UMONS
Université de Mons

BPS meeting
17 May 2017

The Wilson cloud chamber or how to observe natural radioactivity?

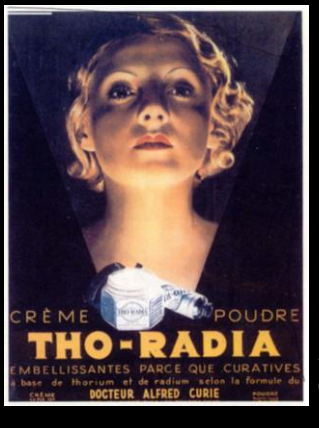
- What is natural **radioactivity** ?
- How to detect - **observe** it ?
- What is a Wilson **cloud chamber** ?
  invention history principle of operation 2 types main discoveries
- How to build and to operate a **home made chamber** ?
  What is observed ? ⇨ **Demo**

Faculté des Sciences

E. Daubie, F. Defontaines, S. Devouge, G. Kohnen
Service de Physique Nucléaire & Subnucléaire

PNSN

What is radioactivity?



Beauty product based on thorium on the market in the years 1920

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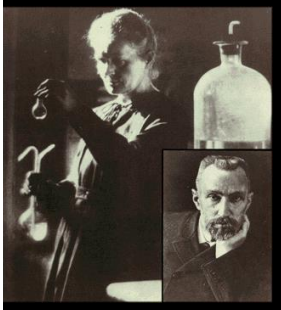
What is radioactivity ?

http://www.dictionary.com/browse/radioactivity

Phenomenon exhibited by and being a property of certain **elements** *spontaneously* emitting **radiation** resulting from changes in the *nuclei* of atoms



Marie & Pierre Curie 1898

↳ radioactive material

Torbernite

$Cu(UO_2)_2(PO_4)_2 \cdot 12\ H_2O$

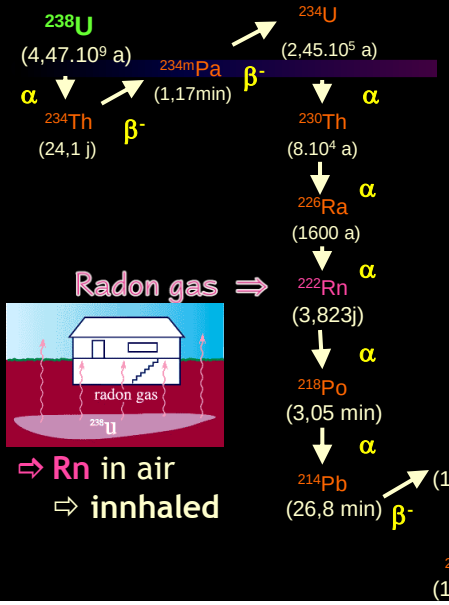
https://fr.wikipedia.org/wiki

uranium

3

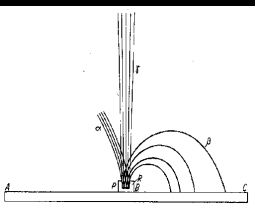
U238 the most common isotope of uranium **found in nature**

Uranium series



↳ emitted radiations

α β γ



Radon gas ⇒

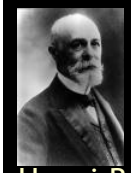
⇨ Rn in air
⇨ innhaled

4

α β γ rays invisible !

⇒ Radiation detectors needed !

∇! Possible confusion



Henri Becquerel
1895

U fluorescence property

Uranium glass (U oxide) glowing under UV light

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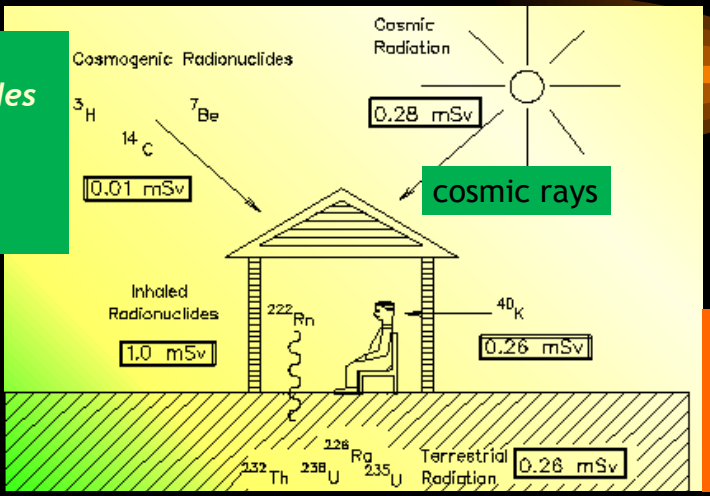
Sources of radioactivity

