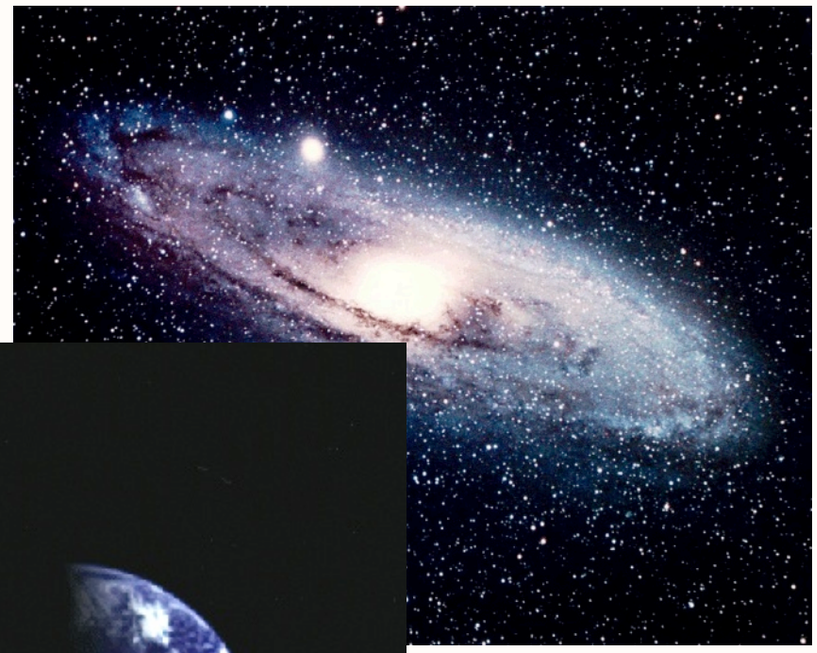
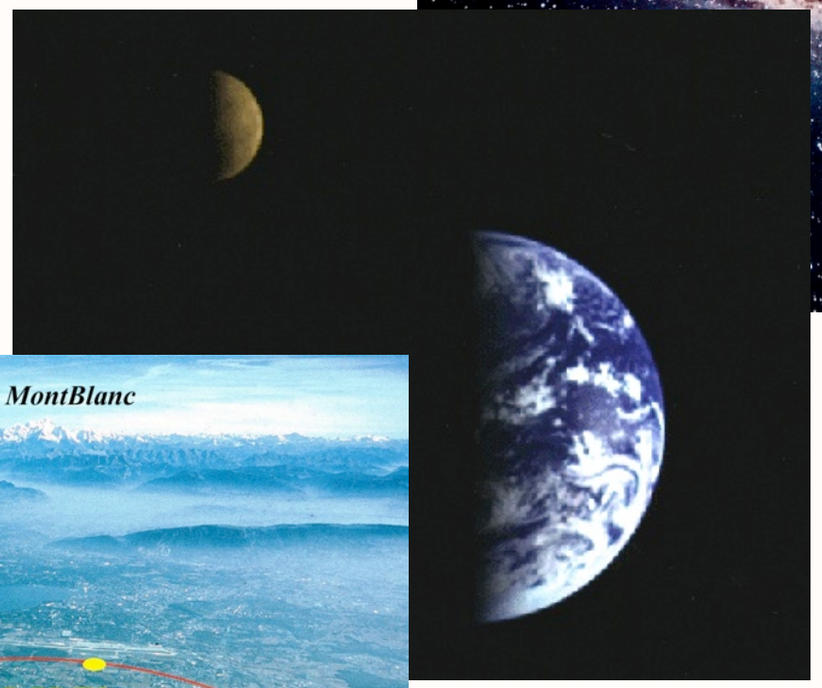
Afstanden

