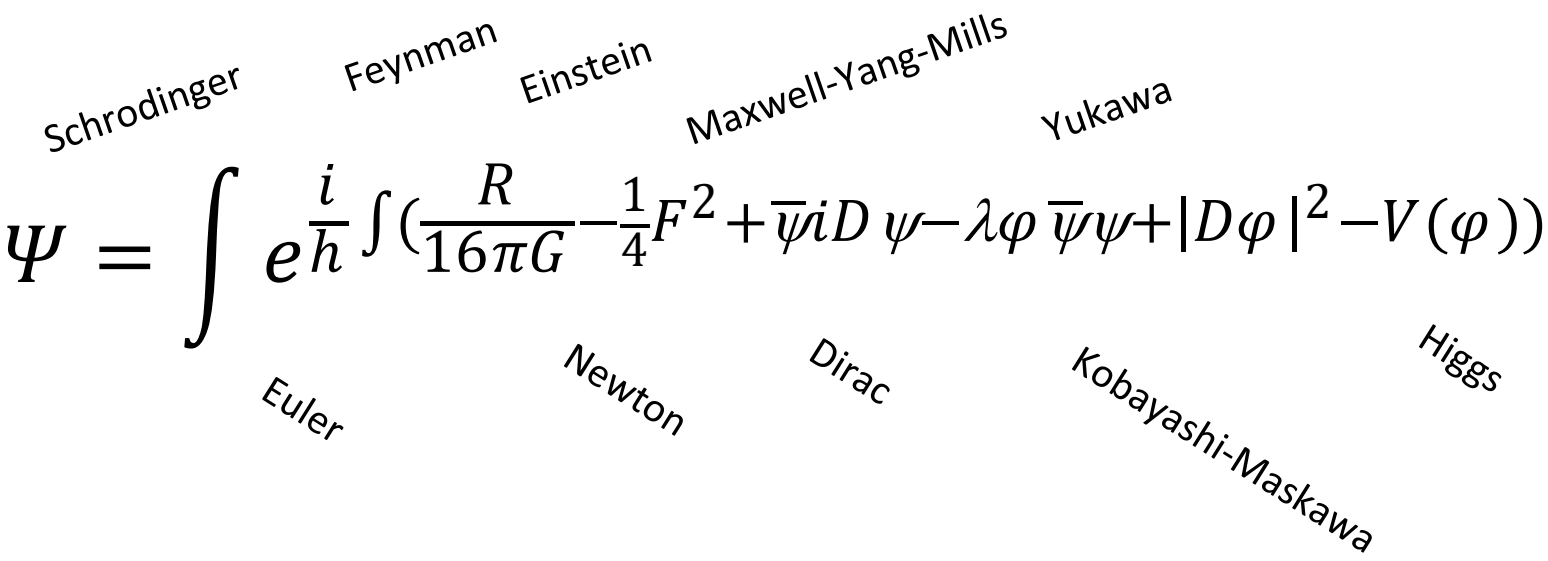
SPH4UI

Modern Topics in Physics

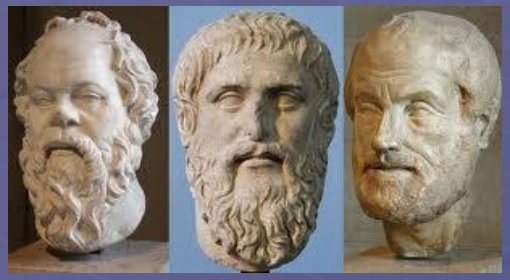
May / June 2016

Theory of Everything
(according to Neil Turok – Perimeter Institute)



Ancient Sciences

Earth as the centre of the universe theory



Socrates Plato Aristotle

5 Classical Elements:

- Earth
- Water
- Air
- Fire

Plus Ether

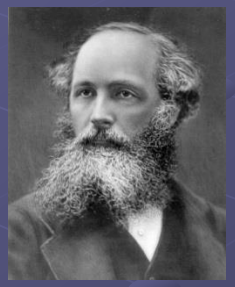
Scientific Revolution

(age of enlightenment)

Classical Physics
- theory of gravity
- Newton's three laws
- optics

Newton

Principia Mathematica (1687)



Maxwell

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

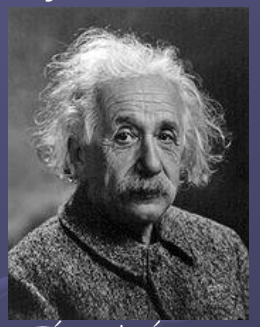
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0\mathbf{J} + \mu_0\varepsilon_0\frac{\partial \mathbf{E}}{\partial t}$$

Maxwell's Equations (1861)

Modern Physics

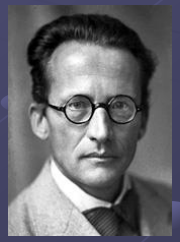
Theory of Relativity (1905 / 1916)



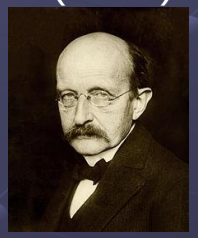
Einstein

Quantum Mechanics (1905)

Heisenberg

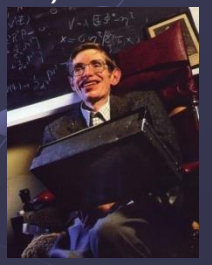


Schrodinger



Planck

String Theory (1990's)
+ ???
+ ???



