck (1900): black body radiation not continuous but quantized
(Nobel prize 1918)

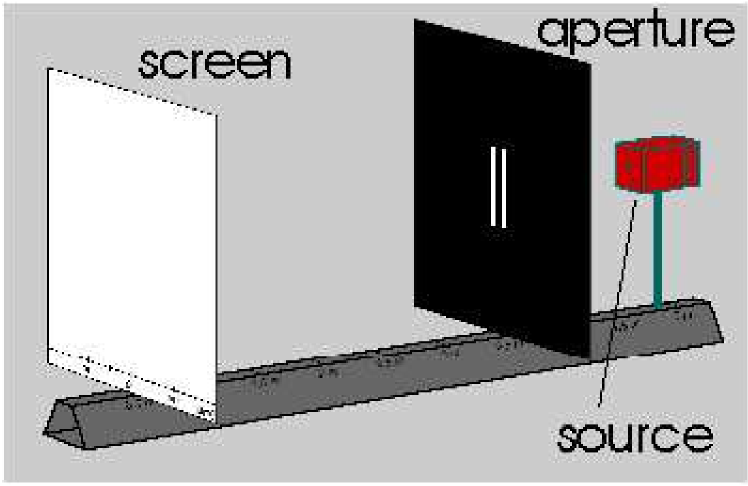


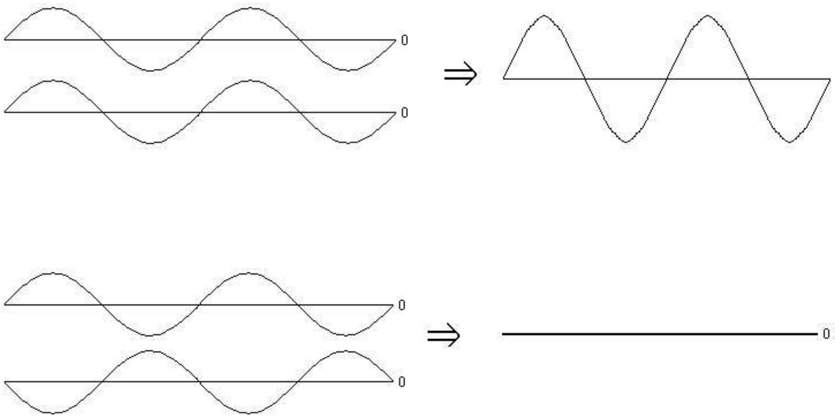


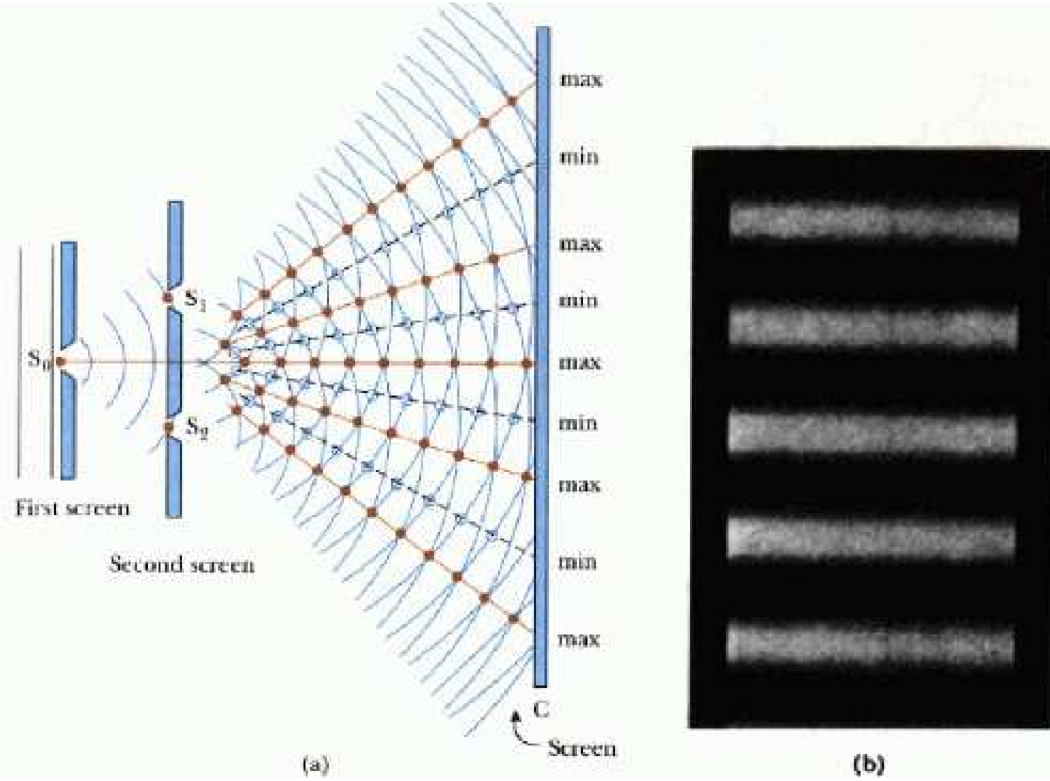
Einstein (1905): Photoeffect $\Rightarrow$ light always quantized $\Rightarrow$ photons
(Nobel Prize 1921)