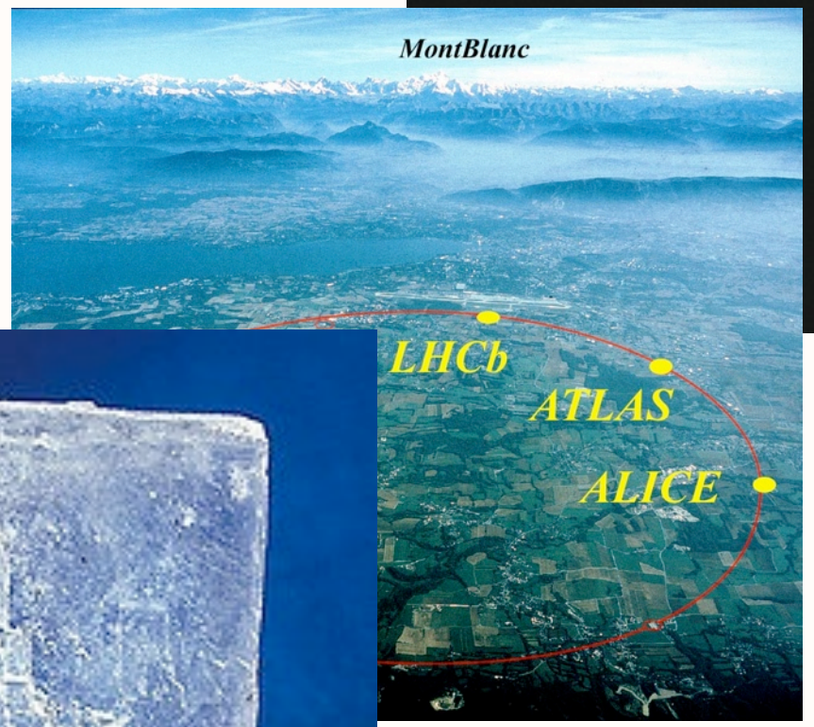
2.000.000 lichtjaar



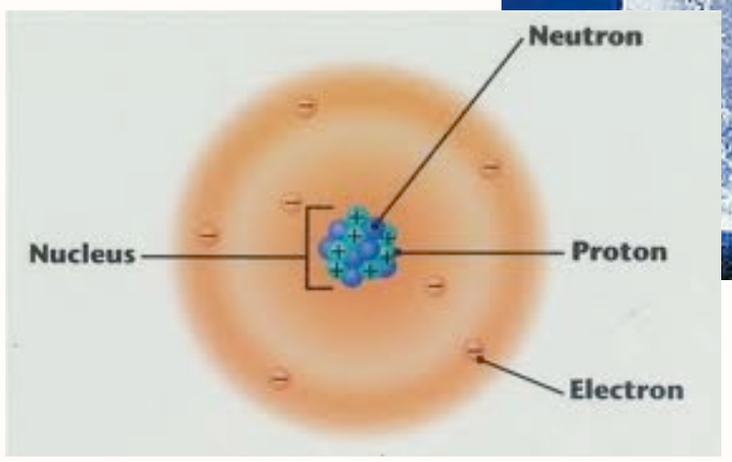
300.000 km



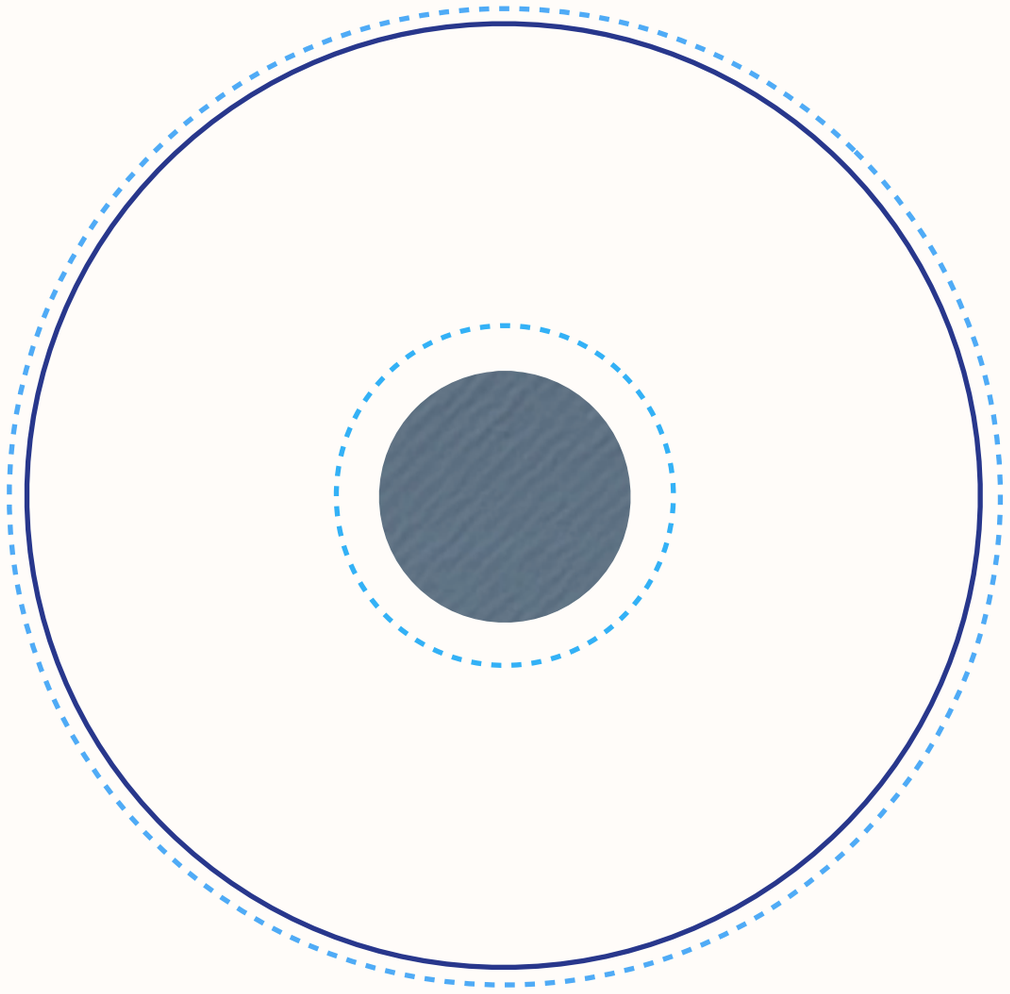
30 km



1 mm



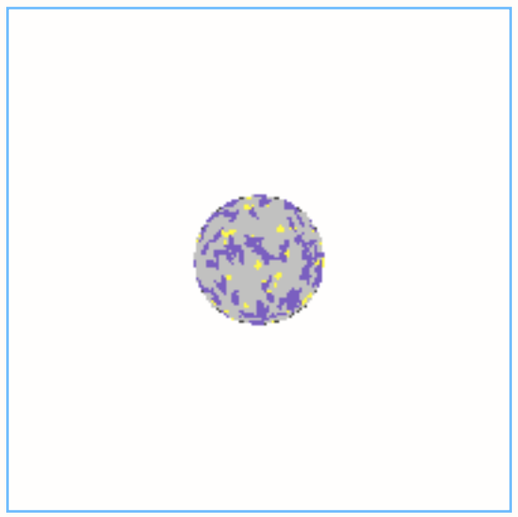
0,000.000.1 mm

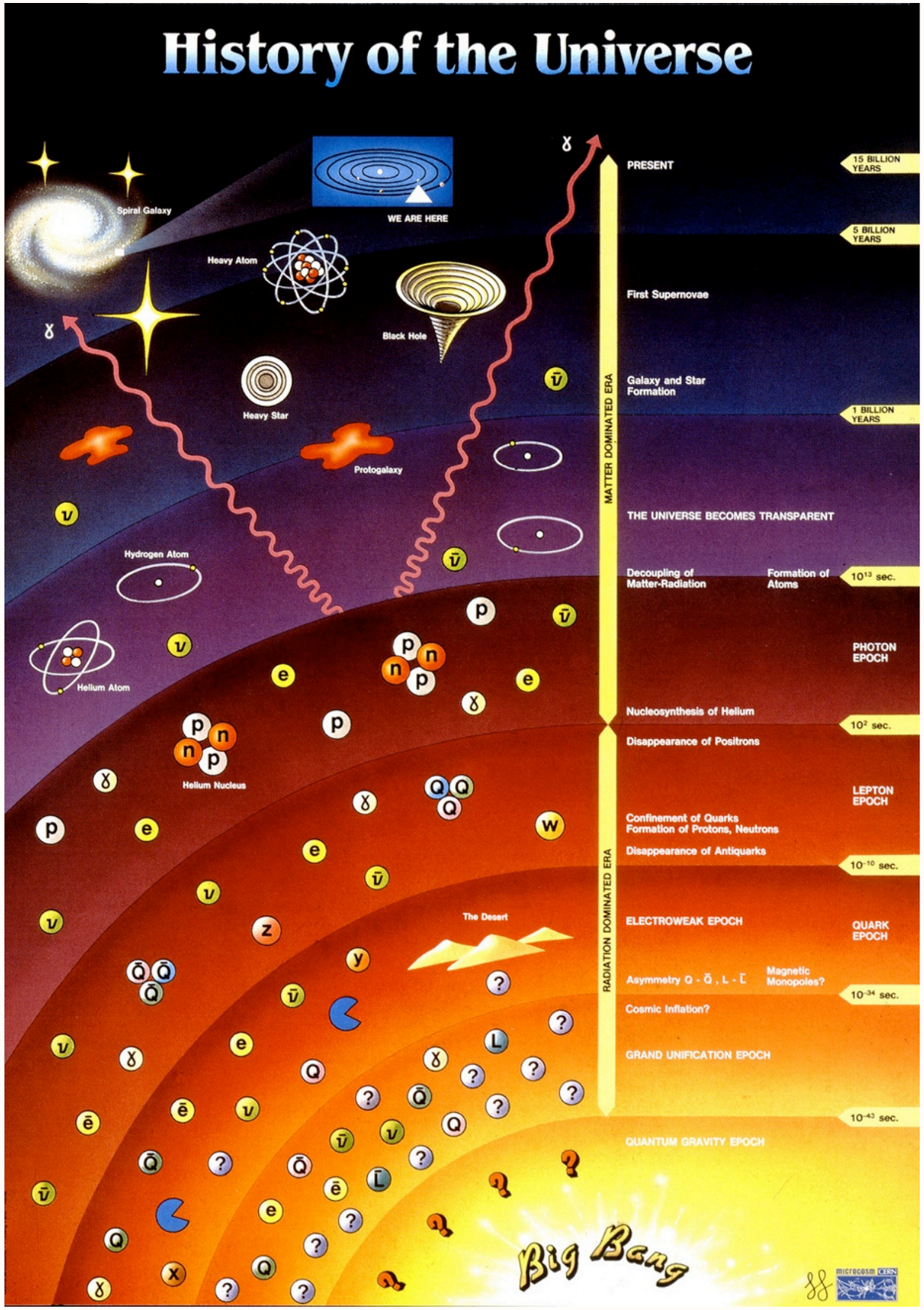


$$M \sim R^3$$

$$g \sim \frac{M}{R^2} \sim R$$

Tijden




History of the Universe
Spiral Galaxy
WE ARE HERE
Heavy Atom
Black Hole
Heavy Star
Protogalaxy
Hydrogen Atom
Helium Atom
Helium Nucleus
The Desert
PRESENT
15 BILLION YEARS
5 BILLION YEARS
First Supernovae
Galaxy and Star Formation
1 BILLION YEARS
MATTER DOMINATED ERA
THE UNIVERSE BECOMES TRANSPARENT
Decoupling of Matter-Radiation
Formation of Atoms
10^13 sec.
PHOTON EPOCH
Nucleosynthesis of Helium
10^2 sec.
Disappearance of Positrons
LEPTON EPOCH
Confinement of Quarks
Formation of Protons, Neutrons
Disappearance of Antiquarks
10^-10 sec.
RADIATION DOMINATED ERA
ELECTROWEAK EPOCH
QUARK EPOCH
Asymmetry Q - Q̄ , L - L̄
Magnetic Monopoles?
