Teaching material in 3 blocks

Made at CERN by

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„Cosmic Rays“

was translated into English by the students
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Special Thanks to
Mr. David Waterman
Alfriston School , Beaconsfield UK

for the supporting in translation and for final reading as a result of Volos Summer School 2013
What comes to us from space?

Click on the screen
What comes to us from space?
In every second reach us...

On every square meter

200 particles

- Where do these particles come from?
- What properties do they have?
- Which secrets do they hold?
Where do these particles come from?

- from our sun
- from other galaxies
- from supernovae
Sun...
Supernovae (Starbust)
Other galaxies
Formation of cosmic radiation
Primary radiation

- comes from space
- consists mainly of protons
- triggers particle showers
- formation not fully clarified
Secondary radiation

- Arise when primary radiation enters the atmosphere

- Particle showers on earth

- Mainly electrons and muons but also
  - All chemical elements
  - Elemental particles
  - Antimatter
The primary radiation from space consists mainly of protons.

We still don’t know the exact causes of their formation.

When the primary radiation enters the atmosphere, then a particle shower arises (secondary radiation).

This particle shower can be detected on the Earth’s surface.

Other particles reach us as the original started from space.

On the Earth we can detect mostly electrons and muons.

At high altitude, you can find nuclei of all chemical elements, pions, kaons and even antimatter particles.
Characteristics: proton

**Proton**
(nucleus of the hydrogen atom)

\[ m_{proton} = 1.6 \cdot 10^{-27} \text{ kg} = 1836 \cdot m_{electron} \]

positive electric charge

\[ Q_{proton} = +e \]

stable
Characteristics: electron

**electron**

\[ m_{\text{electron}} = 9.11 \times 10^{-31} \text{kg} \]

\[ Q_{\text{electron}} = -e \]

negative electric charge

stable
**Characteristics: muon („Who ordered that?“)**

**muon** (= a „heavy electron“)  

**surprise (1937)!**

**mass**  

\[ m_{\text{muon}} = 206 \cdot m_{\text{electron}} \]

**negative electric charge**  

\[ Q_{\text{muon}} = -e \]

**unstable**  

**average life**  

\[ 2,2 \cdot 10^{-6} \text{ s} \]
Main components of cosmic radiation

- **Primary radiation**
  - Proton: Stable
  - Electron: Stable

- **Secondary radiation**
  - Muon: Unstable
How we can prove the radiation?

all detection methods use
charge and energy
of the particles

The spark chamber is an excellent detector
Spark chamber in action

click on the screen
Construction of the Spark Chamber

- Particle
- Noble gas
- Electrodes
- Spark
Operation of the spark chamber

1. Voltage is applied
   - No external particle
   - No charge carriers
   - No lightning
2. External particle flies in chamber
3. Electrons are ripped from other gas atoms, impact ionization
4. Large number of charge carriers
   - Acceleration
   - Spark, lightning
5. Turn off the voltage for a moment
   - No acceleration
   - Spark breaks, no lightning
   - New measurement possible
Operation of the spark chamber

Turn off the voltage for a moment
- no acceleration
- spark breaks, no lightning
- New measurement possible

1. Voltage is applied
- no external particle
- no charge carriers
- no lightning

2. External particle traverses chamber

3. Electrons are ripped from other gas atoms, impact ionization

4. Large number of charge carriers
- acceleration
- spark, lightning

5. New measurement possible
Other detection devices

cloud chamber  counter tube  electrometer
Other detection devices

electrometer
Other detection devices

Geiger-Muller-counter tube
Other detection devices

cloud chamber to build it yourself

Cloud Chamber Workshop
BUILD YOUR OWN CLOUD CHAMBER AT HOME

Particles coming from the universe (cosmic rays) are entering the earth all the time — they are harmless but invisible to us, also called natural radiation. Cloud chambers are detectors to make the tracks of the particles visible. Some decades ago — these detectors were used at CERN in the first experiments to detect particles. Wouldn’t it be nice to build such a detector at home in your kitchen? We show you how to build a small one at home in your kitchen for your own research.

Shopping list:
- A clear, see-through box like plastic container, with flat sides and an open top, roughly 20 x 30 cm (open side) x 15 cm (height)
- A metal plate (at least 5 mm thick) to cover the open side of the container completely (plate must be at least 1 cm longer than the box). The plate should be preferably black and should have a little pressure matching the side walls of the plastic box. As the is probably hard to find, you can also use a flat metal plate and use black electrical tape to make the metal plate surface black.
- A thick felt (few mm), a bit smaller than the bottom of the box.
- 4 eyelets (self-adhesive cable tie holders + cable ties) to attach the felt to the inside of the bottom of the box.
- A small wooden box that is just a little bit larger in area than the metal plate and approx. 5 cm in height. The box later on has to take the lid plates and the metal plate, but the sides should not be much higher so that it doesn’t cover the plastic box.
- A very intense, focused light source, e.g. a slide projector, strong flashlight ...
- Pure (not 70%) isopropyl alcohol — make sure you get the right one — it will only work well with this and it keeps it out of reach of children.
- Dry ice (careful with your hands — always use thick gloves and never touch the box directly! The ice is at -78°C, touching it directly will give you a burn.)
- Safety goggles to handle the ice
- Gloves to handle the ice and the alcohol

A word of warning:
Isopropyl alcohol is not intended for drinking and harms your health if you drink it. So never ever drink it and keep it out of reach of children. Handle it only with plastic gloves. Dry ice is at -78°C, so never touch it directly — it will burn your skin — always use thick gloves and securely package to handle it and wash children carefully. Also dry ice (CO2) evaporates as it heats up which can harm your health in large quantities. So make sure you ventilate your room very well while doing the experiment.
Self – built cloud chamber in action

click on the screen
Other detection devices

cloud chamber
Video: auroras

click on the screen
How are such impressive phenomena created?
How are aurora created?