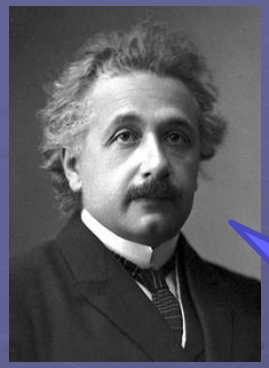
Hawking

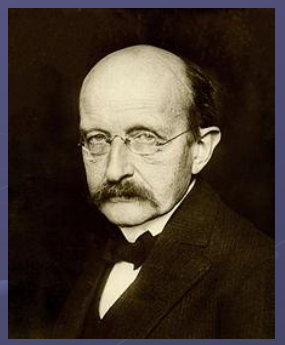
500 BC → 1500 → 1900 →

Common Beliefs

- We all inhabit the same three dimensional space
- Time passes equally quickly for everyone
- Two events either occur simultaneously or one before the other
- Given enough power (energy), there is no limit to how fast one can travel
- Matter can neither be created nor destroyed
- The angles of a triangle add up to 180°
- The circumference of a circle is equal to $2 \cdot \pi \cdot r$
- In a vacuum, light always travels in straight lines

Topics in Modern Physics





Relativity ⇒ ⇐ Quantum Mechanics

2 basic postulates:

- laws of physics are the same in all inertial frames of reference
- cosmic speed limit = c

1 basic postulate:

- light must carry energy in discrete quantities ($E=hf$)

$h=6.626 \times 10^{-34}\ m^2kg/s$
- Called Planck's constant

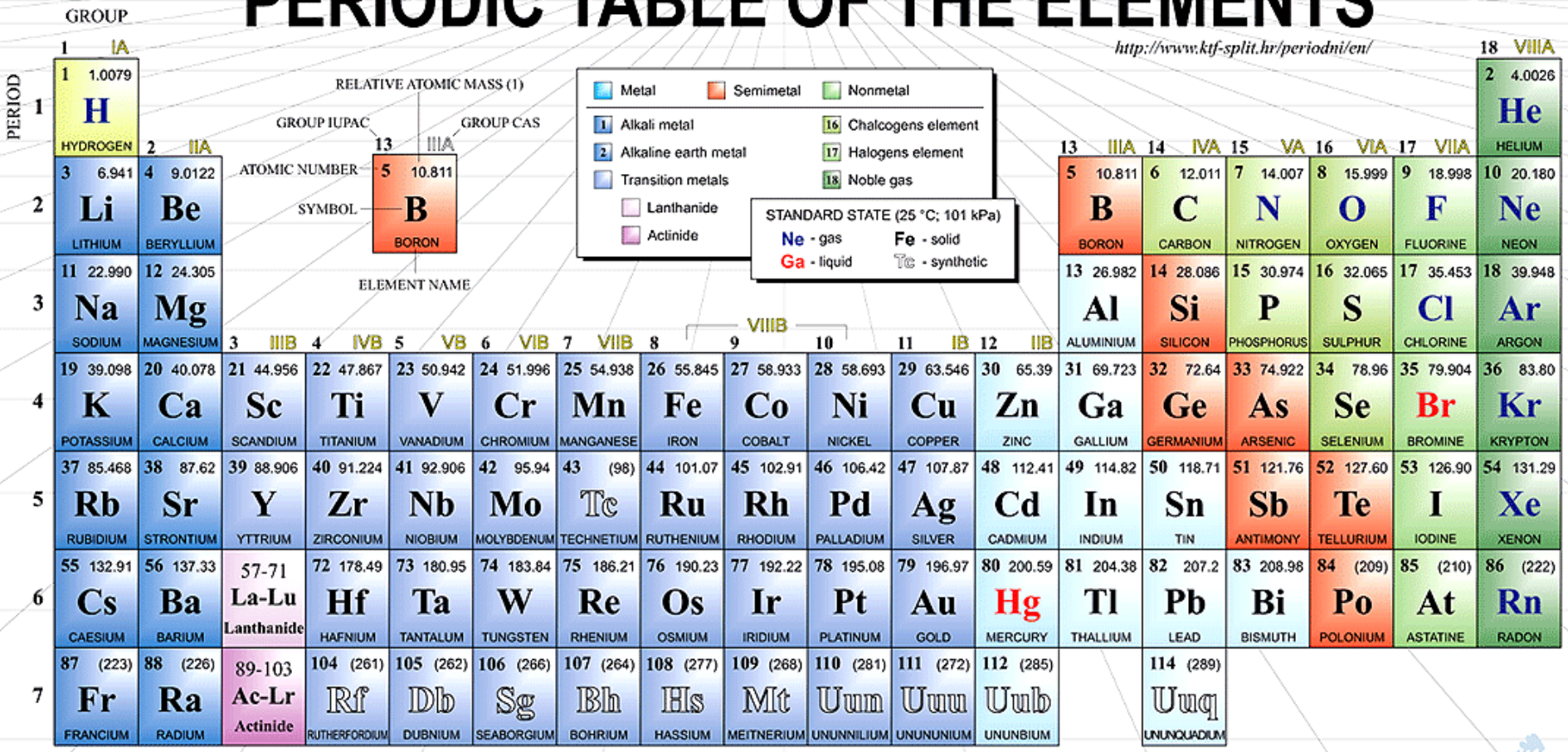
From these two theories a whole new set of branches of physics was born

- Particle Physics
- Special and General Relativity
- Quantum Mechanics
- Cosmology
- Gravitation
- Quantum Information
- Quantum Fields and Strings
- Superconductivity
- Nuclear Physics
- Solid State Physics
- and more …..

