Visualisation of radioactive particles / Diffusion cloud chamber

LEP
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Related topics

α, β, γ-particles, β deflection, ionising particles, Mesons, cosmic radiation, radioactive decay, decay series, particle velocity, Lorentz force.

Principle and task

Radioactivity is a subject in our society which has been playing an important role throughout politics, economy and media for many years now. The fact that this radiation cannot be seen or felt by the human being and that the effects of this radiation are still not fully explored yet, causes emotions like no other scientific subject before.

The high-performance diffusion cloud chamber serves for making the tracks of cosmic and terrestrial radiation visible so that a wide range of natural radiation types can be identified. Furthermore, the diffusion cloud chamber offers the opportunity to carry out physical experiments with the aid of artificial radiation sources.

Equipment

Diffusion cloud chamber PJ45, 230 V	09046.93	1
Isopropyl alcohol, 1000 ml	30092.70	2
Thorium-source	09043.41	1
Radioactive source, Sr-90, 74 kBq	09047.53	1
Support base “PASS”	02005.55	1
Swinging arm	08256.00	1
Support rod, stainl. steel., 250 mm	02031.00	1
Right angle clamp “PASS”	02040.55	1
Object holder, 5 × 5 cm	08041.00	1
Holder for dynamometer	03068.04	1
Scale for demonstration board	02153.00	1
Accessory set for beta deflection	09043.52	1
Stand tube	02060.00	1

Problems

1. Determination of the amount of background radiation
2. Visualisation of α, β, γ-particles and mesons
3. Visualisation of the Thorium (Radon) decay
4. Deflection of β^--particles in a magnetic field

Fig. 1: Experimental set-up: Diffusion cloud chamber.

Setup and procedure

The cloud chamber consists of a chamber base and the observation chamber. The chamber base comprises a cooling element, a power supply, an alcohol reservoir, an alcohol pump and a programmable time switch. The observation chamber is placed onto the chamber base.

The bottom of the observation chamber is formed by a massive, black metal plate (surface 45 cm × 45 cm) which is cooled over the whole surface to about -30 °C by means of the cooling element.

The top plate and the side plates of the observation chamber consist of two glass hoods which are placed one into the other. A grid of fine heating wires is placed between the upper two glass plates. These wires serve for heating this area of the chamber thus keeping the hood free from condensation. At the same time they are held at high voltage thus generating an electric field that attracts the ions. The upper part of the glass hood includes an electrically heated gutter which runs around the whole circumference. Iso-propyl alcohol flows through a bended tube and drops into the gutter.

The alcohol evaporates and diffuses from the upper, warmer area of the chamber to the cold chamber bottom. There the alcohol is condensed into tiny droplets and flows back into the reservoir.

Right above the thin liquid layer covering the bottom a zone of oversaturated alcohol vapour is formed. It's in this area, and only in this area, that the charged material particles coming from the inside or from the outside produce ions along their trajectory. The tiny alcohol droplets preferably attach to these ions thus producing a visible cloud track. The length and the structure of the cloud track give information on the kind of ionizing particles.

In order to guarantee an optimum view on the observation chamber, it is recommended to place the chamber onto a square table (border length about 90 to 100 cm) which should be about 30-60 cm high.

Please make sure that the ventilating slots are not covered and that the cloud chamber is not subjected to direct light coming from above. A slightly darkened room whould be perfect. Use the connecting cable supplied to connect the cloud chamber to mains. The mains connection is located down on the back side. The corresponding mains socket should be protected for 10 A to 16 A.

Adjust the cloud chamber on an absolutely horizontal level with the aid of the adjustable feet in order to provide an even alcohol level in the gutter and thus a clear image.

When you have connected the cloud chamber to mains and opened the front side, remove the alcohol reservoir from its installation place and unscrew the union nut of the double tubing assembly.

Refill the alcohol reservoir, fix the double tubing again and place the reservoir back in place.

Now activate the switches as follows:

mains switch	ON
mode	continuous operation
high voltage	ON

The knurled nut serves for regulating the amount of alcohol dropping into the evaporating gutter. Turn the knurled nut to the left and observe the alcohol flowing through the bended tube and dropping into the gutter. When the gutter is filled to a liquid level of about 1 cm, reduce the alcohol supply to about 2 droplets per second. When the cloud chamber is being operating, the alcohol in the gutter should remain constant at this level. After about 5 minutes, the first white tracks should appear on the black observation surface. If, however, after 1 hour the tracks become a bit fuzzy and milky, you have to reduce the gutter heating by means of the control knob.

If the tracks are too weak, the heating of the gutter must be increased.