Radio nucleides

⇨ on earth surface



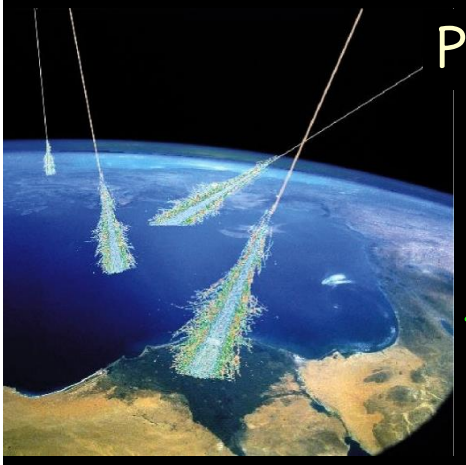
^{40}K

^{238}U

telluric radiations from Earth crust: long $T_{1/2}$

T_{238U}=4,7.10^{9} y + daughters T_{40K}=1,26.10^{9} y

cosmic radioactivity



Primary cosmic rays

- Protons 86%
- Alpha 12,5%
- Heavier nuclei 1,5%

Secondary rays

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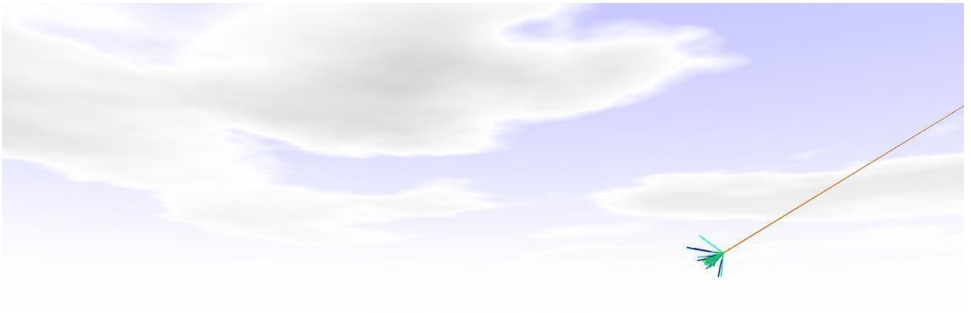
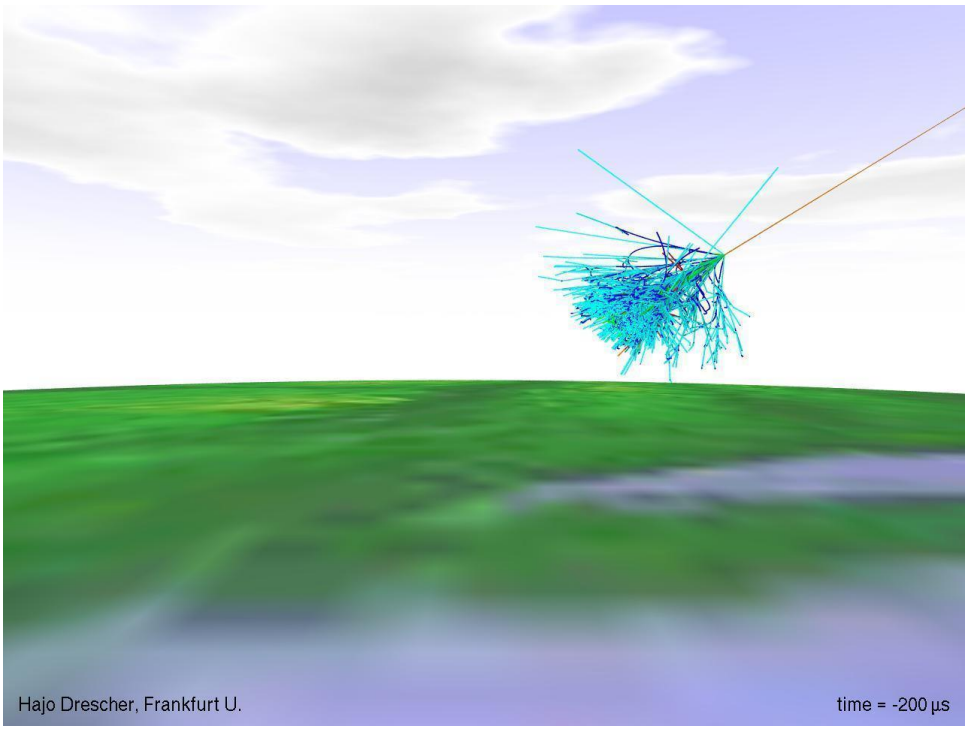
Cosmic cascade or shower

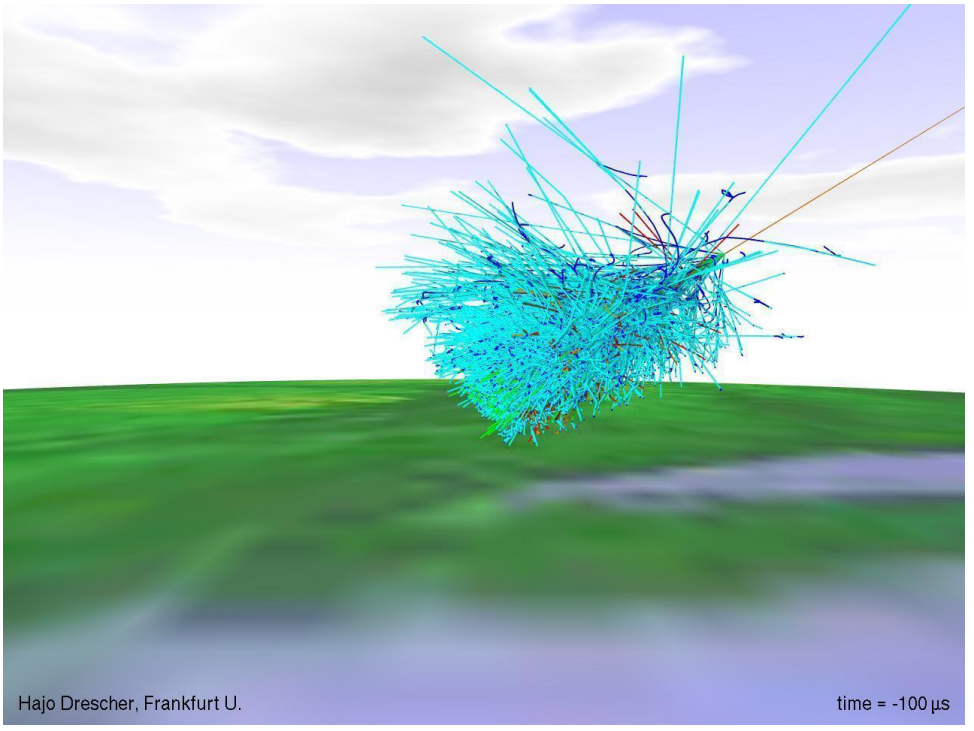
[Lepton-photon 2005 - Uppsala]