1. Particle Physics

PERIODIC TABLE OF THE ELEMENTS

http://www.ktf-split.hr/periodni/en/



LANTHANIDE

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
138.91	140.12	140.91	144.24	(145)	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.04	174.97
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
LANTHANUM	CERIUM	PRASEODYMIUM	NEODYMIUM	PROMETHIUM	SAMARIUM	EUROPIUM	GADOLINIUM	TERBIUM	DYSPROSIUM	HOLMIUM	ERBIUM	THULIUM	YTTERBIUM	LUTETIUM

ACTINIDE

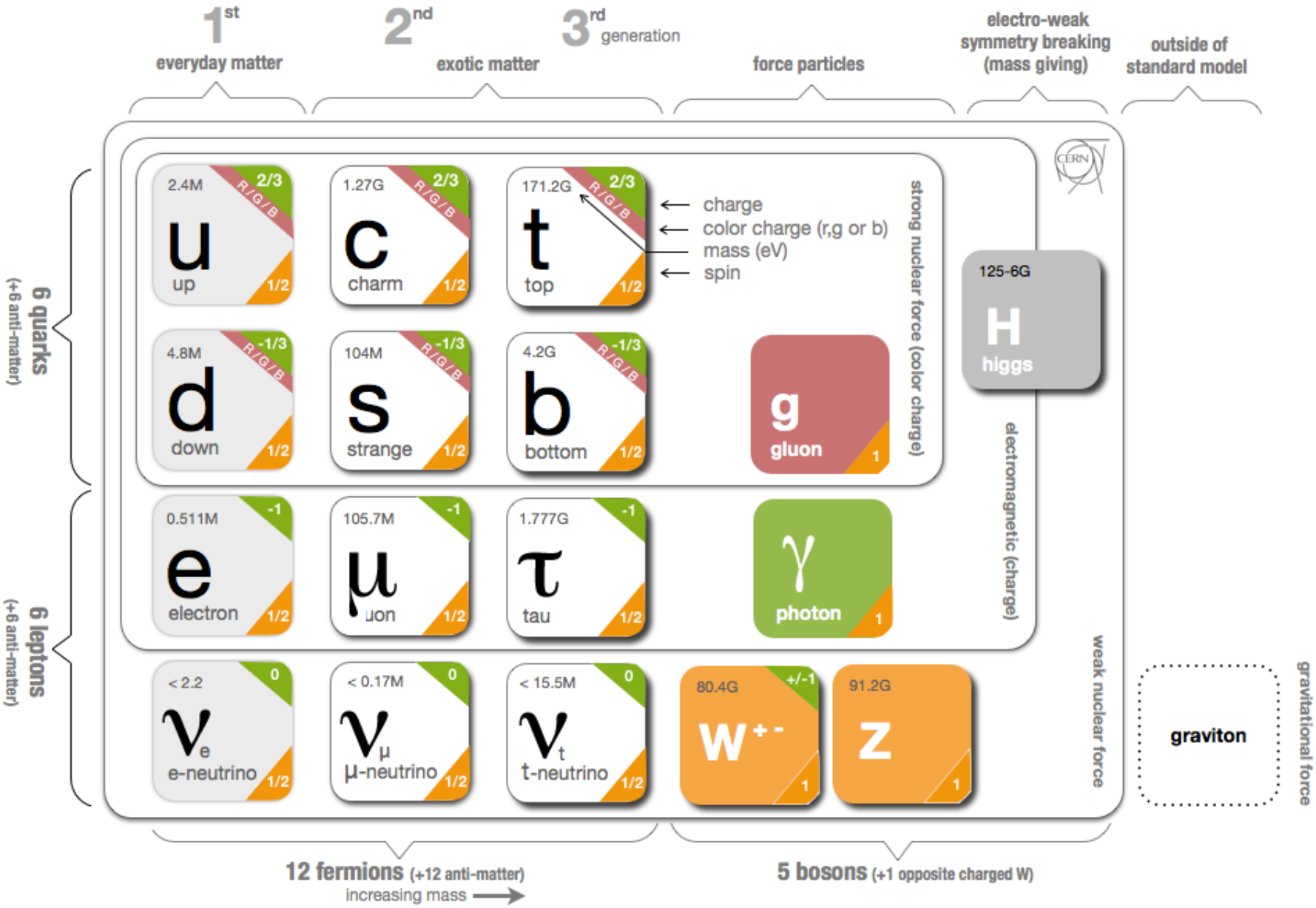
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
(227)	232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
ACTINIUM	THORIUM	PROTACTINIUM	URANIUM	NEPTUNIUM	PLUTONIUM	AMERICIUM	CURIUM	BERKELIUM	CALIFORNIUM	EINSTEINIUM	FERMIUM	MENDELEVIUM	NOBELIUM	LAWRENCIUM

(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)

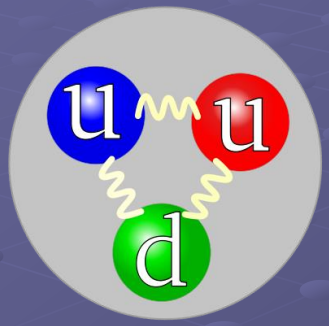
Relative atomic mass is shown with five significant figures. For elements have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@netllinx.com)