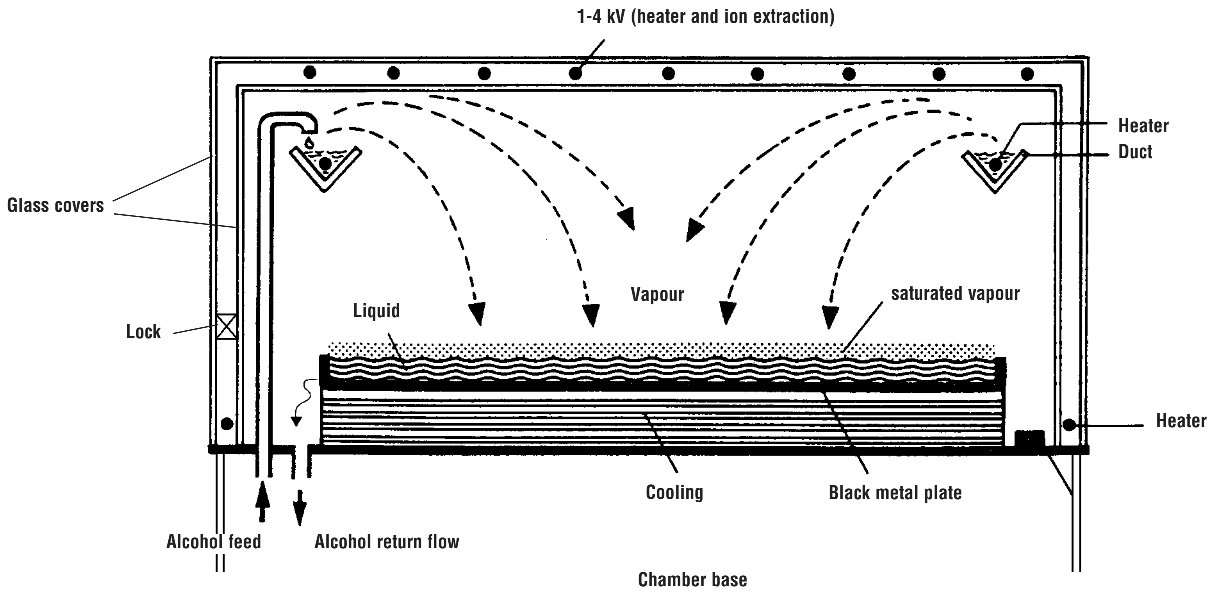


Fig. 2: Section through diffusion cloud chamber.

If you want to run the cloud chamber at automatic operation, set the markers of the programmable time switch to the desired switching time (red marker to switch the cloud chamber on, green marker to switch it off) and set the mode switch to “timer”. For more detailed information see the instructions on the programmable time switch.
Now close the front side by inserting the plate into the right side of the opening, pushing it back to the left stop position and locking it up.

Artificial radiation sources

On the left side of the chamber base there is an opening which serves for introducing artificial radiation sources. Use the head of the screw to push the plate to the right. The ball with pin which is located behind the plate can be turned around with the aid of the pin until the opening towards the inner area becomes visible. Now you can insert an artificial radiation source like, for instance, the thorium source a few centimeters into the inner area of the chamber.

Theory and evaluation

1. Natural Earth radiations

1.1 Cosmic rays

Radiations of particles with a high energy content (an exception: photon rays, which are electromagnetic waves) use to come from space down to every part of our terrestrial atmosphere (the primary cosmic radiations). Here are their main composition:

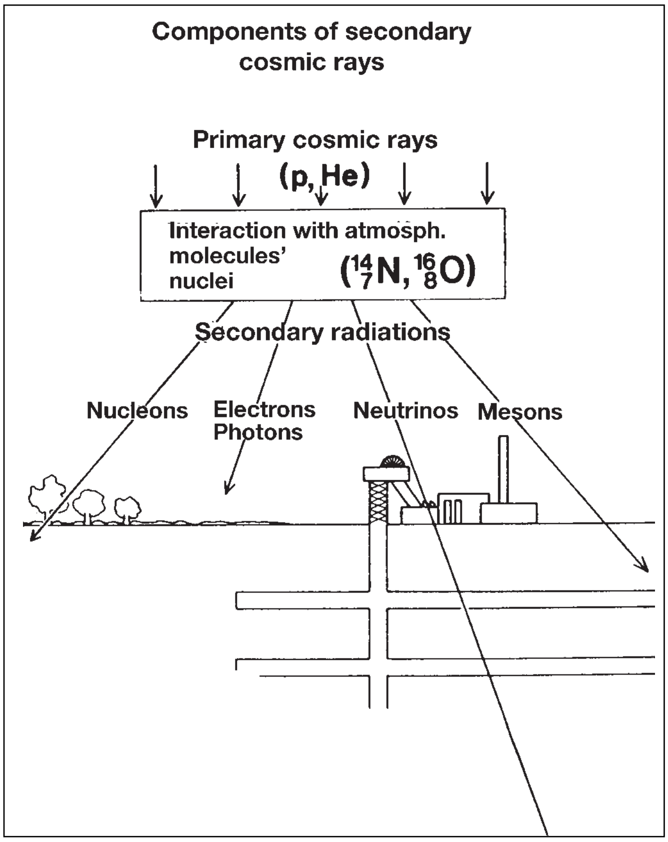
Particles	Percentage
protons	about 90 %
alpha-particles	about 9 %
bigger nuclei	up to 1 %