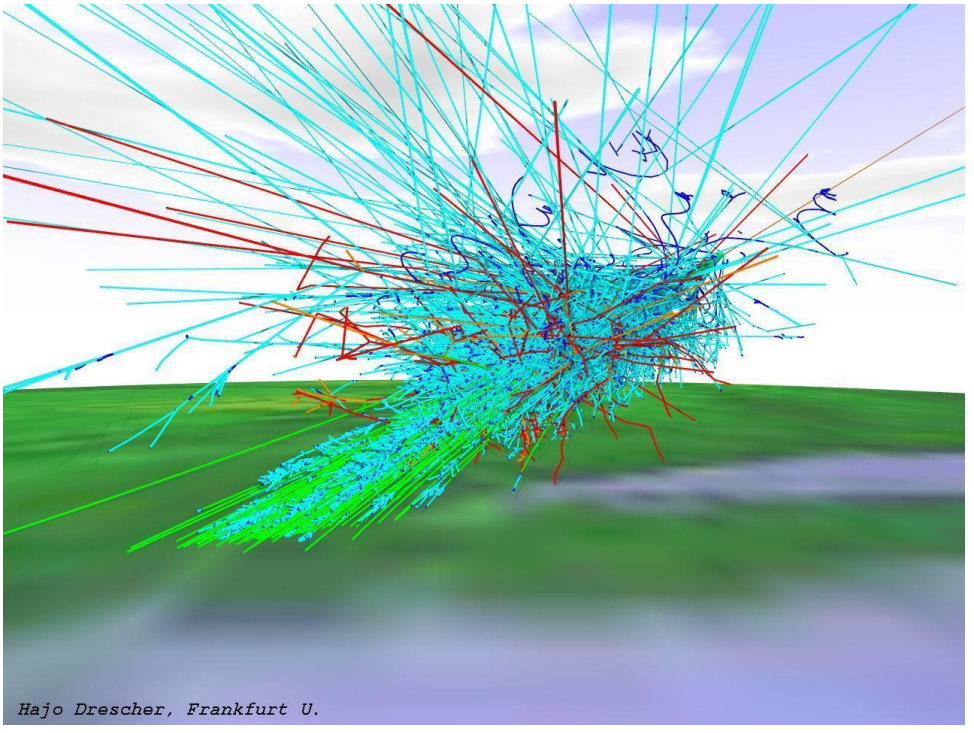
Simulation : very high energy primary cosmic ray reaching the upper atmosphere