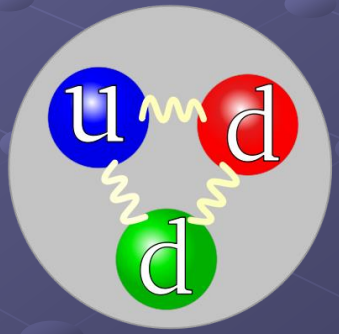

1st
everyday matter
2nd
3rd generation
exotic matter
force particles
electro-weak
symmetry breaking
(mass giving)
outside of
standard model
6 quarks
(+6 anti-matter)
6 leptons
(+6 anti-matter)
2.4M
2/3
R/G/B
u
up
1/2
1.27G
c
charm
171.2G
t
top
charge
color charge (r,g or b)
mass (eV)
spin
4.8M
-1/3
d
down
104M
s
strange
4.2G
b
bottom
g
gluon
1
strong nuclear force (color charge)
125-6G
H
higgs
0.511M
-1
e
electron
105.7M
μ
uon
1.777G
τ
tau
γ
photon
electromagnetic (charge)
< 2.2
0
νe
e-neutrino
< 0.17M
νμ
μ-neutrino
< 15.5M
νt
t-neutrino
80.4G
+/-1
W+-
91.2G
Z
weak nuclear force
graviton
gravitational force
12 fermions (+12 anti-matter)
increasing mass
5 bosons (+1 opposite charged W)

Particle Physics



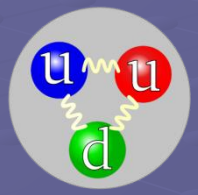
Proton Structure

Up Quark – electric charge +2/3
Down Quark – electric charge -1/3



Neutron Structure

Particle Physics



Proton

Mass of a Proton
= 1,670x10^{-30}kg

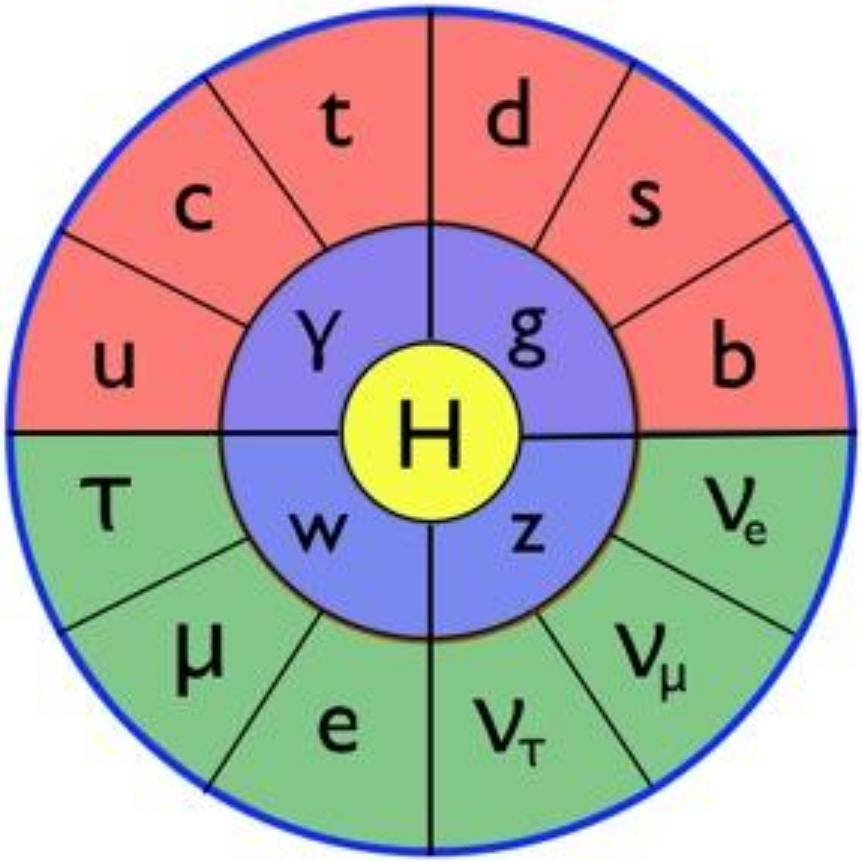
Mass of Up Quark
= 4.27x10^{-30}kg
Mass of Down Quark
= 8.54x10^{-30}kg

2 Ups and 1 Down
= 17.1x10^{-30}kg

Neutron

Missing **1,653x10^{-30}kg** of mass?