The particles penetrating into the atmosphere happen to bang into nuclei of the atmosphere and provoke nuclear reactions as well as nuclear splits. Therefore, new nuclei and elementary particles are created, go on flying and lead to other interactions.
In the atmosphere layers close to earth (less than 20 km high) one can observe only one secondary kind of radiations brought up by the numerous interaction-processes in the superior layers of the atmosphere. One must differentiate four kinds of components which have a different penetrating power (see Fig. 3):

Components of cosmic secondary rays	Components
Nucleons components	protons / neutrons
Electrons and photons components	elektrons / positrons / photons
Mesons components	measons of different charge
Neutrinos components	neutrinos / antineutrinos

In the Diffusion Cloud chamber, all particles charged in electricity can be detected, that is to say: electrons, positrons, mesons, protons and alpha-particles. Photons create only undirectly a trail when, by example, they eject an electron from an atom, which produces a trail of ionisation. Neutrons can lead to nuclear reaction and then, the charged particle from the nucleus creates a trail:

Fig. 3: Natural splitting processes.

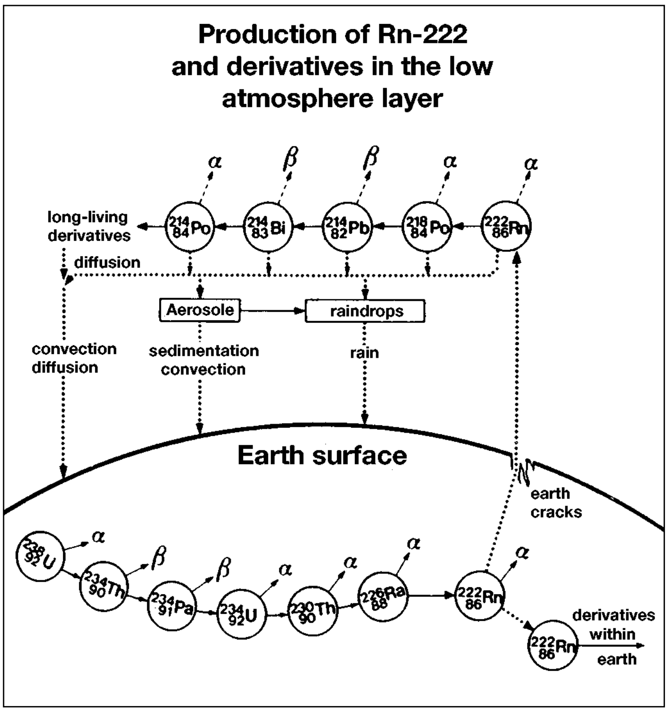


Particles	Symbol	Relative mass	Charge	Radioactive Period
electron	e-	1	-1	stable
positron	e+	1	+1	stable
myon (μ- meson)	μ–	206.77	-1	$1.5 \cdot 10^{-6}$ s
myon (μ+ meson)	μ+	206.77	+1	$1.5 \cdot 10^{-6}$ s
proton	p+	1836.10	+1	stable
neutron	n	1838.62	0	11.7 mn
alpha-particle	α, He^{++}	7294.1	+2	stable

1.2 Terrestrial radiations

All materials on Earth (earth, water, atmosphere, animals…) contain natural radionuclides which send radiations. They have been existing since the creation of Earth (that is to say 4.5 thousand million years) or are constantly being created: U-238; Th-232; K-40 or Rb-87, for instance, belong to the natural radionuclides and have a very long radioactive period. Ra-226; Rn-222; Po-218 or Pb-210 are constantly being created and those radionuclides have a rather short radioactive period in the three natural splitting processes. There exist also natural radionuclides with a relative short-timed radioactive period, but these do not belong to the splitting process. They are constantly being created in the upper layers of atmosphere, such as C-14 from N-14 or H-3 from N-14 or O-16, for instance.

Fig. 4



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

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{12}_{6}C + ^{3}_{1}H$$

$$^{16}_{8}O + ^{1}_{0}n \rightarrow ^{14}_{7}N + ^{3}_{1}H$$

The about 100 natural radionuclides which have been existing since the creation of Earth or which are constantly being created can be found on the whole Earth in different concentrations. That is the reason why there are constant exchanges between earth, water, atmosphere and animal-life (Fig. 4).

That is why the Diffusion Cloud chamber is given materials made of natural radionuclides, which emit radiations.

2. The Diffusion Cloud chamber

How are tracks formed in the Cloud chamber?

The particles of which the radiation consists are unimaginably small. As an example, if we think of 1 trillion (1,000,000,000,000) protons lined up one after the other, they would only give a 2 mm long line! The particles in radiation can therefore not even be seen under the best microscopes.

Under certain conditions, however, the particles can produce cloud tracks which are visible to the human eye. Such tracks enable us to see where the particles have travelled. This is similar to looking at an aeroplane which is flying at a high altitude. The aeroplane itself is not visible from the ground, only the condensation trail can be seen.