10^-34 sec.
Cosmic Inflation?
GRAND UNIFICATION EPOCH
10^-43 sec.
QUANTUM GRAVITY EPOCH
Big Bang
microcosm CERN

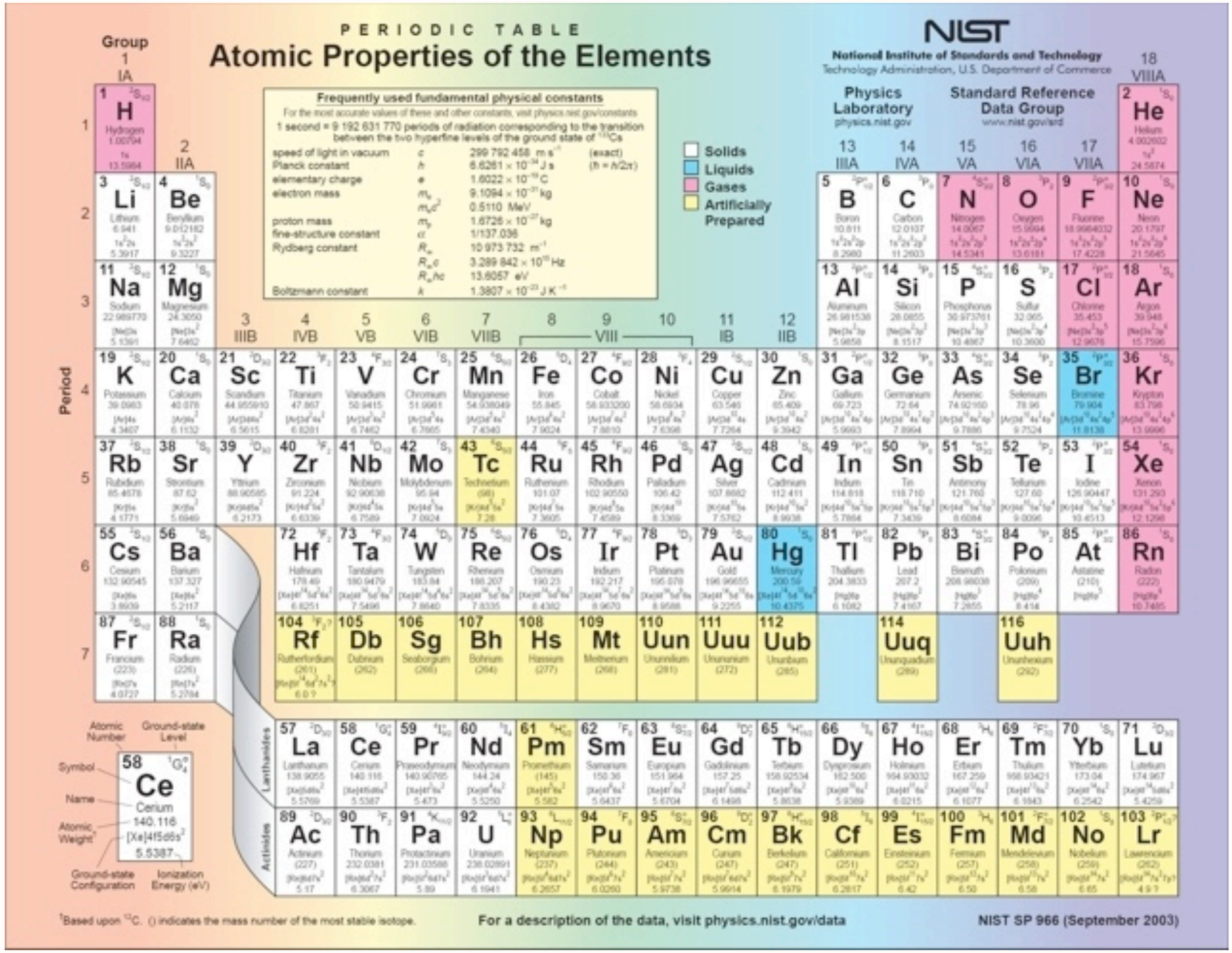
Vormen van materie
beweging en transformatie
in ruimte en tijd

- Behoudswetten:
  - behoud van energie, elektrische lading, ...

- Bewegingswetten:
  - krachtwetten (zwaartekracht, elektrische en magnetische krachten, ...)

- Statistische wetten:
  - gaswetten, hydrodynamica, thermodynamica, ...

Elementen

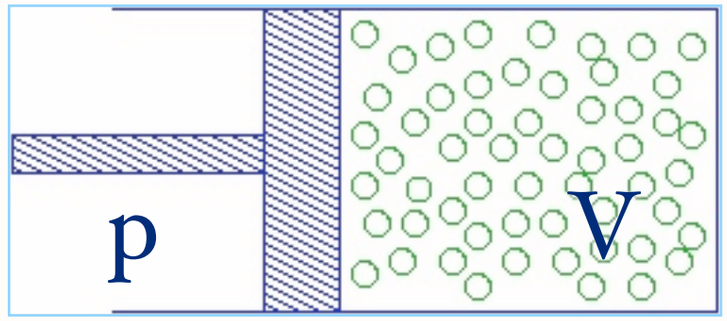


D. Mendeleev

atomaire bouwstenen van de chemie

Atomen en gassen

Gaswet: $pV = N\,k\,T$



⟶ bij dezelfde (p, T) is het
aantal deeltjes per volume-eenheid
voor verschillende gassen gelijk

Loschmidt (1865):

$N_0 = 2{,}687 \times 10^{22}$ deeltjes/liter
bij 273 K en 1 atm

of $k = 1{,}381 \times 10^{-23}$ J/K
(constante van Boltzmann)

Atoommassa's

		relatief
H:	1,68	1
He:	6,65	4
N:	23,3	14
O:	26,6	16
Fe:	92,3	56
U:	399,7	238

x 10^{-24} g

Atomaire afmetingen

van der Waals:

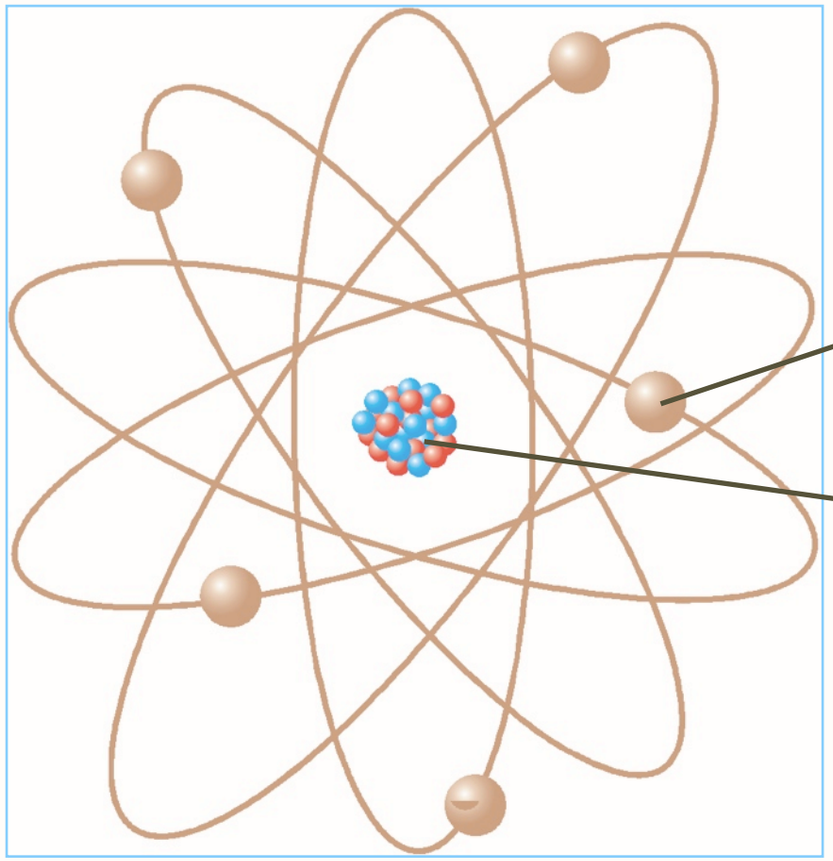
$$p\,(V - Nb) = N\,k\,T$$

d(H) = 0,11 nm

d(He) = 0,06 nm

d(O) = 0,15 nm

d(Fe) = 0,25 nm



elektron

lading -e

kern

lading Ze

Z = aantal protonen

atoomgetal

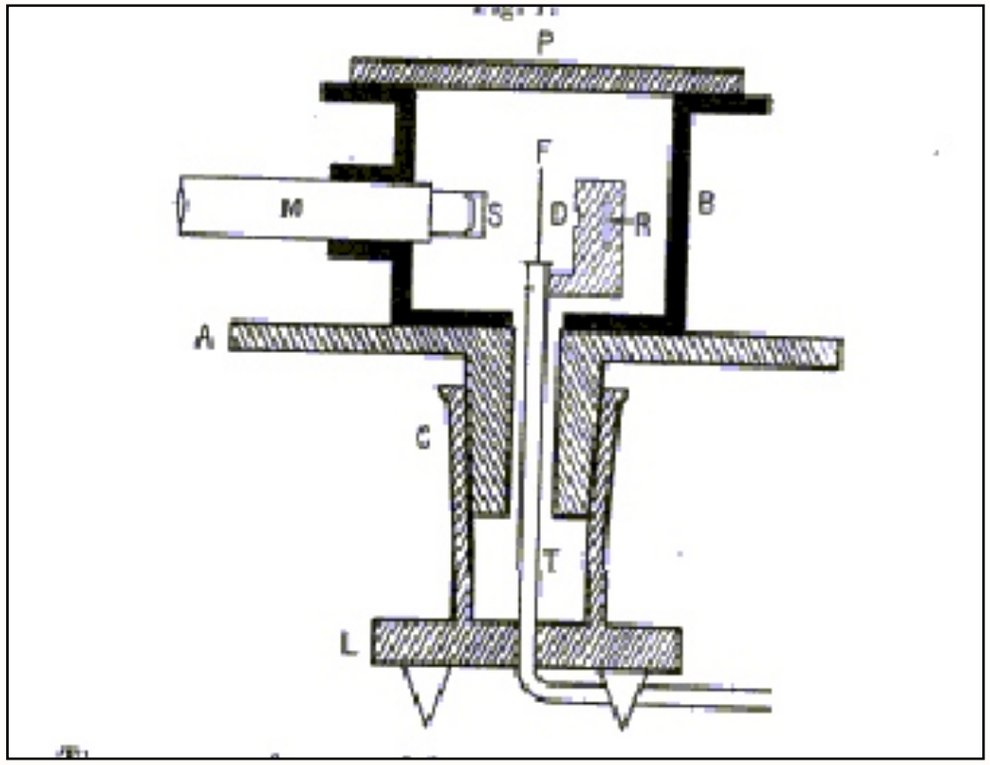
A = aantal kerndeeltjes

E. Rutherford

H. Geiger

$e = 1{,}602 \times 10^{-19}\ C$

Het Geiger -Rutherford experiment



R - α-radioactieve bron

F - folie （goud）

S - scintillatorplaatje

M - microscoop

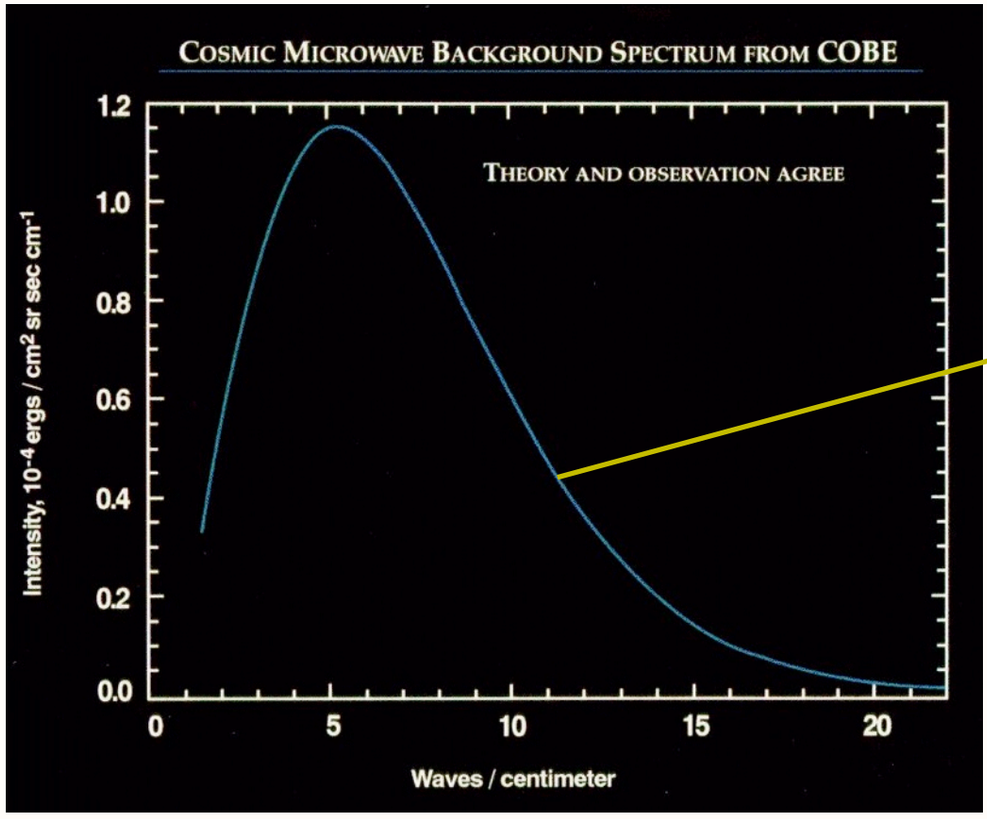
Straling