$$\Rightarrow \boxed{E = h\nu}$$

DOUBLE SLIT EXPERIMENT







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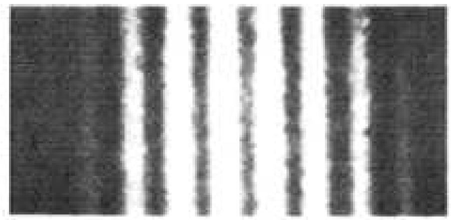
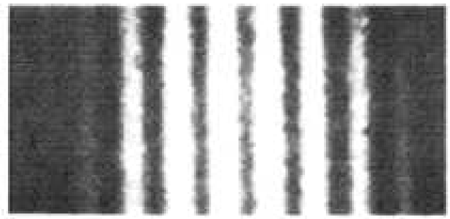


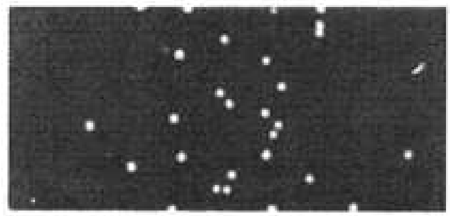
light

DOUBLE SLIT EXPERIMENT

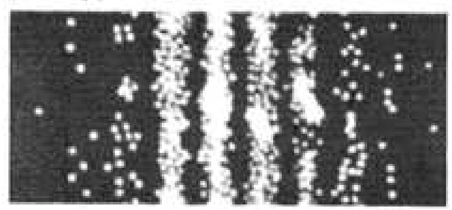


light

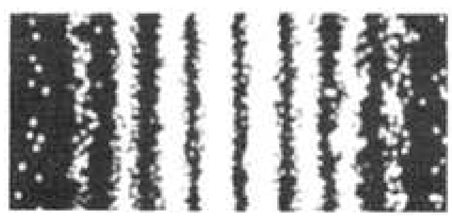
electrons



(a) After 28 electrons



(b) After 1000 electrons



(c) After 10000 electrons

- every particle: particle and wave character

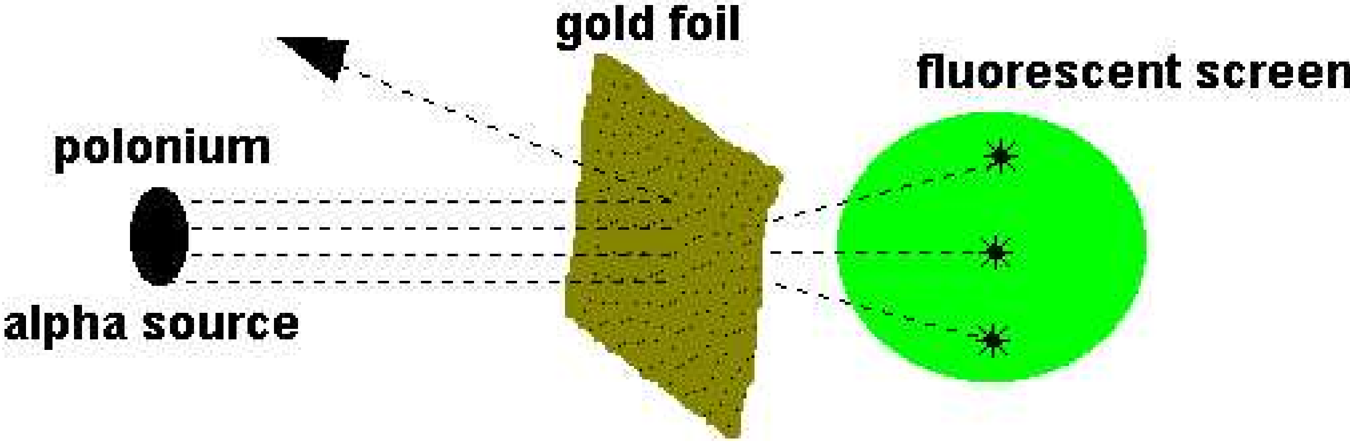
- interference: wave function ψ

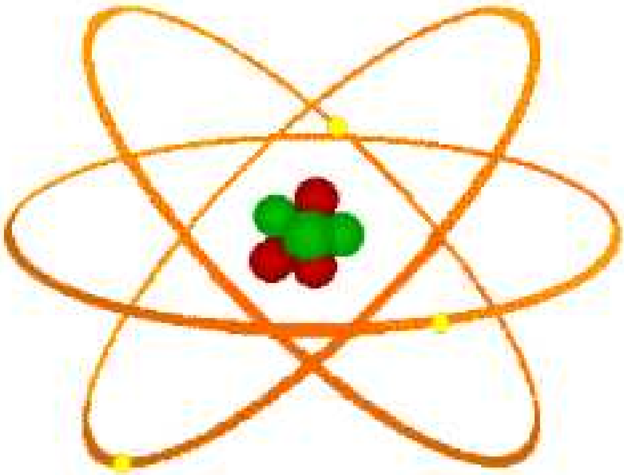
- Born (1929): $|\psi|^2$ = probability

$\Rightarrow$ only probabilities calculable!
(Nobel Prize 1954)