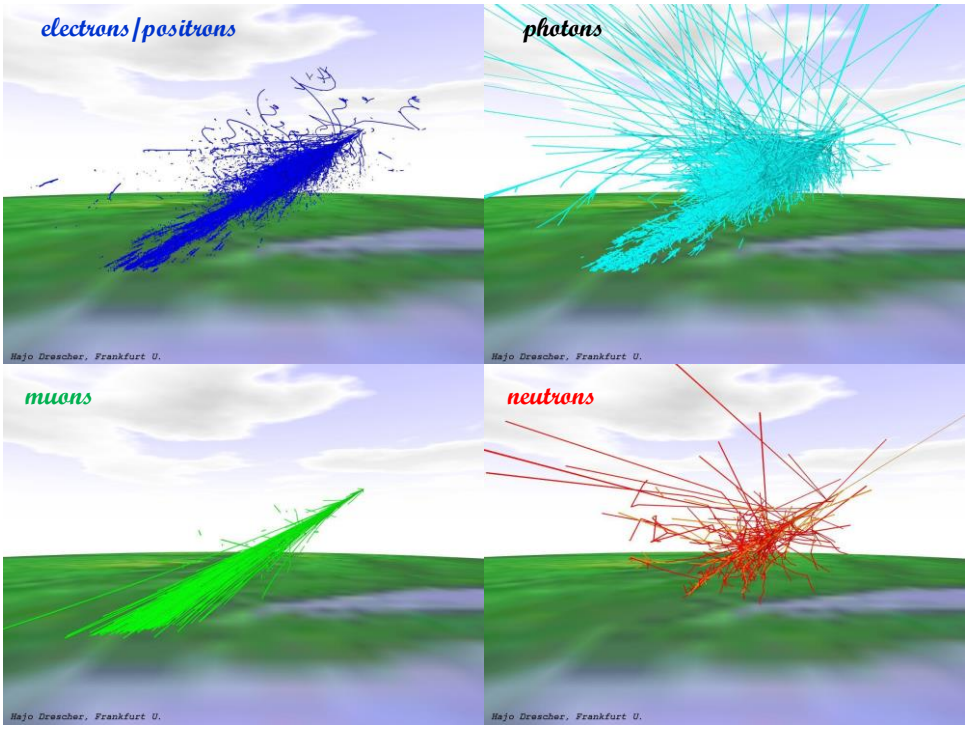


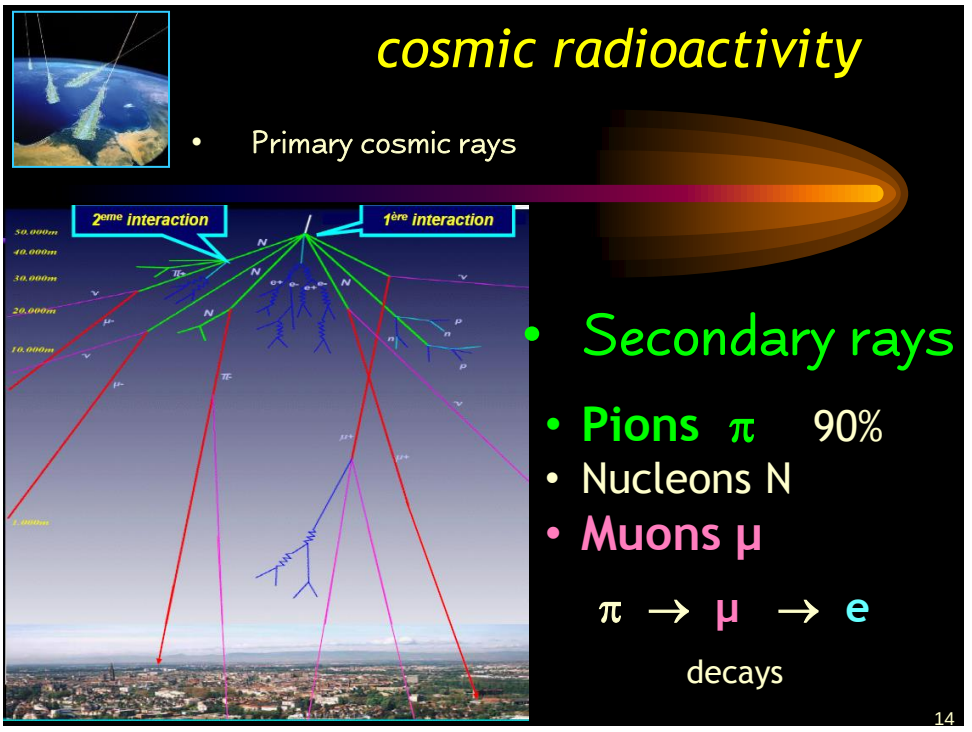

Hajo Drescher, Frankfurt U.
time = -300 µs


Hajo Drescher, Frankfurt U.
time = -200 µs


Hajo Drescher, Frankfurt U.
time = -100 µs


Hajo Drescher, Frankfurt U.


electrons / positrons
photons
muons
neutrons
Hajo Drescher, Frankfurt U.
Hajo Drescher, Frankfurt U.
Hajo Drescher, Frankfurt U.
Hajo Drescher, Frankfurt U.


cosmic radioactivity
• Primary cosmic rays
2eme interaction
1ère interaction
50.000m
40.000m
30.000m
20.000m
10.000m
• Secondary rays
• Pions π 90%
• Nucleons N
• Muons μ
π → μ → e
decays
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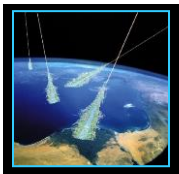
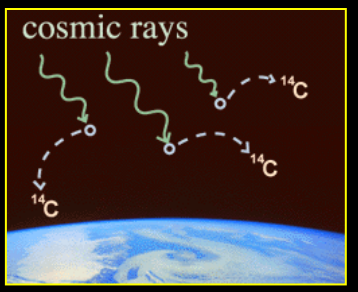


cosmic radioactivity

- Primary cosmic rays
- Secondary rays

$$^{1}_{0}n + ^{14}_{7}N \rightarrow ^{14}_{6}C + ^{1}_{1}p$$



nuclear reactions

- Cosmogenic rays
  ^{14}C ^{3}H ^{7}Be

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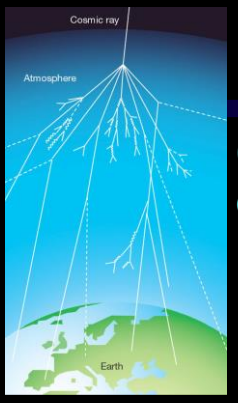
In summary

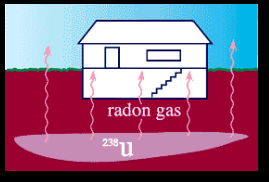


Cosmic rays

GeV - TeV energy

e^+, p, π, μ, Λ …

invisible !

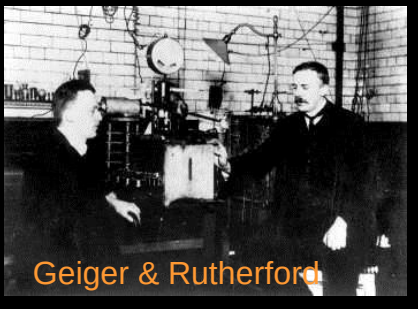


$\alpha\beta\gamma$ rays

MeV energy

How to detect radioactivity ?