Alpha particles, electrons, protons and mesons (each of the particles named carries an electrical charge) all produce cloud tracks in a cloud chamber. (The tracks of the individual particles look different, so that one can determine,

- which particle has flown through the cloud chamber,
- the speed at which it has flown (energy) and
- whether it had a collision or was deflected during its flight.

The alcohol vapour diffusing down from above to the black plate liquefies (condenses to drops), as soon as it reaches the immediate vicinity of the cooled plate.

Above the liquefied alcohol vapour, there is a 1–2 mm thick layer in which the vapour has just not quite liquefied. In this layer, drop formation, and so cloud formation, can be deliberately caused, e.g. by finest dust particles (condensation nuclei) or by a radiation particle flying through. During their flight, radiation particles “damage” (ionize) numerous alcohol molecules, which can then take on very much bigger alcohol drops and so become visible to us. They form the cloud track (Fig. 5).

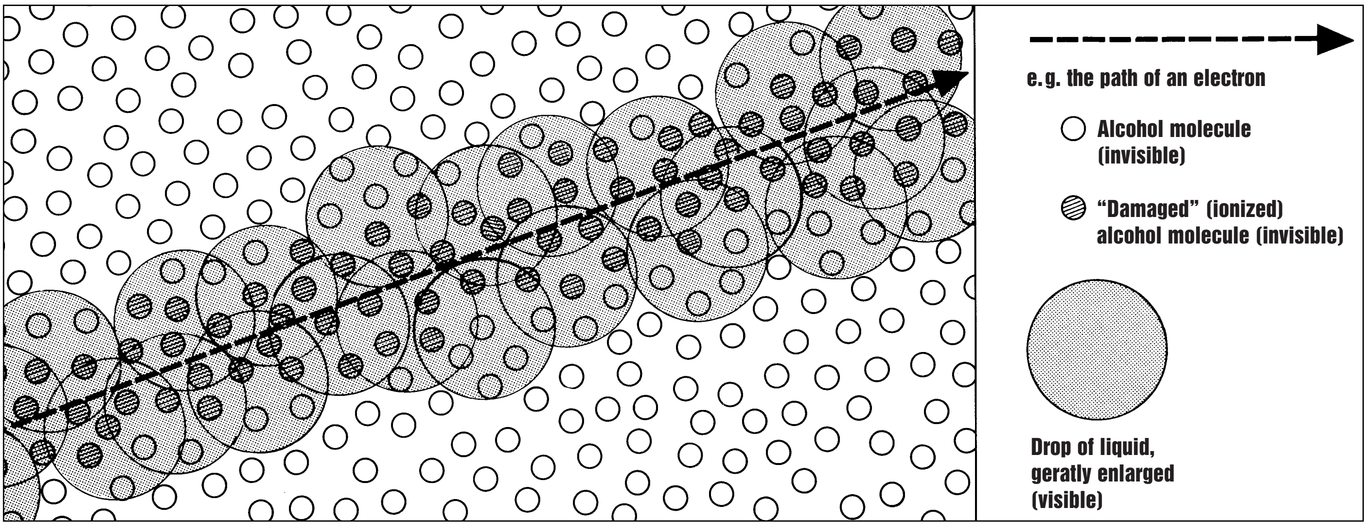
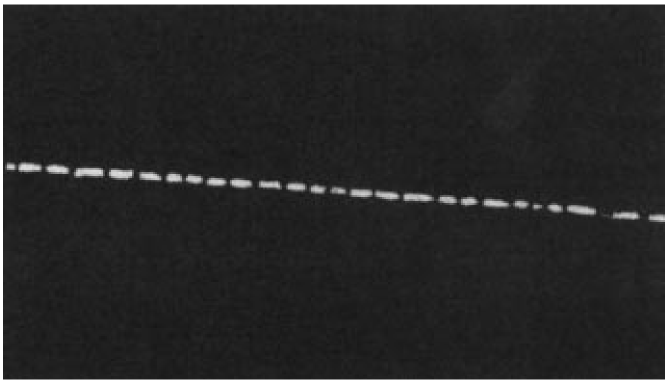


Fig. 5: The creation of cloud tracks in a cloud chamber.

Fig. 6: Track generated by an α-particle.

Fig. 8: Track generated by an electron with a high content of energy.



Problems

1. Determination of the amount of background radiation

All of the radioactive particles described in the previous chapter are continually present as so-called background radiation, unless one is in a special screened off room. When radioactive effects such as, for example, radioactive decay, are studied, then the zero rate resulting from the background radiation which was prevailing at that time must always be subtracted from the effects under observation. In general, the zero rate is about 18 registered impulses per minute. This measurement is usually made by means of a tube counter which is connected to a counting instrument. A glance at the active area of the cloud chamber shows, however, an apparently very great abundance of particles, which one tends to associate rather with the presence of a radioactive material in the chamber than merely to the background radiation. A little trick helps here to categorize the density of the particle tracks as really being due to background radiation.