Where did the missing mass come from?
Gluons – energy
Plus Kinetic Energy



Fermions
Matter

Quarks

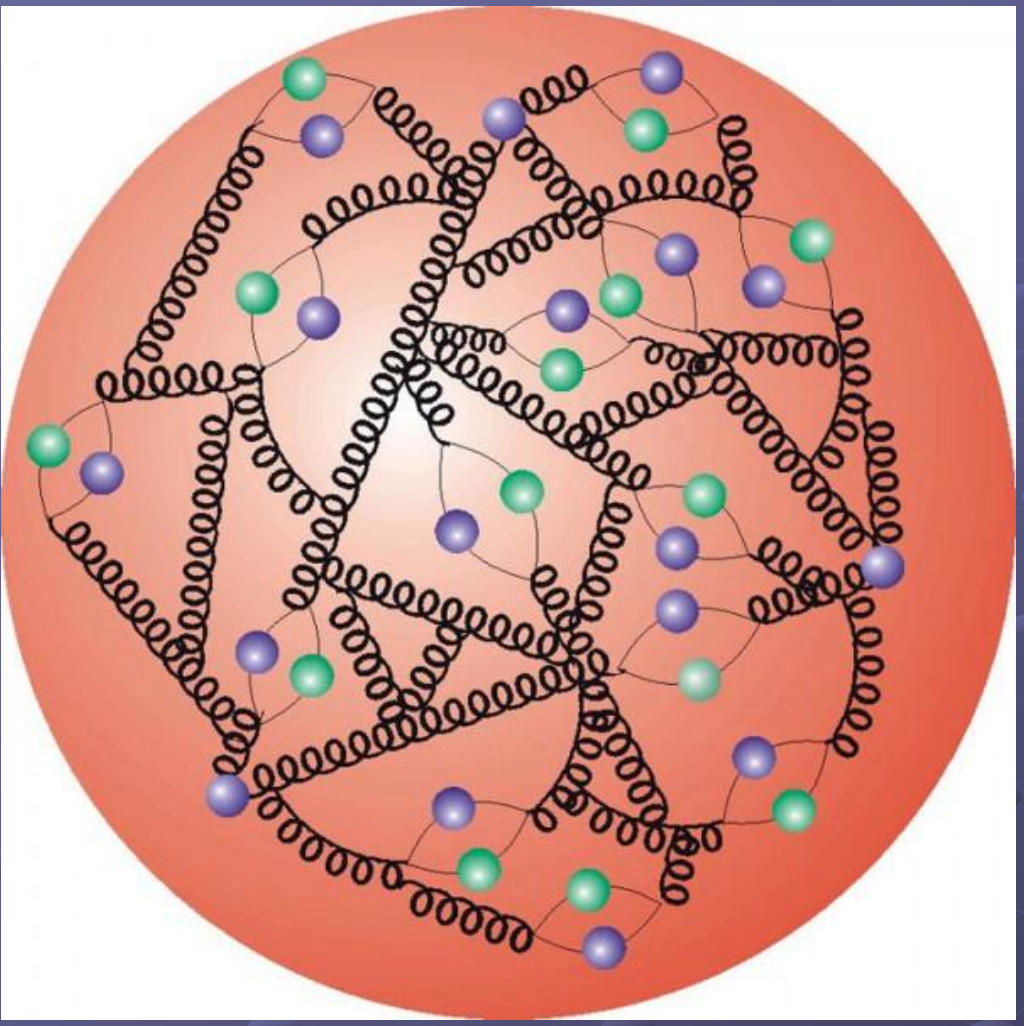
Leptons

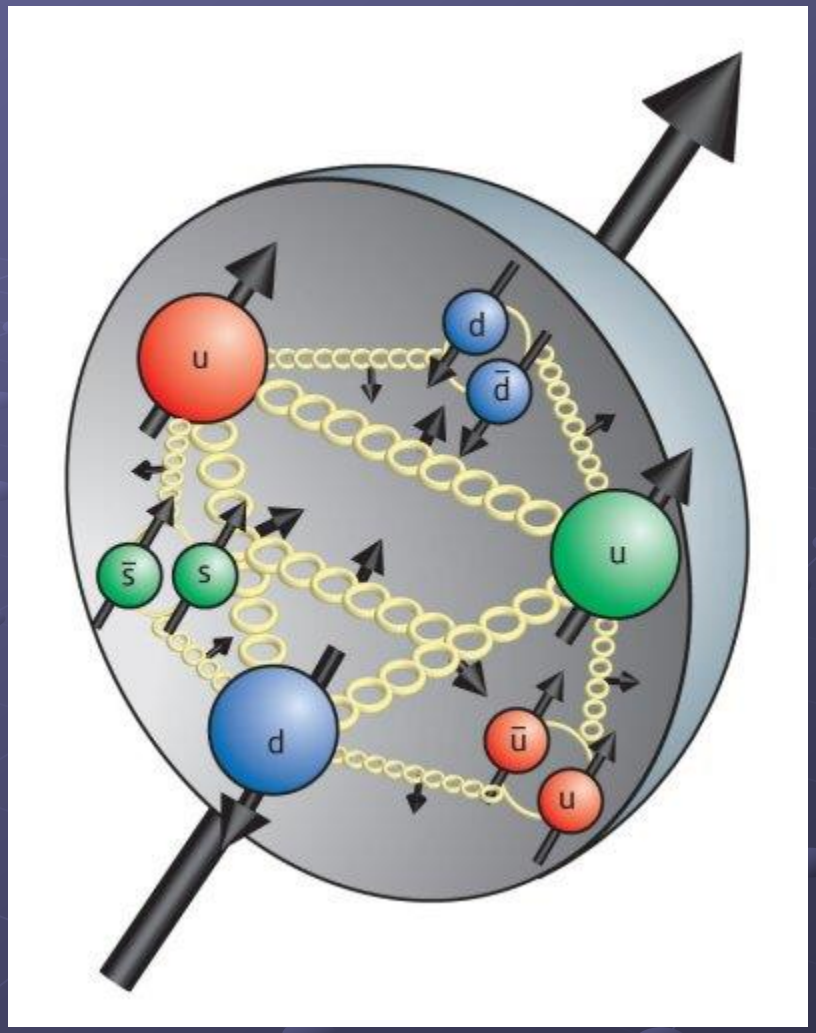
Bosons
Force Carriers

Gauge bosons

Higgs boson

Particles of the Standard Model

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2. Relativity

Postulates of Relativity

1. Laws of physics are the same in all inertial frames of reference
2. Cosmic speed limit = c

Gamma Function

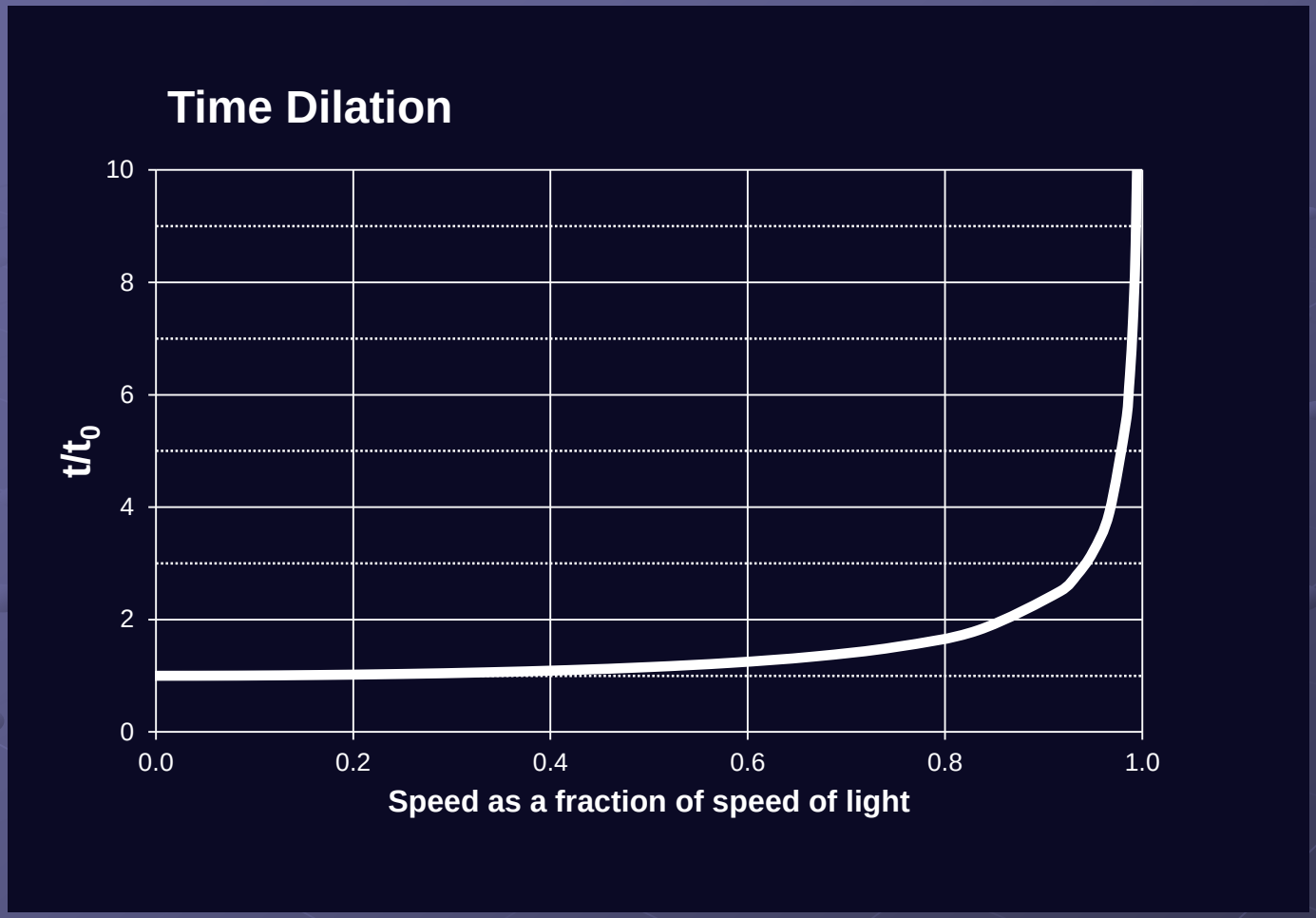
$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Time Dilation

$$t = t' \cdot \gamma$$

t=time measured on earth (non-moving reference frame)
t'= time measured on moving object

Special Relativity



t = time measured on earth

t_o = time measured on moving object

Example:
At v=95% the speed of light

t/t0=3.2
- that means that for every 3.2 years that pass on earth only 1 year passes on the moving object)

Relativistic Velocities

Recall – the relative velocity of two objects can never exceed the velocity of light.

$$V_{AC} = \frac{V_{AB} + V_{BC}}{1 + \frac{V_{AB} \cdot V_{BC}}{c^2}}$$

a quick intro…

General Relativity

General Relativity Takes into Account Gravity

Einstein's Breakthrough : Equivalence Principle

The gravitational force experienced by an object in an inertial frame of reference is identical to the force on an object caused by acceleration in a non-inertial frame of reference.

Gravity = Acceleration

An accelerating frame of reference is changing it's velocity –> in a moving frame of reference the clocks run differently than in a stationary frame of reference.

Therefore ….

In a frame of reference with a strong gravity field the clocks will run differently than a frame with a weak gravitational field

Gravity = Acceleration

The stronger the gravitational field – the slower clocks run . . . .

The weaker the gravitational field – the faster clocks run …..