Zwart lichaam: perfecte absorptie en emissie

M. Planck

Planck/Einstein:
fotonen
$E = h f = h c q$

$h = 6{,}63 \times 10^{-34}\ Js$



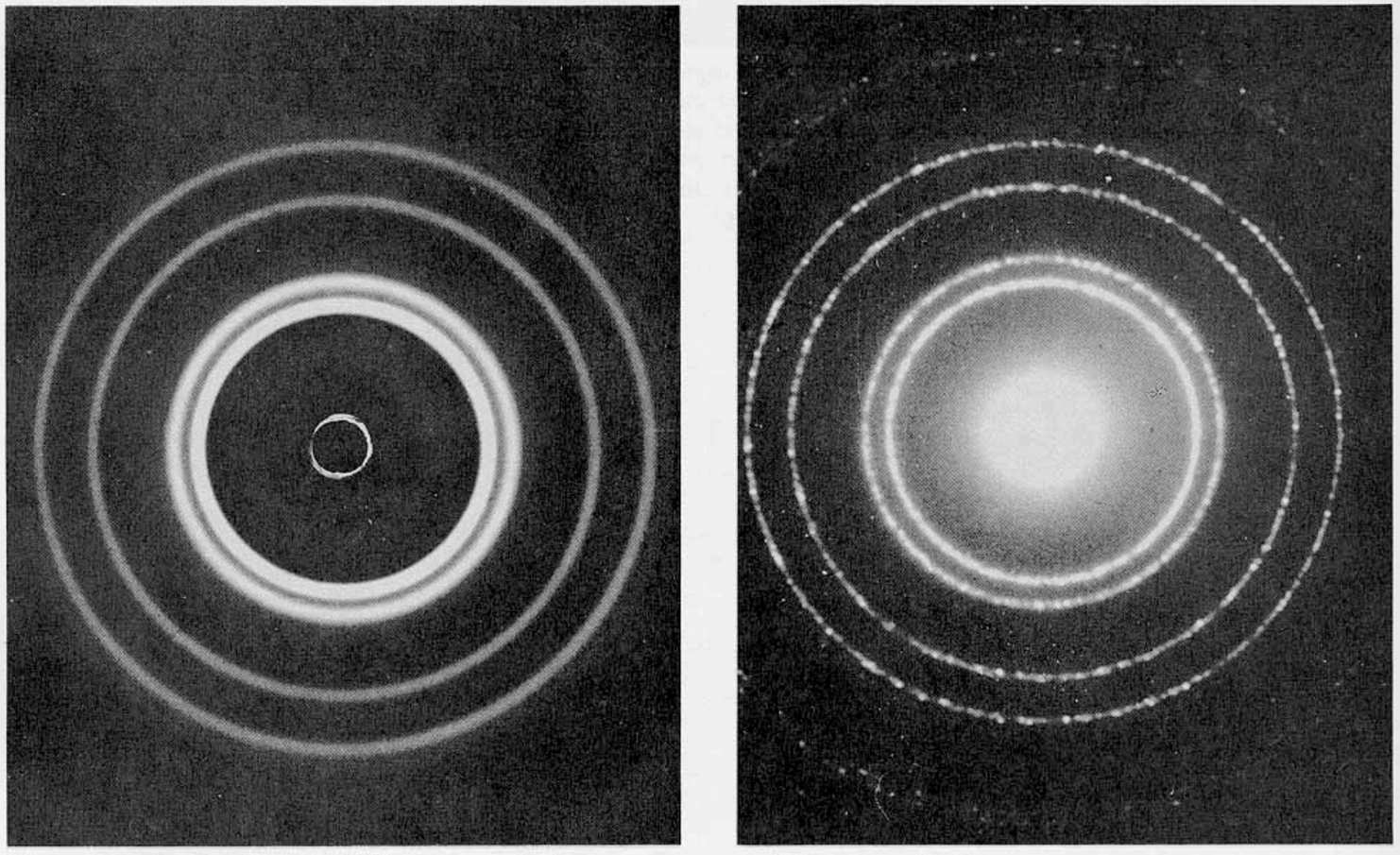
Intensiteit

T = 2,73 K

Golfgetal
q = aantal golven/cm
$= 1 / \lambda$

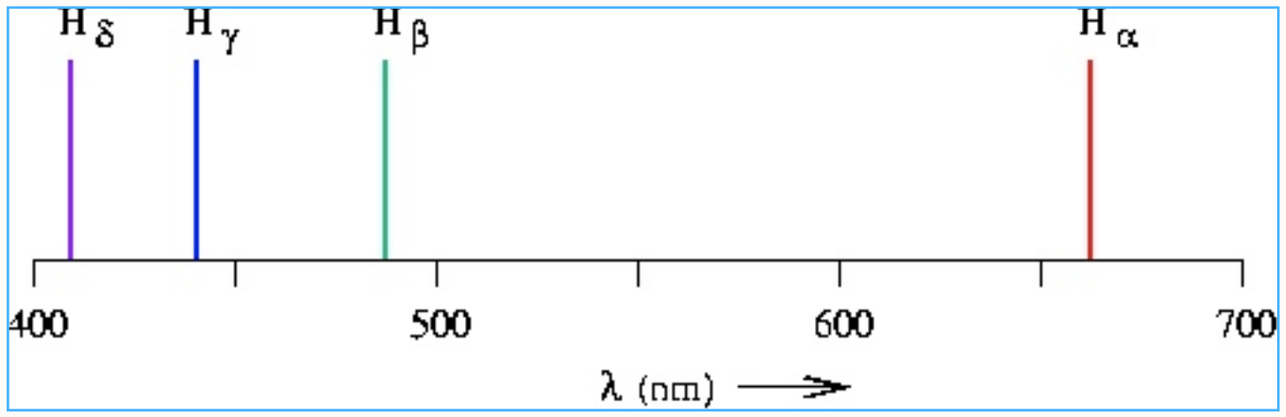
Materiegolven

The diffraction pattern on the left was made by a beam of x rays passing through thin aluminum foil. The diffraction pattern on the right was made by a beam of electrons passing through the same foil.