Detectors - Monitors



Geiger & Rutherford

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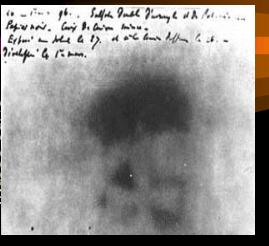
Historical detectors

- Photographic emulsions

Typical pattern 1896



© Musée Curie

- Geiger counter

Typical sound 1908-1928

- Wilson cloud chambers

Typical radiation tracks 1911

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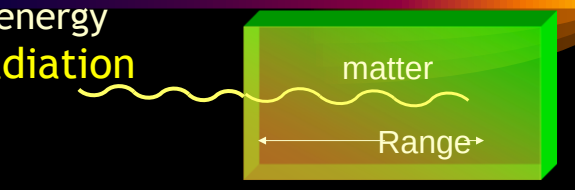
Particles, rays = Ionizing radiations

MeV to TeV energy
Ionizing radiation



zoom

ΔE lost > V_{ion} of matter

⇨ Creation of ion^+ / e^- pairs

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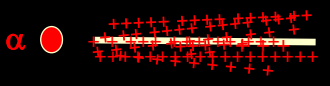
each type of radiation ⇒ its typical ionisation track

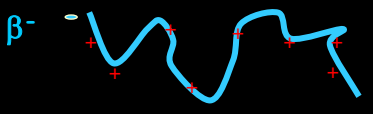
α particles many ionizations – small range – short straight track

≈ 50 000 pairs /cm air



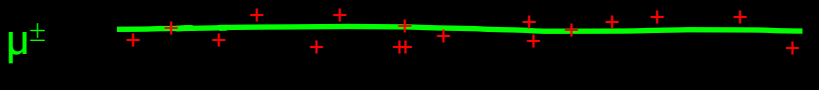
β particles

less ionizations – longer range – longer and chaotic track



≈ 100 pairs /cm air

μ particles – long straight track



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Cloud chambers

Am241

Cosmic rays

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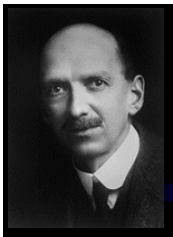


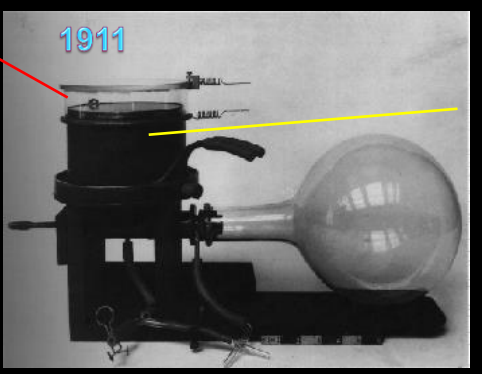
Wilson cloud chamber

Charles Wilson Scottish meteorologist
interested in cloud formation initiated by electricity

Nobel Prize 1927

Transparent cylindrical vessel
16.5 cm diameter
3.4 cm high

gas-vapor mixture
at the vapour saturation
Ex Air – water vap.
Argon-alcohol vap.



vessel
floor
piston

Fast expansion

Adiabtic approx.

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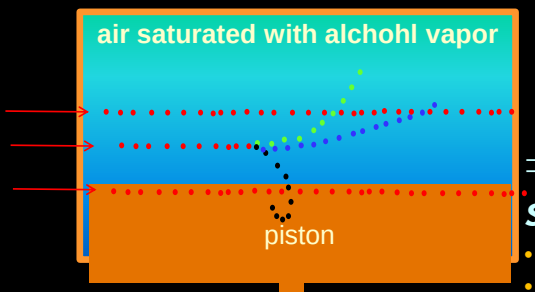
principle of operation

Expansion-type cloud chamber

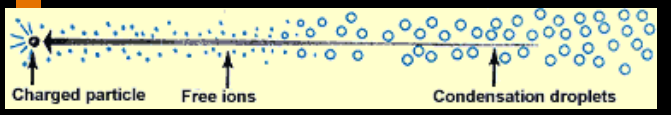
piston downwards



Flash+ camera

⇒ ***supersaturated state***

- Recompression 1s
- Recovery phase (draining of ions) 1-10 min ☹



ions$^+$ perturbation ⇨ condensation ⇨ tracks of droplets

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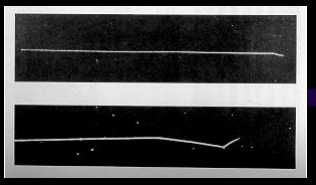
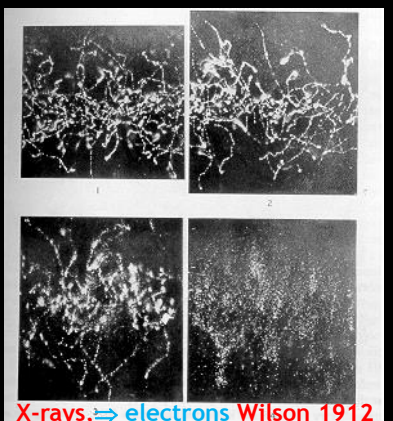
Cloud Chamber : pictures



1st Alpha-Ray tracks Wilson 1912

scattering



X-rays, ⇨ electrons Wilson 1912

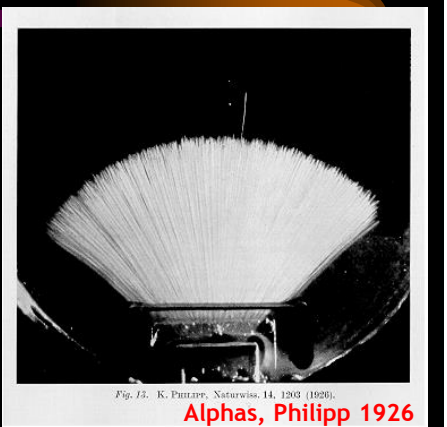


Fig. 13. K. Philipp, Naturwiss. 14, 1203 (1926).