Anyone who is not shocked by quantum theory has not understood it.
Neils Bohr : 1922 - Nobel Prize winner for Physics

3. Quantum Mechanics

I think I can safely say that nobody understand quantum mechanics.
Richard Feynman : 1965 - Nobel Prize winner for Physics

What is Quantum Mechanics

At it's core quantum mechanics is the study of matter – energy interactions at the sub-atomic scale.

Scale of the Universe

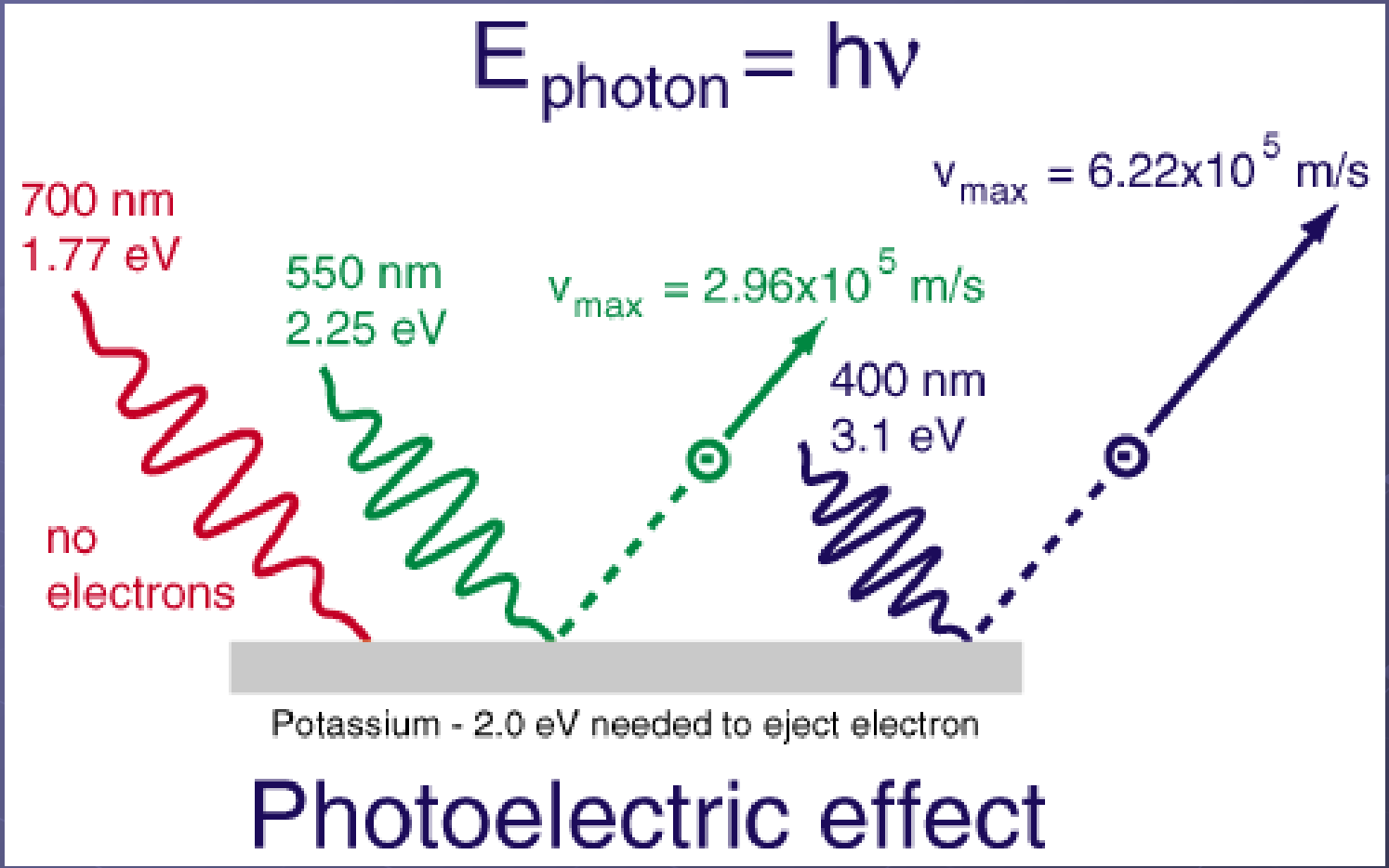
Key Discoveries Leading to Modern Quantum Theory

1887 – Heinrich Hertz discovers the Photoelectric Effect

1900 – Max Planck suggests that Electro-Magnetic Energy can only be emitted in quantized form