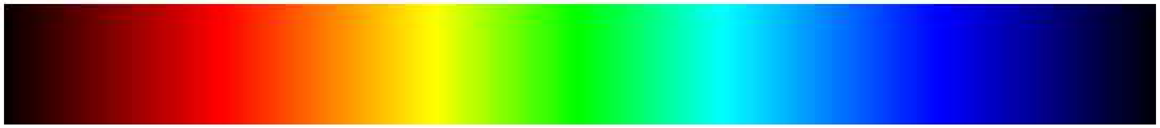
ATOMS

- Rutherford (1911): small nucleus, large electron orbits

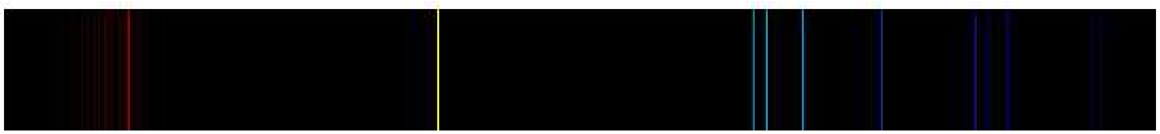




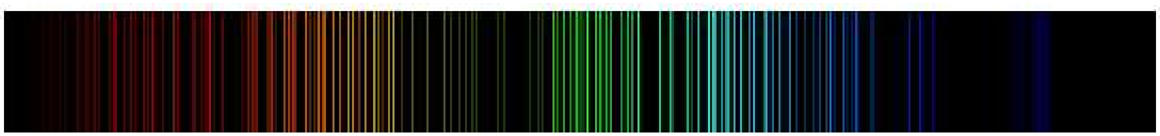
ATOMS



white light



helium



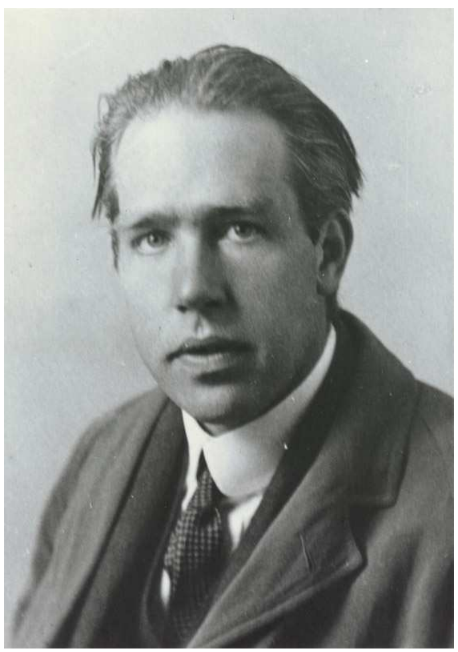
phosphorus

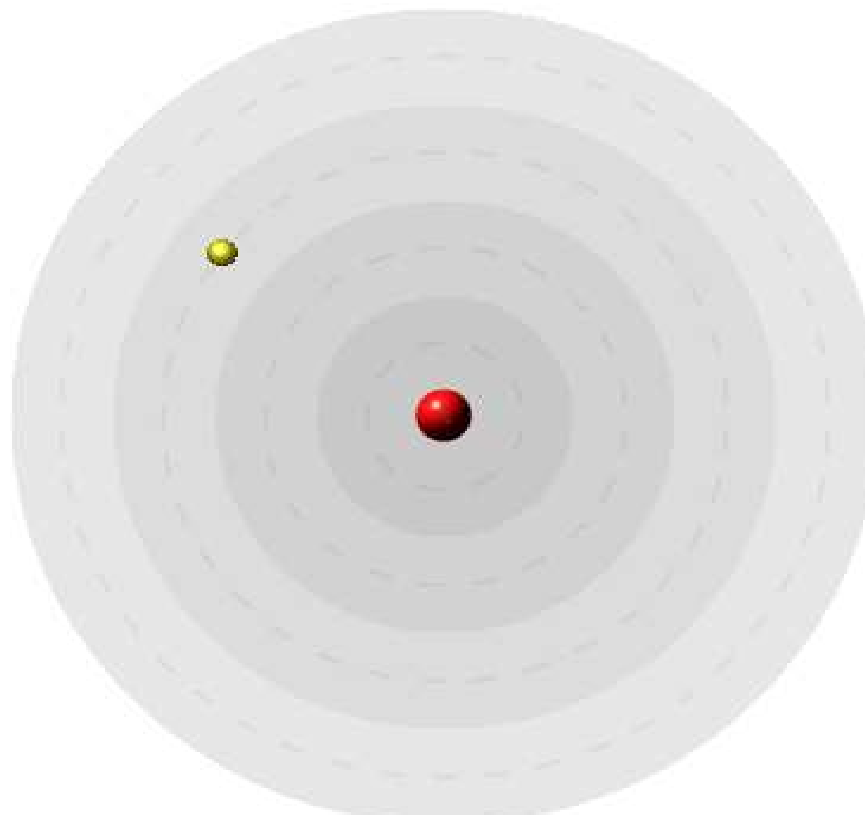
- light emission: discrete spectral lines ???