Alphas, Philipp 1926

From W. Riegler's talk / CERN

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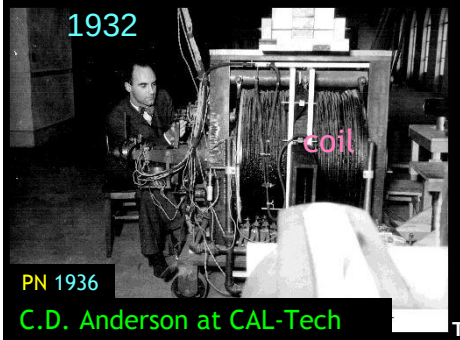
Cloud Chamber : famous pictures

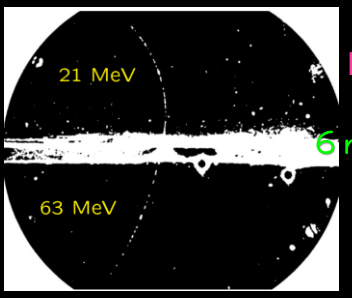
cosmic ray studies 20s - 50s

Anti-electron or positron discovery



PN 1936

C.D. Anderson at CAL-Tech



B = 1,5 T

6 mm thick Pb plate

Q

+e

-e

The ionization of the particle, its deflection and its behaviour in passing through Pb are the same as those of an electron.

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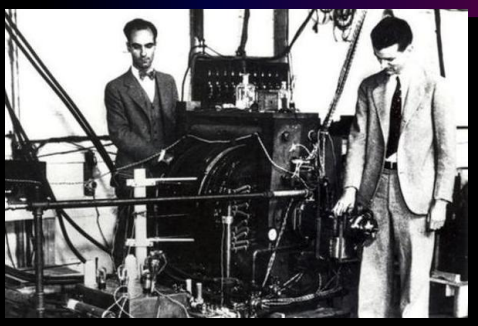
Cloud Chamber : famous pictures

1936 Muon discovery « heavy electron »



Carl Anderson & Seth Neddermeyer

at Caltech - same magnet cloud chamber as used to discover the positron in 1932

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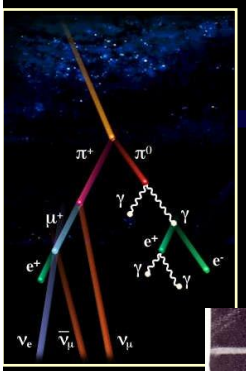
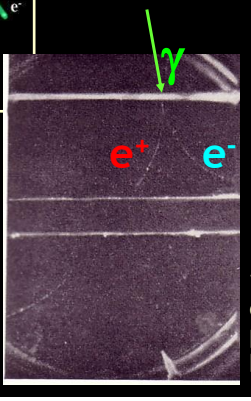
Cloud Chamber : pictures

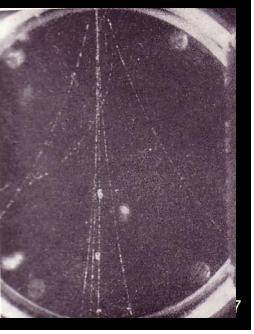


V shape events



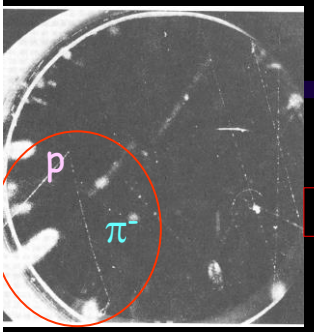
Production e^+e^- pair in Pb plate

Cosmic-ray "shower" Several e^+ e^-



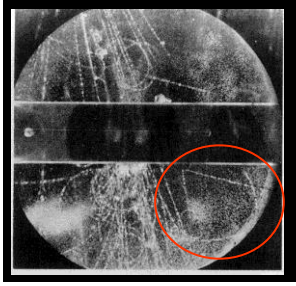
Cloud Chamber : pictures

50s Strange particles discoveries

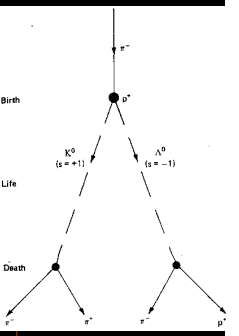


Neutral particle $\Lambda^0 \rightarrow \pi^-$ p

V shape events



Neutral partcile $K^0 \rightarrow \pi^+ \pi^-$



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another type of operation

A Continuously Sensitive Diffusion Cloud Chamber

1939 Dr A. Langsdorf [Univ. of California - Berkeley]

Supersaturation necessary for condensation of a vapor upon ions is maintained continuously by the diffusion of an initially warm saturated vapor through a noncondensing gas into a refrigerated region.