Take a piece of typing paper and cut out a hole of about 0.8 cm diameter in the middle of it. Lay the piece of paper flat on the glass plate of the cloud chamber. Now, from a distance of about 10 cm from the paper, look through the hole with one eye and observe the active area of the cloud chamber. Count twenty “parts” of particle tracks which are visible through the hole and measure the time elapsed while doing so. This trick with the hole in the paper simulates the opening of a tube counter. Only those particles which hit the tube counter opening can be registered. From the multitude of particle tracks in the cloud chamber, only those are now visible which pass through an opening which corresponds to that of a tube counter. The zero rate which is theoretically to be expected can be so confirmed.

2. Visualization of α, β, γ-particles and mesons

In the chamber, one can observe tracks of “clouds” which are generated by α-particles, protons, electrons/positrons and mesons.

a) Example 1

Most of time, one can observe short tracks and thinner, longer tracks. To begin with, let us concentrate on short, but the biggest tracks (Fig. 6).

The appearence of α-tracks on the whole observation place is statistically dispersed, that is the reason why one cannot foretell when and where the next track will appear.

In the air, α-particles measure about 5 cm but in the steam of alcohol they are not longer. Moreover, α-particles can be absorbed by a single sheet of paper. How can they reach the interior of the Cloud chamber?

On the one hand, α-particles may have been liberated in the chamber itself by a radioactive nucleus. On the other hand, it may be protons with a high content of energy which were formed during the secondary radiations process in the atmosphere. They can penetrate into the chamber across the glasprotection. After penetrating the chamber, if their energy content is low enough as to being able to give their energy to the atom-electrons of the gas inside the chamber, they generate a track, which looks like the one of the α-particles (Fig. 7).

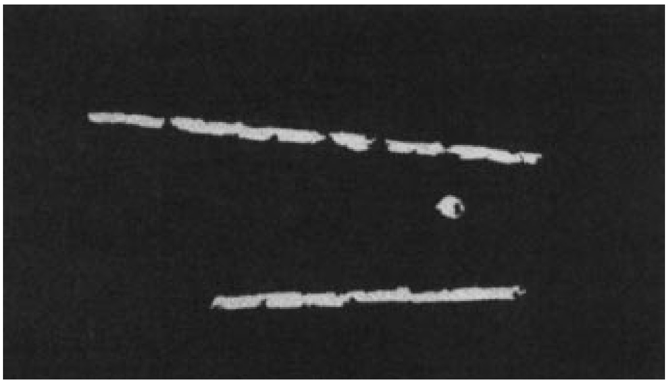


Fig. 7: Track generated by protons.

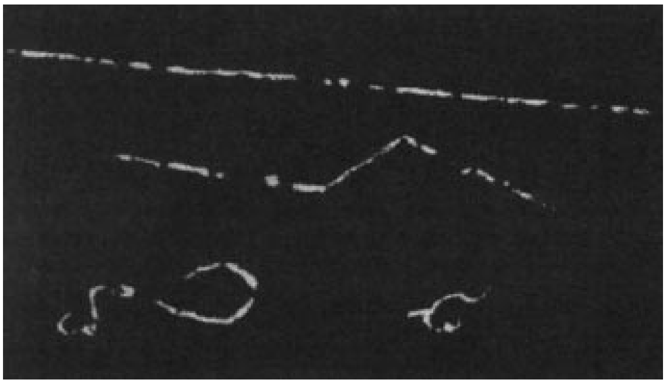


Fig. 9: Track generated by repeated deviated β-particle.

Fig. 10: Tracks of β-particles with a low content of energy.

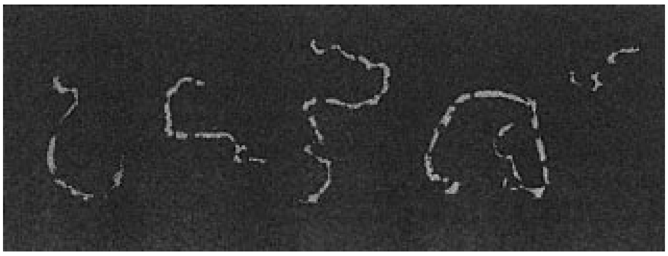
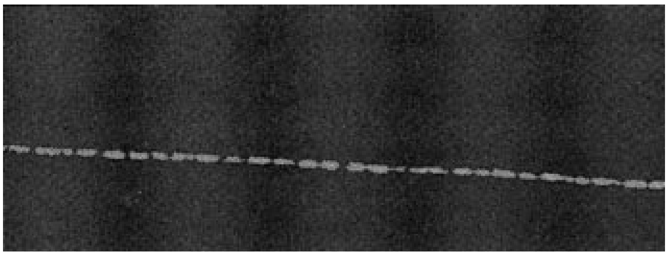


Fig. 12: Track generated by a meson.



When the particle penetrate vertically the layer of supersaturated Alcohol steam, one can recognize only a spot as an ionisation trace.

b) Example 2

When the observer now observes the thin and to some extend very longer tracks (tracks with low drops density), one will be puzzled by the large amount of track manifestations. Therefore, we recommend you to consider precise forms – that is to say: the length of those tracks.