ATOMS

- Bohr (1913): electron orbits quantized
  (Nobel prize 1922)

change of orbit: photon emission with fixed energy
$\Rightarrow$ discrete spectral lines





ATOMS

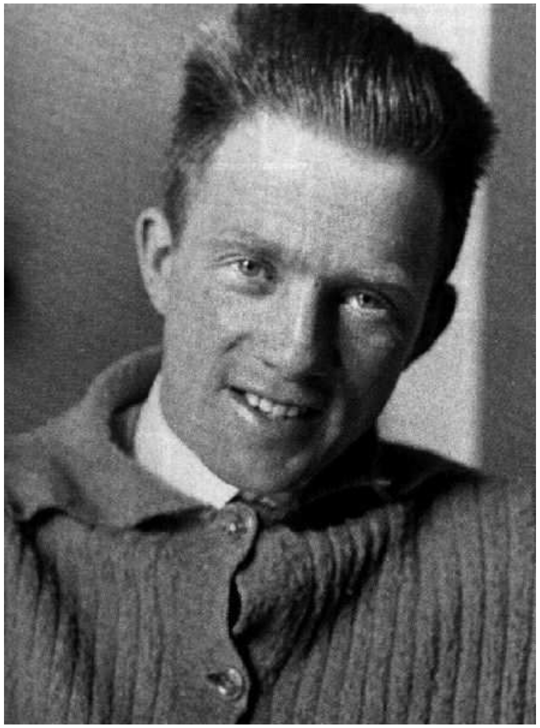
- Pauli (1924): only two electrons per orbit
  $\Rightarrow$ atoms stable
  (Nobel prize 1945)

- derivation of Pauli principle 1940

UNCERTAINTY RELATION

- Heisenberg (1927): $\Delta x \cdot \Delta p \geq \dfrac{\hbar}{2}$
  (Nobel prize 1932)

- Schrödinger equation (1926): calculation of ψ
  (Nobel prize 1933)

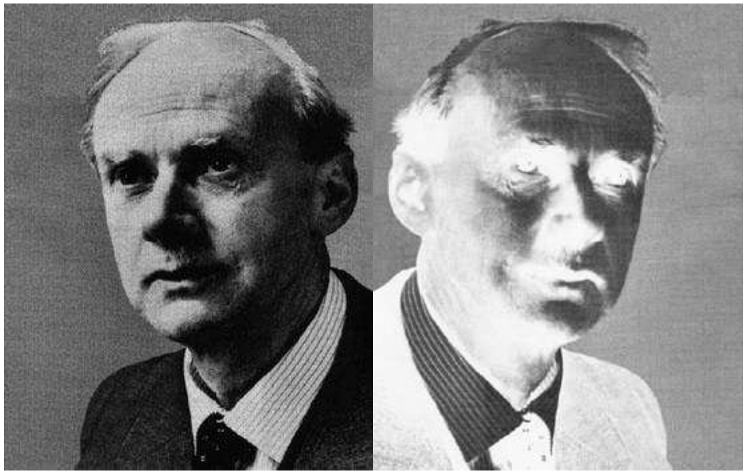


IV ELEMENTARY PARTICLES (QUANTUM FIELD THEORY)