Röntgenstraling elektronen

Atoomspectra

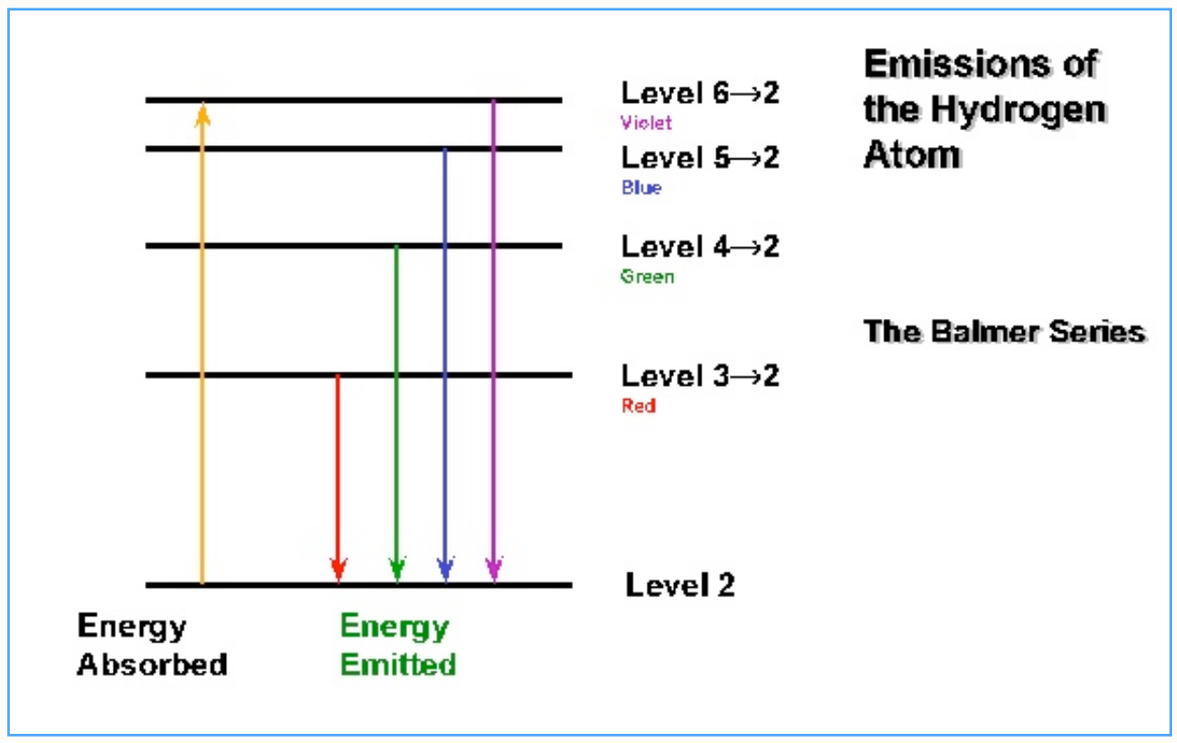


N. Bohr

Waterstofspectrum: Balmer lijnen

Energieniveaus van het elektron in het waterstofatoom

$$2 \pi r = n \lambda$$



A. Einstein

Relativiteit

De lichtsnelheid
c= 300 000 km/sec
is een universele
constante

Equivalentie van massa en energie:

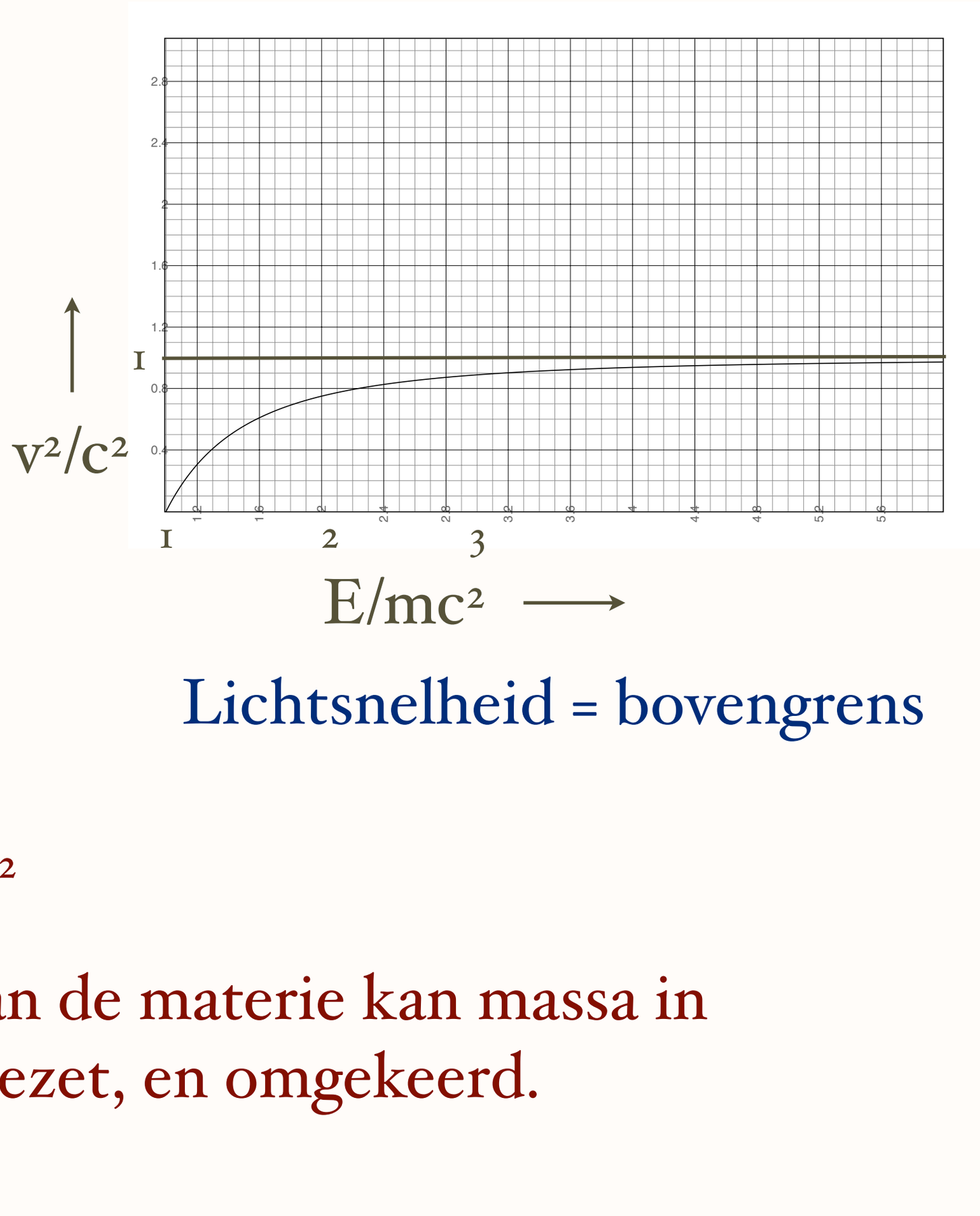
$$E = \gamma\, m\, c^2$$

Tijddilatatie:
bewegende klokken lopen langzamer

$$\Delta t = \gamma\, \Delta \tau$$

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

$$\frac{v^2}{c^2} = 1 - \frac{m^2 c^4}{E^2}$$

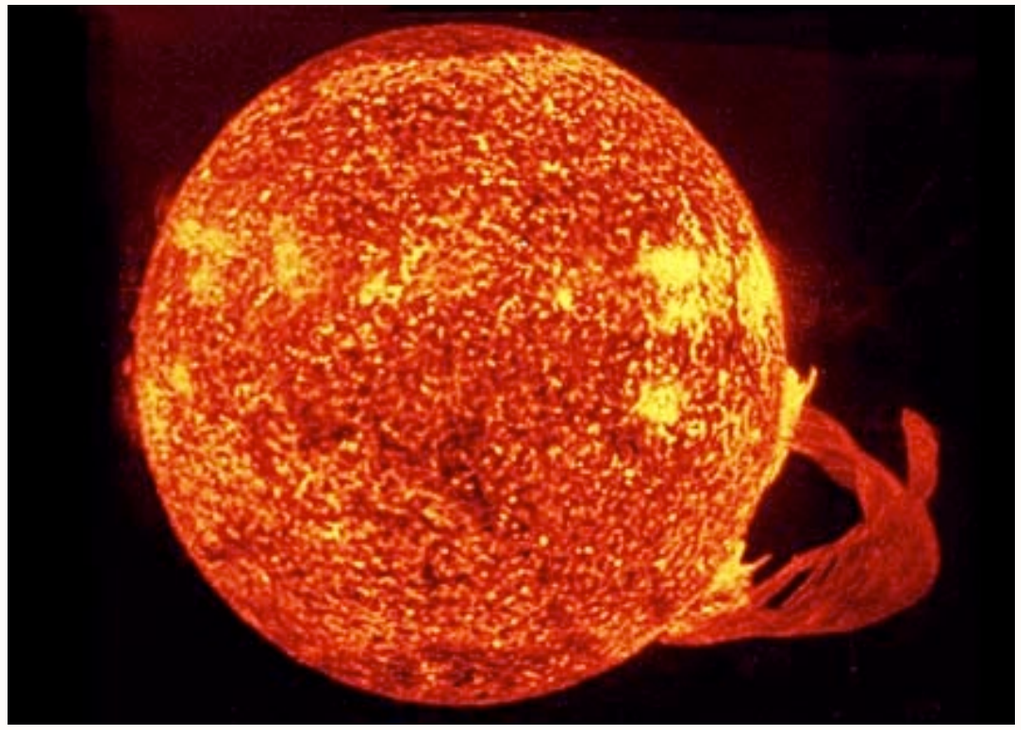


Lichtsnelheid = bovengrens

v = 0:

rustenergie $E_0 = m c^2$

Bij transformaties van de materie kan massa in energie worden omgezet, en omgekeerd.

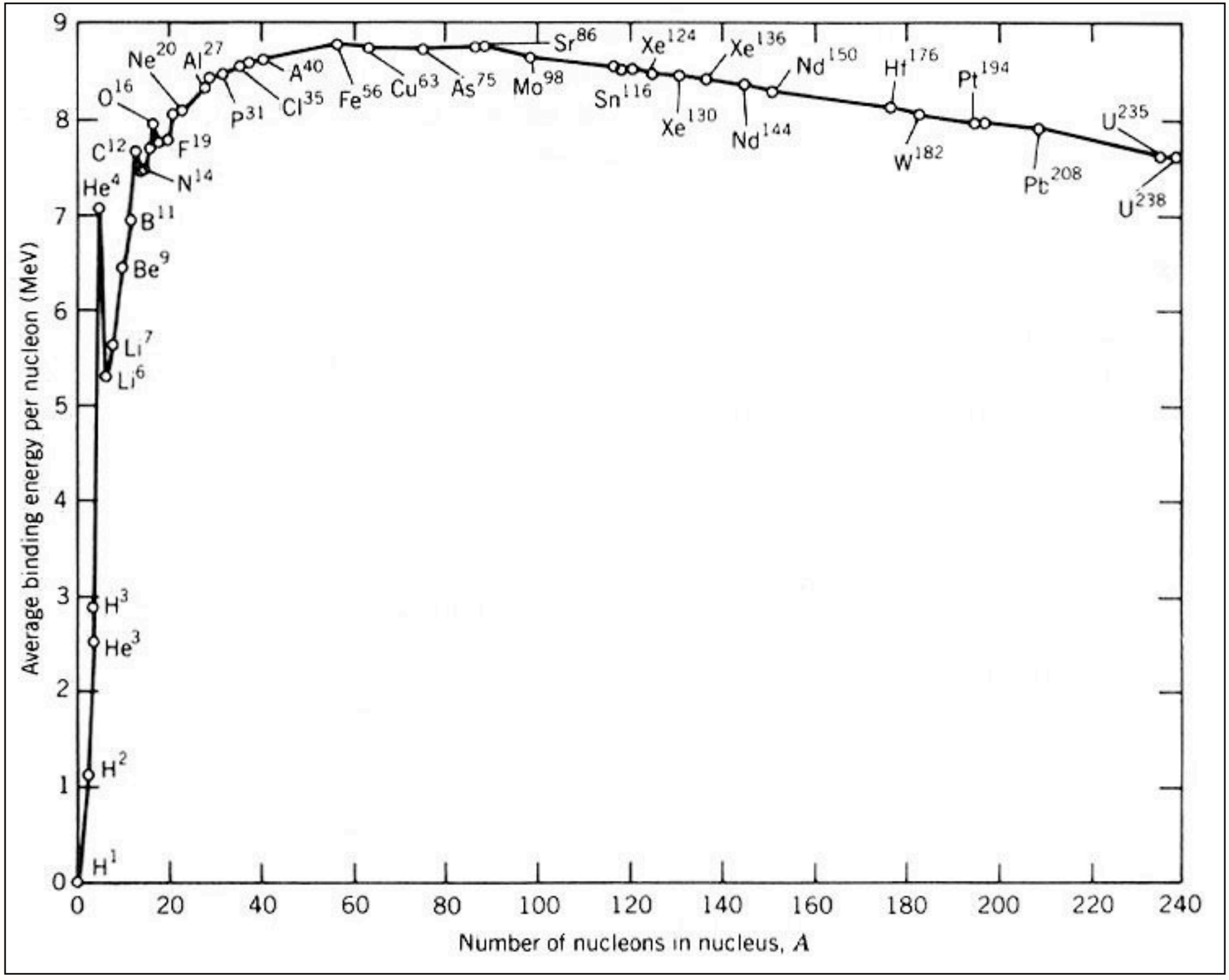


Kernfusie:

$4p + 2e \rightarrow \alpha + 2\nu + 26{,}7\ \text{MeV}$

Onze zon zet iedere seconde 570 miljard kilogram waterstof om in helium en verliest alleen daardoor 4,5 miljard kilogram aan massa