- First of all, observers should try to recognize a thin, straight and long trajectory – across the whole observation place. This shows particularly fast (with a high content of energy) electrons (Fig. 8).
- Slowly flowing electrons (i.e. with a low content of energy) have shorter trajectories, which are partly curved or buckled (Fig. 9) because of deviation.
- Electrons with a very low content of energy generate short trajectories, which look ornated or tortuous because of many deviations of the atoms in the steam layer (Fig. 10).
- Provided you place a powerful Ra-emitter, the γ-quanta will penetrate the chamber across the glas and release a large amount of photon-electrons or compton-electrons. Then, a formation of short and many times tortuous “worm-like” trajectories appears on the whole surface (Fig. 11).

c) Example 3

Mesons, which represent 90 % of the secondary cosmic rays can be detected in the Cloud chamber too. μ-mesons take an important part in this process since they have a positive or a negative elementary charge and their weight corresponds to 207 times electrons weight.
Mesons with a high content of energy create trajectories which look like tracks generated by electrons. However, high moderated mesons ionize highly and produce tracks which correspond nearly to those of α-particles. Therefore, it will be very difficult, in individual cases, to know whether one is being observing α-particles, protons, mesons or electrons (Fig. 12).
Since the average life-time of μ-mesons corresponds to micro-seconds, one can occasionally observe the dissociation of a μ-meson into an electron and into two invisible neutrinos in the Cloud chamber. The electron does not move to the same direction as the meson before, so that one can observe a characteristic bend in the track (Fig. 13). However, after the collision, one can clearly observe a thinner track, since the electron has a smaller ionisation density than the meson. The number of generated pairs of ions in each trajectory (in comparable conditions) are as follows:

- α-particles: 10.000
- protons: 5.000
- electrons: 100
- gamma-quanta: 1 (specific ionisation).

3. Visualization of Thorium (Radon) decay

The source (09043.41) contains a small quantity of a thorium salt (Th^{232}) which continually supplies radon gas (Rn^{220}), according to the decay chart (Fig. 14). Carefully blow it through the side opening of the cloud chamber by pressing the rubber bulb just once, and immediately close the opening of the cloud chamber. As soon as turbulence has abated, “V” shaped tracks are to be seen (Fig. 15).
On comparing these with the tracks described under point 2, it is clear that they are α particle tracks. The α particles all have the same energy, and should therefore produce tracks of the same length, but shorter and longer tracks can be clearly seen here. The explanation for this is that the α particles fly aross the active layer of the cloud chamber in various directions. Only those particles which fly parallel to the plate surface produce tracks of the maximum length. The shortest tracks – points – are produced when the layer is traversed vertically to the plate.

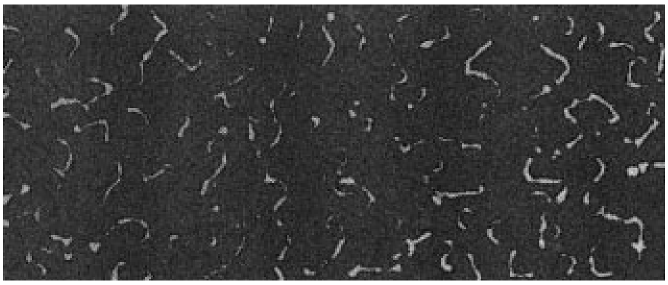


Fig. 11: Track generated by protons-electrons and compton-electrons.

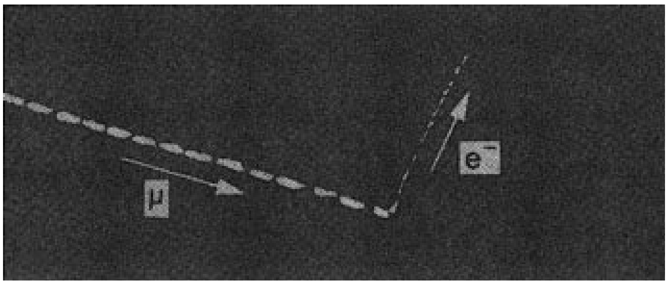


Fig. 13: Track of dissociation of a μ-meson into an electron and two neutrinos.