- Dirac (1929): relativistic quantum theory ⇒ Dirac equation

⇒ existence of antimatter

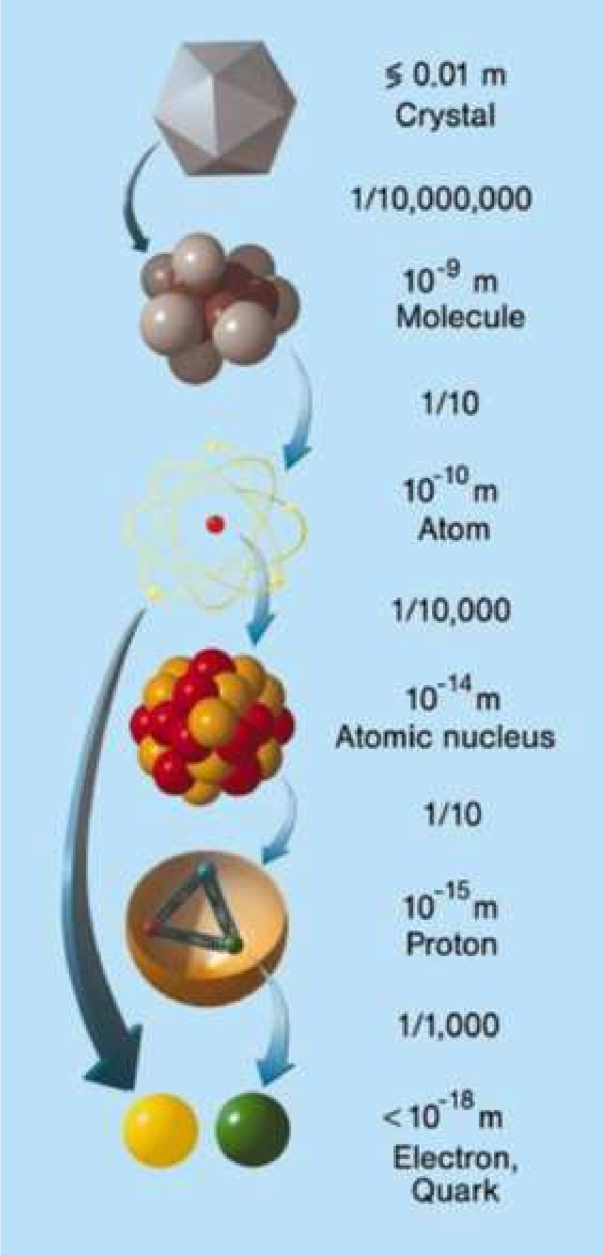
(Nobel prize 1933)