+25°C

-78°C

Expansion Piston movement

Temperature gradient

supersaturated state achieved near the bottom

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Our Home made chamber

Components & operation

1/ Airtight glass container (≈ 35 × 25 × 18 cm)

2/ Felt glued on the bottom floor

Spray pure isopropanol on the felt

3/Insulation box

Fill the box with dry ice

4/ metallic plate covered with black tape

Put down onto the dry ice layer

container turned upside -down

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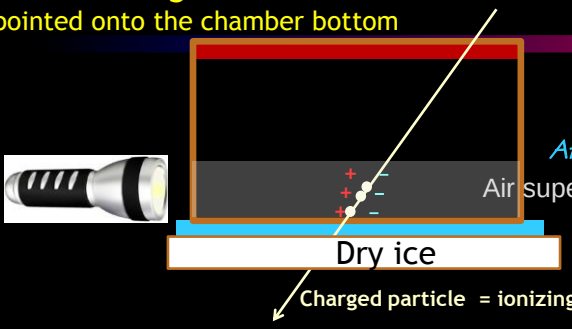
Our Home made chamber
Components & operation

5/ intense light source
pointed onto the chamber bottom



After a few minutes :

Air supersaturated with alcohol vapour
≈ cm high

After a few minutes :

Muon vapor trails
curls

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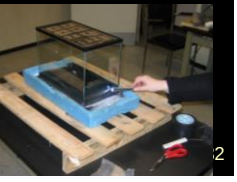
Our Home made chamber
Critical points

- Pure isopropanol (99 % purity)
- Rubber insulation strip for door or window to ensure *airtightness* of the chamber

- Intense light source (LEDs)

- *Turtle tub more convenient than an aquarium*



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Cloud chambers

Diffusion-type
Continuous-type

Many models !
Many designs !

Petri dish
4$

- Home made

- For sale

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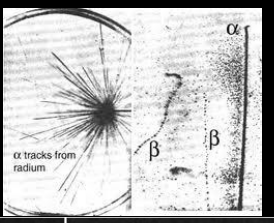
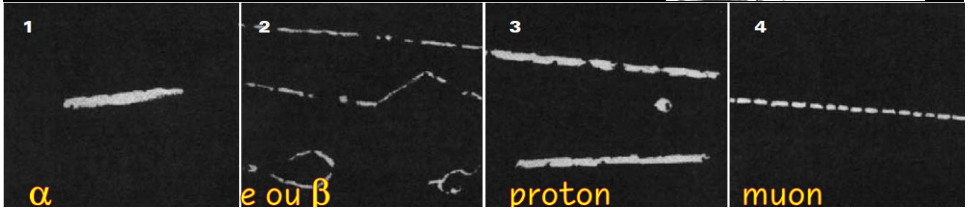
What can be observed ?

Water vapor trail
⇨ track of a plane passage
⇨ Which kind of plane ?

Using radioactive sources

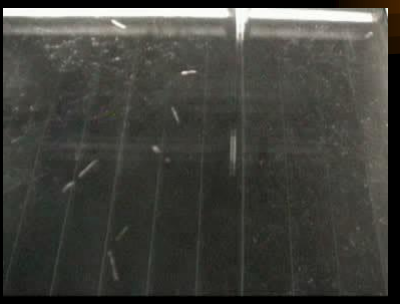


Track patterns



What can be observed ?

Cosmic rays



Allow to oberve live particles
⇒ Idea of the cosmic flux

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As educational tool

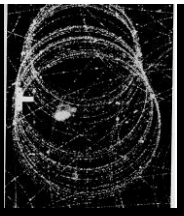
- Nuclear physics
- Cosmic ray physics
- Particle physics
- Thermodynamics
- Special relativity

$\mu \rightarrow e\ \nu\nu$ $\tau = 2\ \mu s$

Needed to understand : muons can reach Earth surface

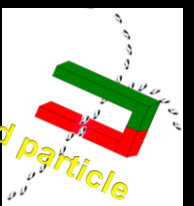
$$d = 210^{-6} \cdot c = 610^{2} m$$
$$d' = \gamma d = 30 km$$
$$\gamma = \frac{E}{m_0} = \frac{5000}{100} = 50$$

- ElectroMagnetism



$$p = mv = \frac{m_0 \beta c}{\sqrt{1-\beta^2}}$$
$$e\left(\vec{v} \times \vec{B}\right) = m\frac{v^2}{R}$$
$$p_T = 0,3BR$$
$$[GeV/c] = 0,3[T][m]$$

Fast electron in a magnetic field at the Bevatron, 1940



to understand how charged particles bend when affected by a magnetic bield

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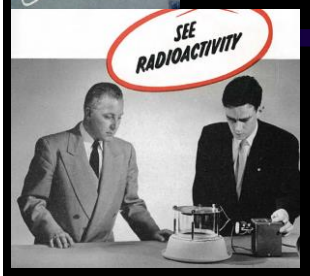
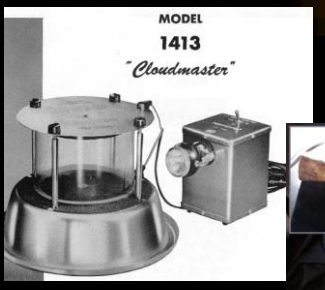
As educational tool



August 19, 1953

EDUCATIONAL INSTRUMENTS	Page Catalog	Price
Model 1613A "Classmaster"	24	$149.50
Model MR-1 Meter	24	35.00
Model 1413 "Cloudmaster"	25	99.00
Model 1413C	25	49.50



2016 model

Specifications

Voltage Supply — Reliable one-tube vibrator power supply controlled by toggle switch. Completely shock-protected by 4.7 megohm "health" resistor. Supplies 1200 volts d. c. to chamber.
Chamber — 6-section unit with spun aluminum base. Black wrinkle finish on floor of chamber permits easy viewing of "tracks."
Operation — 2 lbs. of dry ice will operate chamber for around an hour.
Power Supply — 110-115 volts, 50-60 cycles.
Dimensions — Power Supply 4" x 4⅛" x 5¼". Chamber 11½" diameter, 8½" high.
Weight — 8 lbs. Shipping weight 11 lbs.
Supplied Complete with all necessary components and instructions. No alcohol or dry ice.