Thorium-decay series

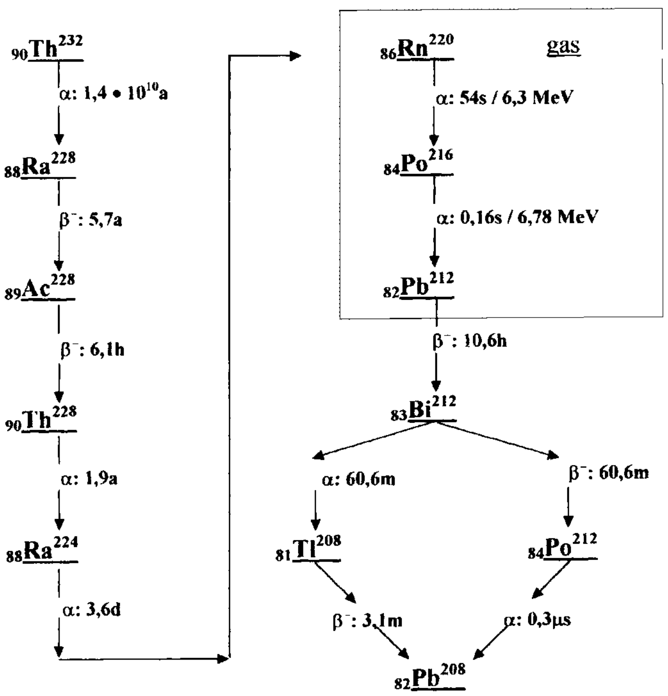


Fig. 14

Fig. 15.

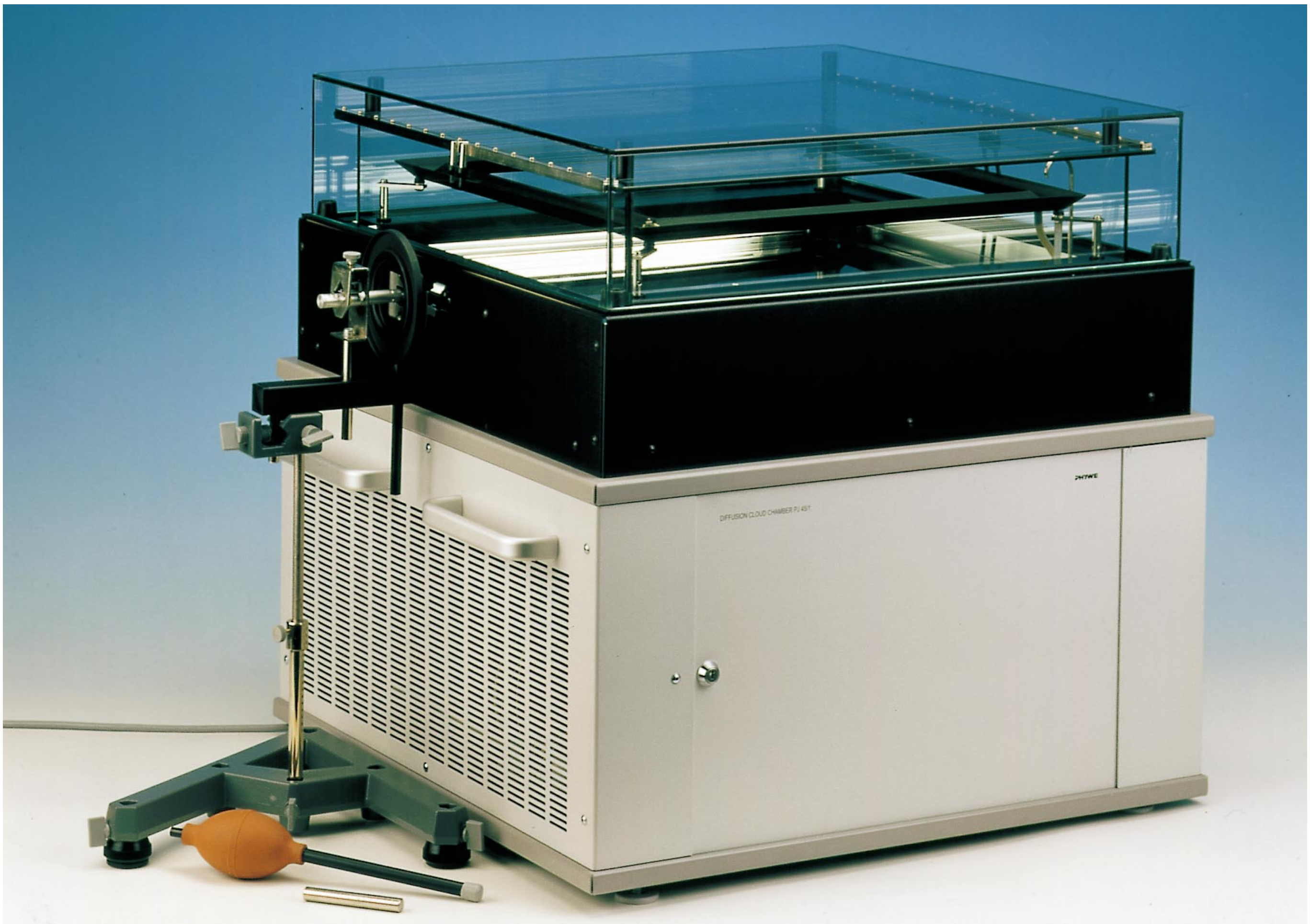


Fig. 16: Experimental set-up: deflection of β-particles.

Fig. 17: Details of the set-up for β-deflection.

Rn^{220} decays with a half-life of 54 s to Po^{216} which decays further, also under emission of α rays, with a half-life of 0.16 s to Pb^{212}. These two successive α decays are responsible for the "V" shape. As the two decay steps are not correlated to each other, there is no definite angle relationship between the α particles which fly apart. All "V" shapes, up to stretched out, linear ones, are to be observed.