- today: there exists an antiparticle for every particle

- $E = mc^2$: annihilation/creation of massive particles into/from e.g. photons

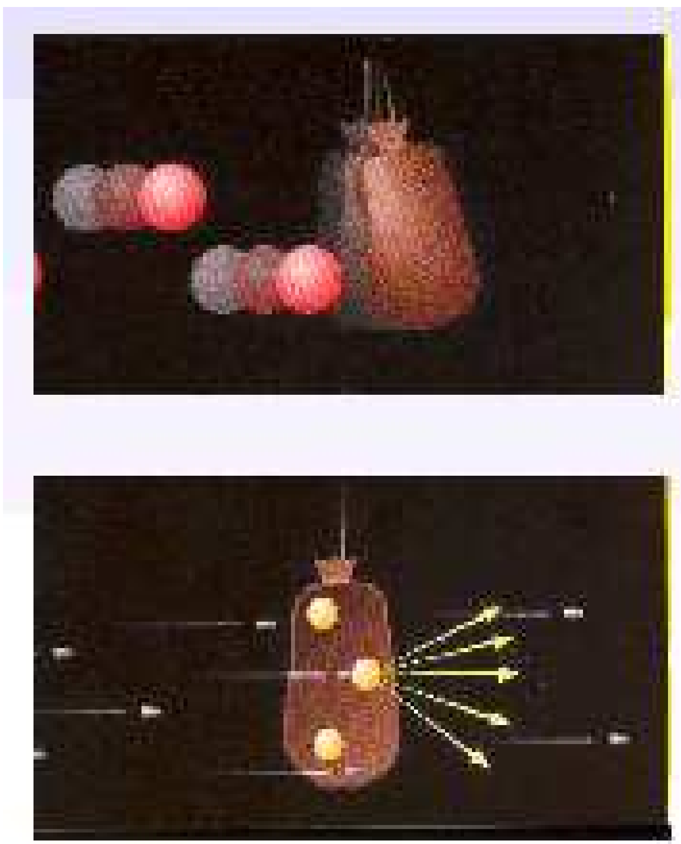
FROM CRYSTAL TO QUARK

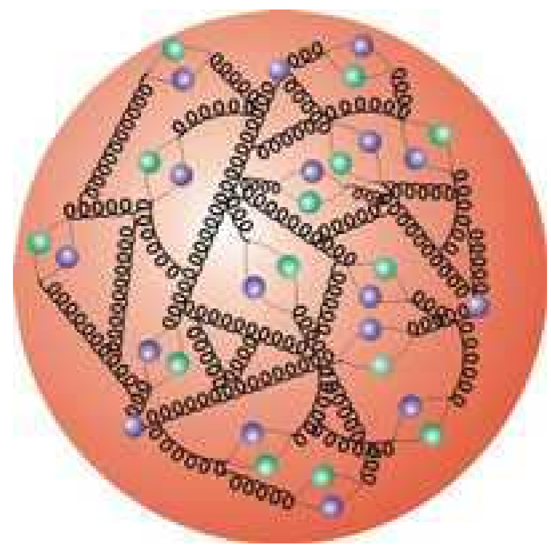


SCATTERING EXPERIMENTS

- Spatial resolution becomes better with larger momenta:

$$\Delta x = \frac{\hbar}{p}$$

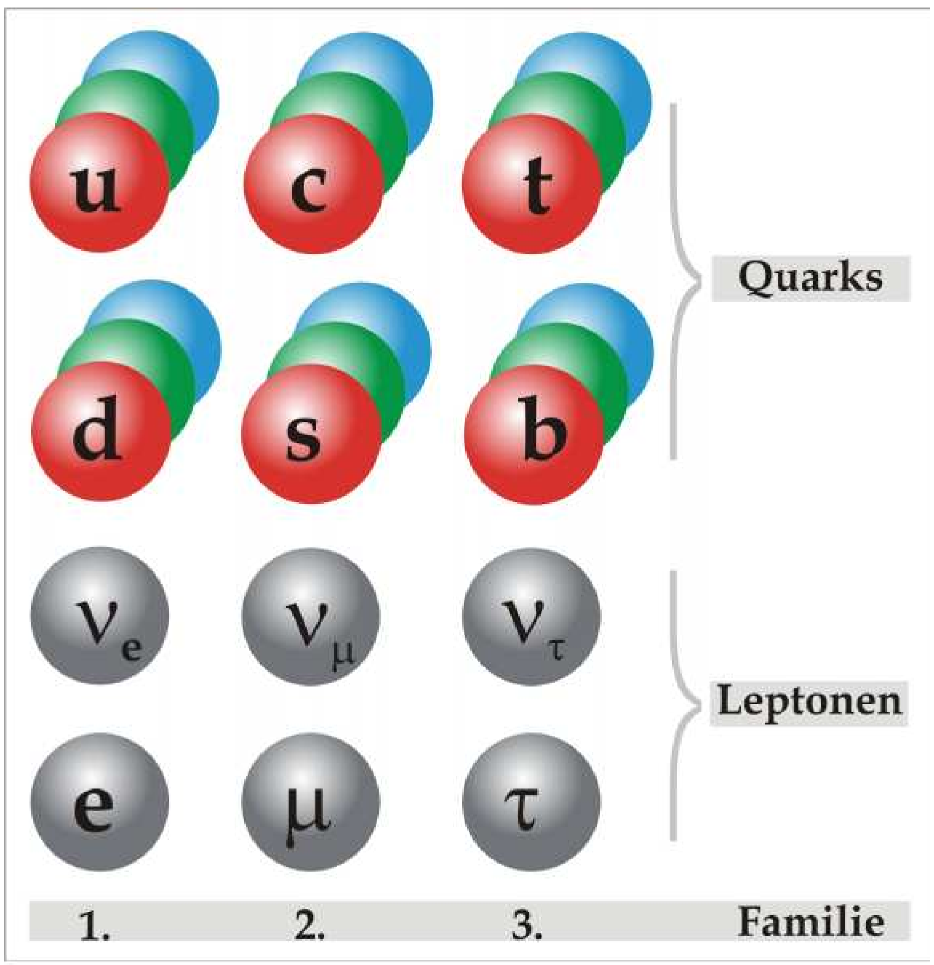




PARTICLES

- Pauli (1931): radioactive decays $\Rightarrow$ neutrino exists (discovered 1953)

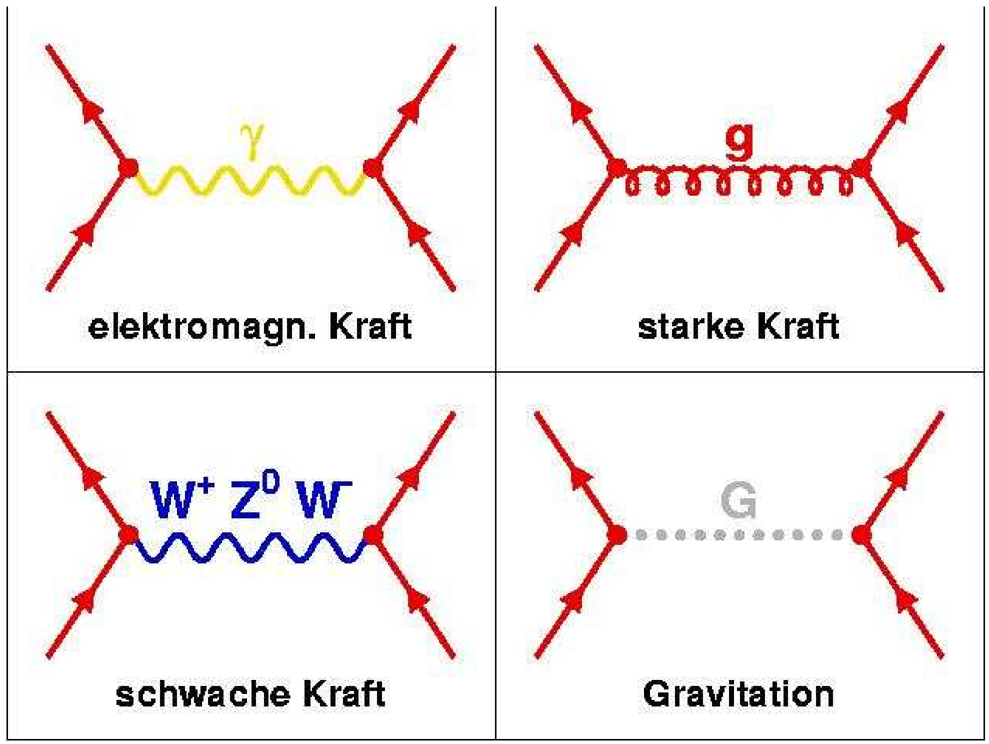
- Gell-Mann/Zweig (1964): existence of quarks (discovered 1969)

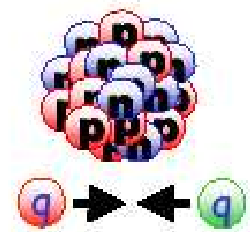


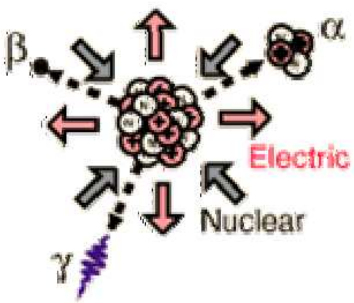
FORCES

electromagnetic force

strong force







weak force

gravity