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 homemade chamber?
  - What is observed? ⇒ Demo

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Service de Physique Nucléaire & Subnucléaire
What is radioactivity?

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

Radioactive material

Radioactive material

U238 the most common isotope of uranium found in nature

Uranium series

Emitted radiations

Alpha (α) Beta (β) Gamma (γ)
\( \alpha \beta \gamma \) rays invisible!

\[ \Rightarrow \] Radiation detectors needed!

\( \triangledown ! \) Possible confusion

U fluorescence property

Henri Becquerel
1895

Uranium glass (U oxide) glowing under UV light

Sources of radioactivity

Radio nucleides
\( \Rightarrow \) on earth surface

Cosmogenic Radionuclides

\( ^{40} \) \( ^{238} \) \( ^{232} \)

Cosmic Radiation

\( 0.28 \) mSv

Inhaled Radionuclides

\( 1.0 \) mSv

Telluric radiations from Earth crust: long \( T_{1/2} \)

\( T_{238U} = 4.7 \times 10^9 \) y + daughters

\( T_{40K} = 1.26 \times 10^9 \) y

Cosmic rays

Terrestrial Radiation

\( 0.28 \) mSv

\( 40K \)

\( 238U \)
**cosmic radioactivity**

**Primary cosmic rays**
- Protons 86%
- Alpha 12.5%
- Heavier nuclei 1.5%

**Secondary rays**

**Cosmic cascade or shower**
[Lepton-photon 2005 - Uppsala]

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

- Primary cosmic rays
- Secondary rays
  - Pions $\pi$ 90%
  - Nucleons $N$
  - Muons $\mu$

$$\pi \rightarrow \mu \rightarrow e$$
decays
cosmic radioactivity

- Primary cosmic rays
- Secondary rays

\[ ^{1}n + ^{14}N \rightarrow ^{14}C + ^{1}p \]

nuclear reactions

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

In summary

Cosmic rays
- GeV - TeV energy
- $e^+$, p, $\pi$, $\mu$, $\Lambda$ ...

invisible!

$\alpha \beta \gamma$ rays
- MeV energy
How to detect radioactivity?

Detectors
- Monitors

Geiger & Rutherford

Historical detectors

• Photographic emulsions
  Typical pattern  1896

• Geiger counter
  Typical sound  1908-1928

• Wilson cloud chambers
  Typical radiation tracks  1911
Particles, rays = Ionizing radiations

MeV to TeV energy Ionizing radiation

ΔE lost > $V_{\text{ion}}$ of matter

Creation of ion $^+ + e^-$ pairs

Each type of radiation ⇒ its typical ionization track

α particles: many ionizations - small range - short straight track

$\alpha$ particle track

≈ 50 000 pairs /cm air

β particles: less ionizations - longer range - longer and chaotic track

$\beta^-$ particle track

≈ 100 pairs /cm air

μ particles: long straight track

$\mu^+$ track
Cloud chambers

Am241

Cosmic rays

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.
**principle of operation**

Expansion-type cloud chamber

piston downwards

- air saturated with alcohol vapor
- piston

⇒ **supersaturated state**

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

ions⁺
perturbation⇒ condensation⇒ tracks of droplets

**Cloud Chamber: pictures**

1st Alpha-Ray tracks
Wilson 1912

scattering

X-rays, ⇔ electrons Wilson 1912

From W. Riegler’s talk / CERN

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Alphas, Philipp 1926
Cloud Chamber: famous pictures

cosmic ray studies 20s - 50s

Anti-electron or positron discovery

1932

PN 1936

C.D. Anderson at CAL-Tech

B = 1.5 T

5 mm thick Pb plate

21 MeV

63 MeV

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

1936  Muon discovery  “heavy electron”

Carl Anderson & Seth Neddermeyer

at Caltech - same magnet cloud chamber as used to discover the positron in 1932
Production \( e^+e^- \) pair in Pb plate

Cosmic-ray "shower" Several \( e^+e^- \)

Neutral particle \( \Lambda^0 \to \pi^- p \)

Neutral particle \( K^0 \to \pi^+ \pi^- \)
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 on spon ions is maintained continuously by the diffusion of an initially warm saturated vapor through a noncondensing gas into a refrigerated region.

Expansion
Piston movement

Temperature gradient

supersaturated state achieved near the bottom

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
Our Home made chamber

Components & operation

5/ intense light source pointed onto the chamber bottom

After a few minutes:
Air supersaturated with alcohol vapour
\( \approx \) cm high

Charged particle = ionizing radiation

After a few minutes:
Muon vapor trails curls

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
Cloud chambers

Diffusion-type
Continuous-type

Many models!
Many designs!

• Home made
• For sale

Petri dish
4 S

What can be observed?

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

Using radioactive sources

Track patterns

1
2
3
4

α
γ or β
proton
muon
What can be observed?

Cosmic rays

Allow to observe live particles
⇒ Idea of the cosmic flux

As educational tool

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

Needed to understand: muons can reach Earth surface

\[ \mu \rightarrow e \nu \nu \quad \tau = 2 \, \mu s \]

\[ d = 210^6 \cdot c = 610^7 \, m \]
\[ d' = \gamma d = 30 \, km \]
\[ \gamma = \frac{E}{m_\mu} = \frac{5000}{100} = 50 \]

- ElectroMagnetism

\[ p = mv = \frac{m_\beta c}{\sqrt{1 - \beta^2}} \]
\[ e(\vec{\gamma} \times \vec{B}) = \frac{m_\nu^2}{R} \]
\[ \rho_T = 0.3 \, BR \quad \left[ (eV / c) = 0.1[T][m] \right] \]

Fast electron in a magnetic field at the Bevatron, 1940

Charged particle to understand how charged particles bend when affected by a magnetic field
As educational tool

August 19, 1953

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<th>EDUCATIONAL INSTRUMENTS</th>
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<tr>
<td>Model 1413A &quot;Cloudmeter&quot;</td>
<td>24</td>
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<td>Model 1413B &quot;Netter&quot;</td>
<td>28</td>
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<td>99.50</td>
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<tr>
<td>2016 model</td>
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Nuclear's exclusive Model 1413 "Cloudmeter"—a Con-
nomasonic Cloud Chamber—provides a spectacular display of
clouds when vaporized alcohol or water is used. The large size of
the Cloud Chamber permits easy reading of "tracks.

Specifications

Voltage Supply: 120 volt, 60 cycle, fused power supply.
Power Supply: 120 volt, 30 cycle, fused power supply.
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Air cooling system, Peltier based

Cloud Chamber as a toy

In the 50s

Atomic cloud chamber kit for children!
For exhibitions or workshops

- At CERN
- Astrophysics or particle physics outreach activities
- ...

Thanks for your attention!

http://www.hep.phy.cam.ac.uk/outreach/cloud.html
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https://www.youtube.com/watch?v=AMaDqaRzDm4
https://www.youtube.com/watch?v=pewTySxFTQk

More fun on
https://www.youtube.com/watch?v=noP7HT-UIns
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