Nuclear's exclusive Model 1413 "Cloudmaster" — a Continuous Cloud Chamber—provides a spectacular display of "tracks" caused by alpha, beta, gamma, and meson radiation. Vapor "tracks" occur in a sensitive layer about three-quarters of an inch thick near the floor of the chamber.

Recently introduced, it has become popular because of its simplicity and ease of operation. The sharp change in temperature necessary for the creation of the supersaturated "sensitive" layer is produced by easily-obtainable isopropyl alcohol and dry ice. Power unit provides necessary spot light and a 1200 volt d. c. "sweep voltage" to the cloud chamber. Completely safe electrical connections and radiation source. If suitable d. c. voltage supply is available, Model 1413C Cloud Chamber may be ordered separately.

+ ^{210}Pb sample

Air cooling system, Peltier based

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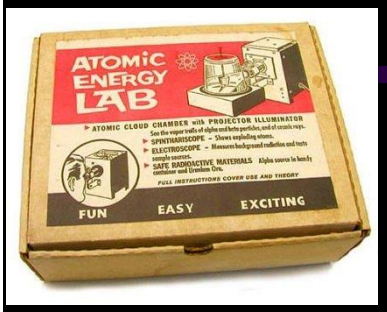
Cloud Chamber as a toy

In the 50s



Atomic cloud chamber kit for children !

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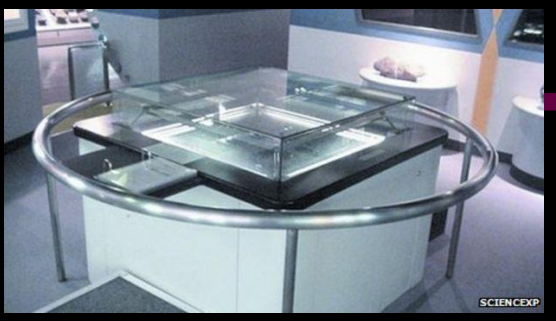
For exhibitions or workshops



- At CERN
- Astrophysics or particle physcics outreach activities
- …

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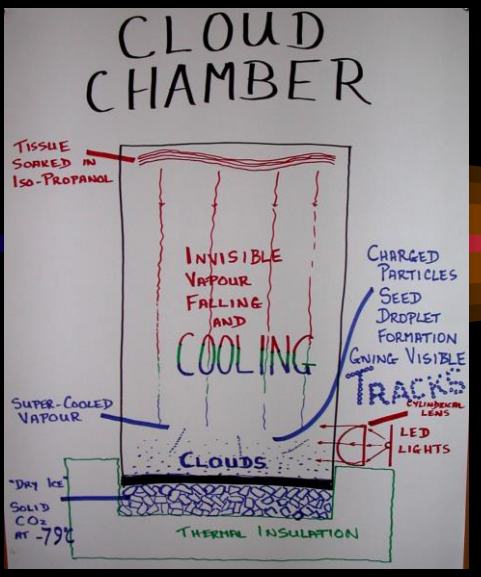
Thanks for your attention !



http://www.hep.phy.cam.ac.uk/outreach/cloud.html

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References

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https://scool.web.cern.ch/sites/scool.web.cern.ch/files/documents/SCoolLAB_CloudChamber_DIYManual_2017_v3.pdf
https://icecube.wisc.edu/outreach/activity/cloud_chambers
http://astrobulletin.amnh.org/exhibitions/einstein/promos/for-educators/building-a-cloud-chamber-cosmic-ray-detector/ (Andy Foland's Cloud Chamber Page)
[2] E. Segré, Nuclei and Particules, W.A.Benjamin Inc., 1965, pp. 99-102
C. Grupen and B. Shwartz, Particle detectors, Cambridge University Press, 2008, pp. 160-162.
[3] Louis LEPRINCE-RINGUET, les rayons cosmiques, Ed. Albin Michel, 1945
R. Mermod, De l'électron aux quarks, Presses Polytechniques et Universitaires Romandes, 1999, pp. 9-23

More info

https://icecube.wisc.edu/outreach/activity/cloud_chambers

https://home.cern/students-educators/updates/2015/01/how-make-your-own-cloud-chamber

http://www.hep.phy.cam.ac.uk/outreach/cloud.html

http://www.cloudylabs.fr/wp/hadron_pictures/

More fun on

https://www.youtube.com/watch?v=noP7HT-Uins

https://www.youtube.com/watch?v=AMaDqaRzDm4

https://www.youtube.com/watch?v=pewTySxfTQk

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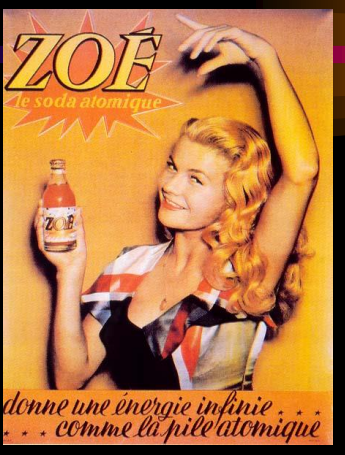
Pub …



Vers 1950, même après Hiroshima, l'énergie atomique reste un vecteur porteur pour la publicité

Publicité pour une ligne de produits de beauté parue dans Vogue en novembre 1916