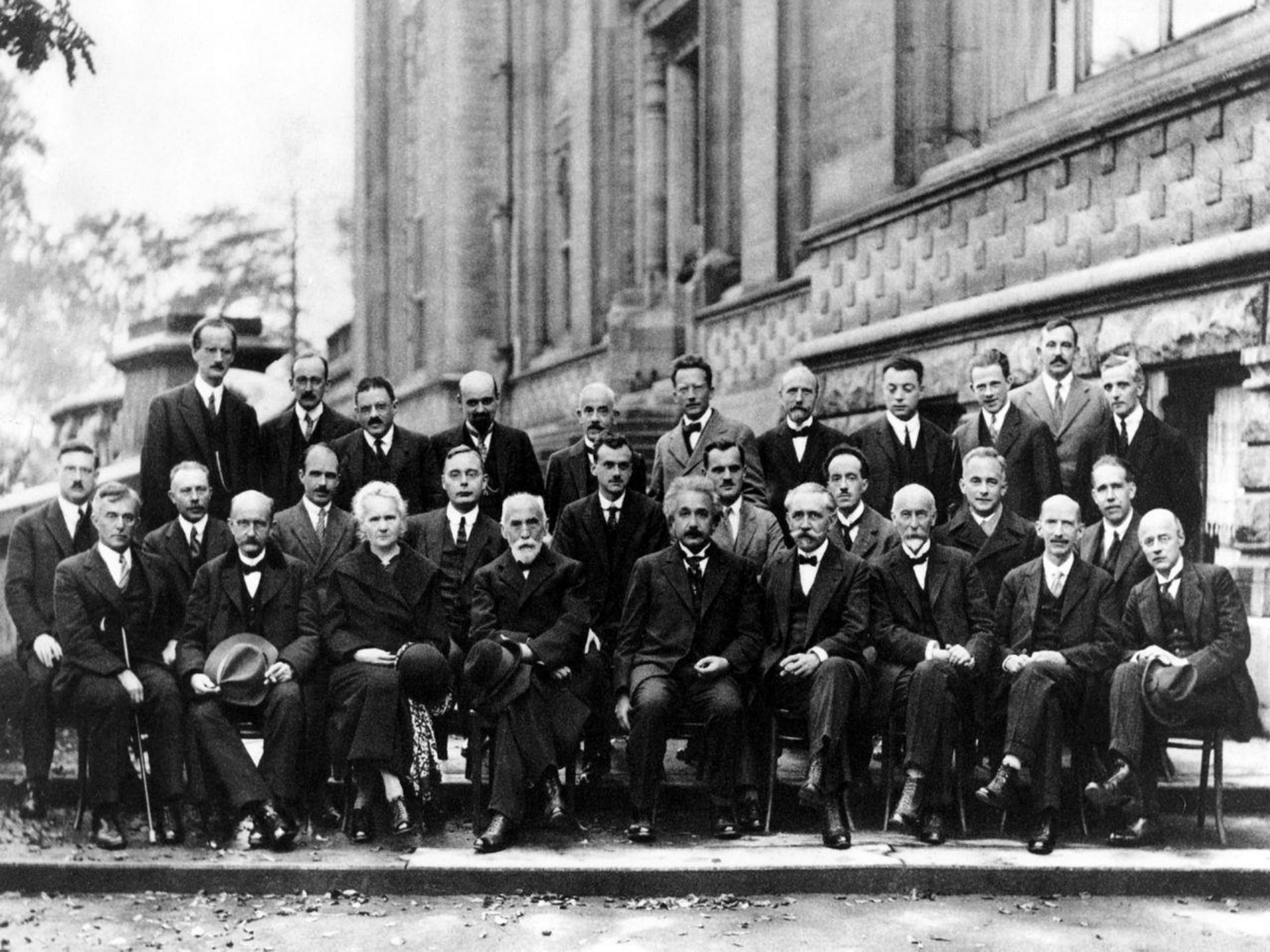
$$E=hf$$

1905 – Einstein uses Max Planck's quantization of light theory to explain the Photo-Electric Effect



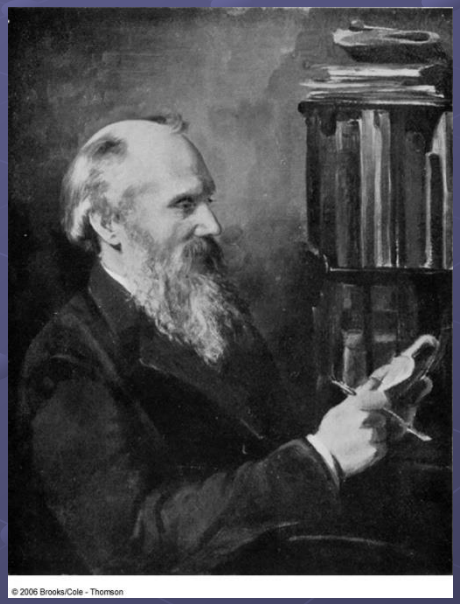
Einstein coupled Planck's formula with the colour of light (wavelength and frequency) to explain the Photo-Electric Effect

This is what he got his Nobel prize for in 1918



Is there anything left unknown?

There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.



(1900 – Lord Kelvin – yea the guy the temperature scale is named after)

The basic ingredients of reality

The 4% of the universe we know about...*

QUARKS

UP	CHARM	TOP
u	c	t
DOWN	**STRANGE**	**BOTTOM**
d	s	b

LEPTONS

ELECTRON	MUON	TAU
e	μ	τ
ELECTRON NEUTRINO	**MUON NEUTRINO**	**TAU NEUTRINO**
ν_e	ν_μ	ν_τ

BOSONS

FORCE CARRIERS

PHOTON

γ

Electromagnetism

$W Z$

Weak nuclear

GLUON

g

Strong nuclear

MASS GIVER

HIGGS BOSON

H^0

...and the 96% we don't

DARK MATTER

DARK ENERGY

GRAVITY

* for simplicity antiparticles are not shown

- Dark Energy – the universe is expanding faster than it should….
- Dark Matter – the galaxies are rotating faster than they should (the apparent gravitational force is higher than can be accounted for)
- Gravity – quantum gravity – how can we understand quantum effects of the very small and gravitational effects of the very large at the same time (important to understand black holes and the big bang)

- Is light a particle or wave or both – is there a single model that describes both phenomena? (same question for electrons)

- Time – why does time only flow in one direction? Why are some things irreversible (cracking an egg, burning a log on a fire)

- Others??????