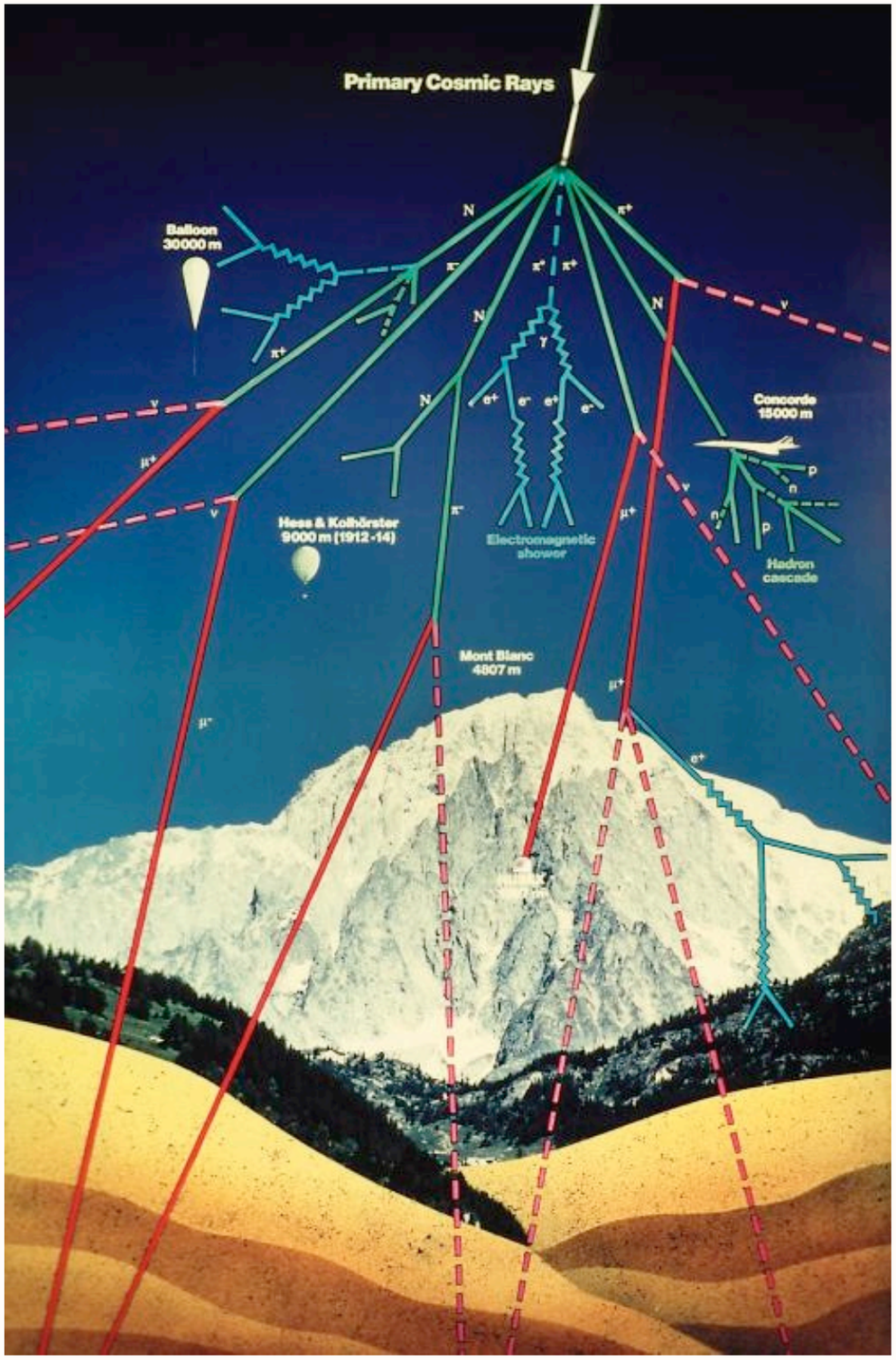
(De totale massa van de zon is 1.988×10^{30} kg)



M. Goeppert - Mayer

Bindingsenergie van kernen

Natuurlijke bronnen van hoog-energetische deeltjes



Kosmische straling:

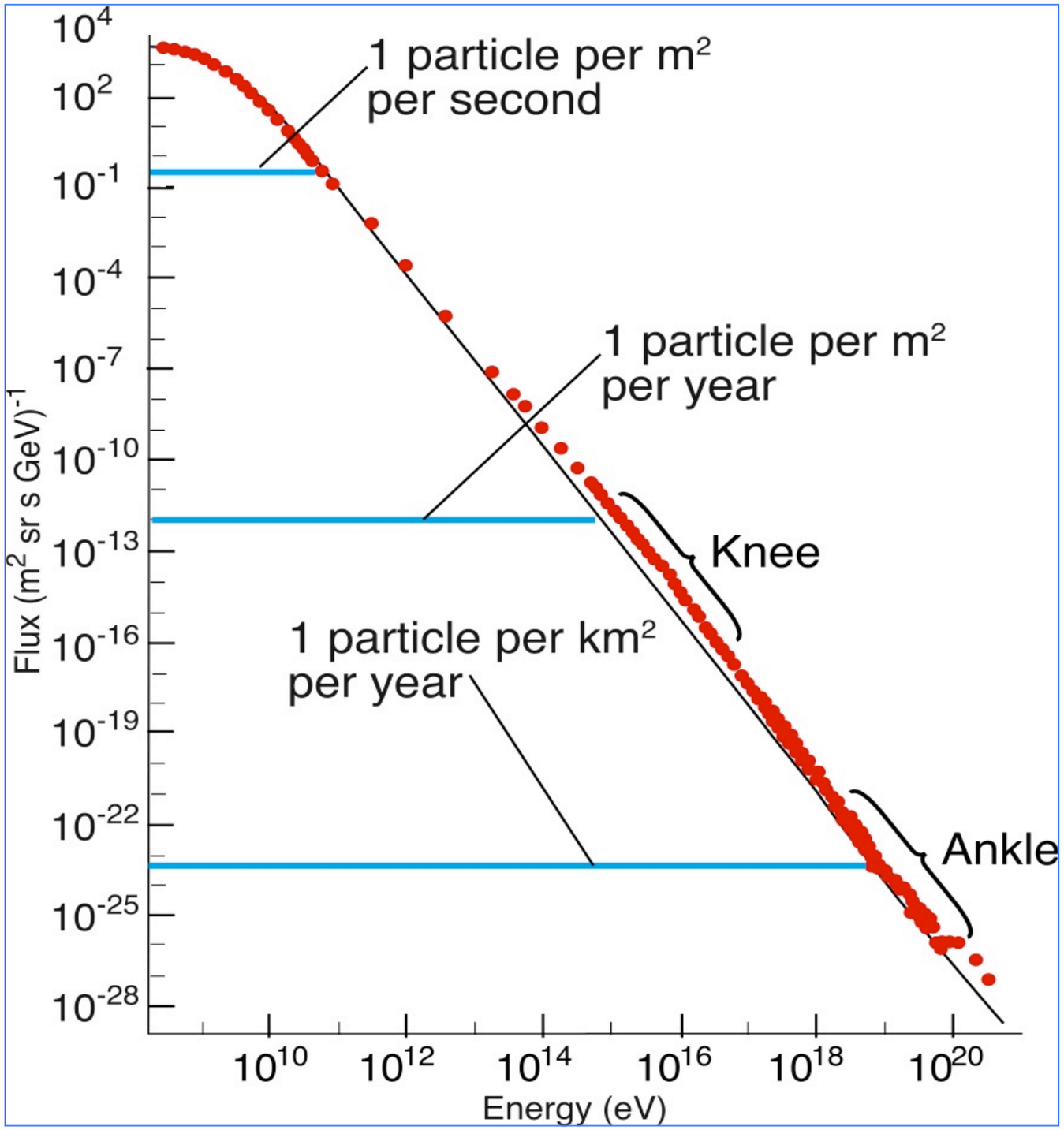
ioniserende straling van buiten de atmosfeer

- secondaire μ-deeltjes:

  $c\,\tau = 660$ m

- produkt van botsingen tussen kerndeeltjes

V. Hess



Energiespectrum van de primaire kosmische straling:

aantal deeltjes per vierkante meter per seconde met energie tussen 10^8 en 10^{20} eV dat de atmosfeer binnendringt