On looking at them more closely, it can be seen that the branch of the "V" track is frequently not at the same position. Breaks in such tracks occur, which can up to a centimeter or so long. These interruptions in the tracks are due to the movement of the Po^{216} atoms, which do not themselves produce an ionized track. They have a half-life of about 0.16 s, and during this time they travel along the path where the track is interrupted. As soon as they emit an α particle, the track becomes visible again.

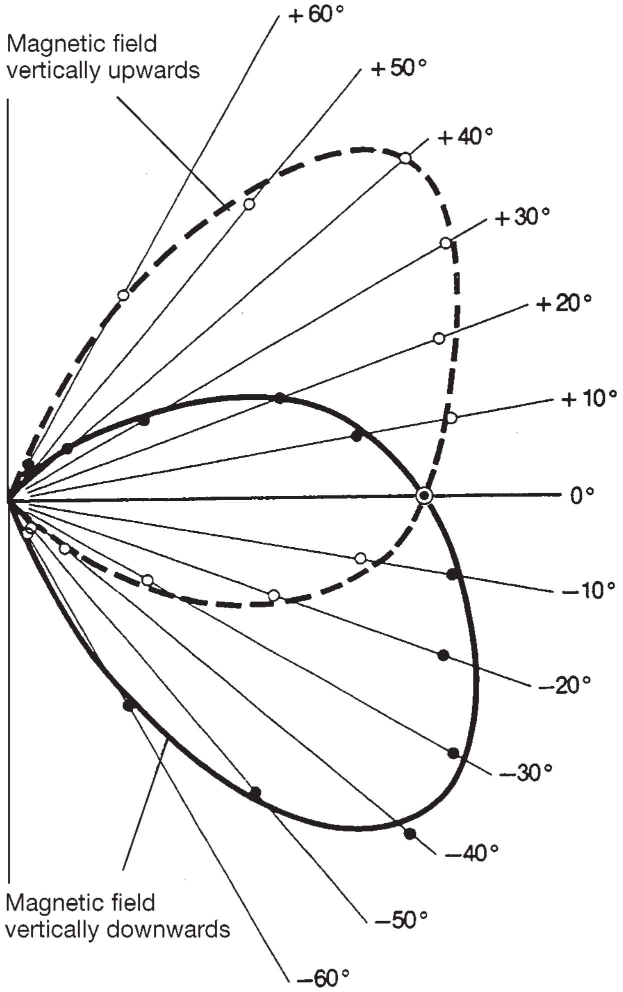
After about one minute, the number of "V"s in the cloud chamber is distinctly less, which confirms the half-life of 54 s.

Decays originating from Pb^{212} (Fig. 14) have essentially half-lives of from hours to minutes. They therefore do not contribute any further activity worth mentioning to the cloud chamber when Po^{216} has decayed. It should also be noted, that only relatively few radioactive atoms (Rn^{220}) were blown into the chamber (in principle, one could have counted them by counting the number of "V"s), to disintegrate there. The cloud chamber therefore again shows only the natural background radiation within a few minutes of the injection of Rn^{220}.

4. The deflection of β^- particles in a magnetic field

The set-up is as shown in Figures 16 and 17. Always use the metal dummy without specimen, not a pin with specimen, to adjust the height of the set-up and the rotatable magnet.

Fig. 18



When a specimen pin is inserted, never look in the opening! Slide the active end of the Sr^{90} pin in the side opening of the cloud chamber and finely adjust the height, until distinct tracks can be seen in the chamber.

This experiment shows qualitatively, that the direction of the propagation of radiation from a Sr^{90} pin can be influenced by a magnetic field. Figure 18 shows the preferred direction of the β^- rays with two different magnetic field orientations. The area of maximum radiation intensity is at an angle which is distinctly different to zero. In the case of these β^- rays, we are dealing with moving electrons, which are naturally deflected in a magnetic field because of the Lorentz force. We can use the "right hand rule" to prove the negative polarity of the carrieres of charge (β^- rays, electrons). Hold the middle finger of the right hand in the direction of deflection (force direction) and the forefinger in the direction of the field (from the north pole to the south pole of the magnet, from red to green). Now spread your thumb out at 90° from the middle finger and forefinger, it points in the direction of the electric current associated with the movement of the carriers of charge. This movement is always towards the specimen. It is so clear, that negative particles must be radiated out from the specimen, as the "right hand rule" relates to carriers of positive charge.

The tracks in the cloud chamber show even more, however:
Other than with α particles, which all have about the same energy, the β^- particles show a distinct energy spectrum, as on each disintegration, not only an electron but also an anti-electron neutrino is emitted, which also carries off energy. Because of this, the electrons, as they all have different speeds, are also deflected to different amounts by magnets.
With the Sr^{90} specimen, the β^- radiation overlies even the γ radiation, which is not deflected by magnets but results in a widening of the club-shaped radiation in the 0° direction.