- Cosmic rays from the Sun reach the atmosphere
- Energy is transferred to air atoms
- Excitation of atoms in the air
- Energy output of the air atoms in the form of light
  - Nitrogen – blue light
  - Oxygen – green and red light
How were these cosmic rays first detected?

- Viktor Hess (1912)
- ballooning up to a altitude of 5 km
- conductivity of the air rises
- What is responsible? - a new type of radiation!

Cosmic radiation!
Victor Hess (Austria) wanted to clarify, where the ionizing radiation at the Earth’s surface came from – from below or from above?

He observed this radiation using the discharge of an electrometer.

His measurements led him to make a balloon flight to a height of 5000m.

To his surprise, he discovered that the discharge was faster as the altitude increased.

He concluded that the ionizing radiation must come from space.

In 1936, Hess received the Nobel prize in physics.
Who discovered the radiation?

- Victor Hess
  - with a self developed electroscope
- discovery of the cosmic radiation (1912)
- Nobel prize in physics (1936)
About the particle showers
How is a particle shower created?

containing 1,000,000 particles within a circle of $d=5$ km on the surface of the Earth?
A particle shower is created........as a fruit cocktail
A fast proton from space hits a proton (or neutron) in an atomic nucleus in the air (oxygen or nitrogen).

A part of the proton energy transforms to generate the new (secondary) particles with their respective mass and energy.
Mass results from energy?
Mass results from energy?

The energy of the proton is transformed into the mass of the secondary radiation.

Albert Einstein 1905: mass and energy are converted into each other!
Mass results from energy?

Part of the energy from the fast proton creates the mass of the secondary particles.

Einstein explains this amazing process with his famous equation

$$E = m \bullet c^2$$

It says, that mass and energy are interconvertible.
Which fruits are in the cocktail?
What is in the cocktail?

electron

muon

matter

positron

antimuon

antimatter
What is in the shower?

- **Matter and antimatter**
  - **Basic building blocks of all atoms**
    - Proton
    - Electron
    - Muon
  - **Antiproton**
  - **Positron**
  - **Antimuon**

These particles are the fundamental building blocks of our world.
What comes to us?

- proton, electron
- muon
- antiproton, positron, antimuon

more nuclear transformations

also radioactive nuclei! (C-14)

decay in atmosphere

proof on earth
What comes to us?

The secondary radiation essentially consists of protons, electrons and muons, the basic building blocks of our Earth and the associated antiparticles.

They can also trigger more nuclear transformations, which can create more radioactive nuclei.

The carbon isotope C-14, that is important for the age determination of fossils, arise only in this way.

Many of the particles are unstable, therefore only a few of them reach the Earth.
What is coming to us? (energy spectrum)

Energiespektrum der kosmischen Strahlung

<table>
<thead>
<tr>
<th>Anzahl der Teilchen</th>
<th>Energie des Teilchens</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/m² je min</td>
<td>$10^{12} \text{eV}$</td>
</tr>
<tr>
<td>5/m² je Tag</td>
<td>$10^{14} \text{eV}$</td>
</tr>
<tr>
<td>1/m² je Tag</td>
<td>$10^{16} \text{eV}$</td>
</tr>
<tr>
<td>65/km je Jahr</td>
<td>$10^{18} \text{eV}$</td>
</tr>
<tr>
<td>0,005/km² je Jahr</td>
<td>$10^{20} \text{eV}$</td>
</tr>
</tbody>
</table>
Energy spectrum

The particles have very different energies.
Despite their low mass the highest-energy particles have the energy of a well hit tennis ball.

The unit of energy used is the Electronvolt (eV)

\[ 1 \text{ Joule} = 1 \text{ Nm} = 6.24 \times 10^{18} \text{ eV} \]
The highest-energy particles are very rare!

Example: \(10^{20}\ eV\)

particles of energy on an area of 1km\(^2\)

1 event in 200 years

As a result the search for them is complex and difficult!
Search for the highest-energy particles

*Kascade* experiment (Karlsruhe)

- area 700 m • 700 m
- Detection of primary particles up to $10^{18} \text{eV}$
- so far about 40 000 000 air showers were measured
Click on screen
Auger Observatory in Mendoza

largest system in the world!

Proof of showers up to $10^{20}$ eV
Detectors at the Auger Observatory

total area: 3000 km²

1600 detectors
Particle accelerator *made by man*

Maximum energy of the protons in the largest particle accelerator of the world

(LHC at CERN)

$7 \times 10^{12} \text{ eV}$
Maximum energy of the protons of cosmic rays entering the Earth's atmosphere

\[10^{20} \text{ e V}\]
Particle accelerator *in space*

cosmic rays

gigantic natural accelerator
Muons counter at the Jungfraujoch near Bern

spark chamber

1. Bern  542 m height
2. Jungfraujoch  3571 m height

Are there any Muons?

What results are expected?
profile muon (Who ordered that?)

larger mass than electrons

\[ m_{Myon} = 206 \cdot m_{Elektron} \]

\[ Q_{Myon} = -e \]

negatively charged, carries one elementary charge

unstable

average lifetime = \(2.2 \cdot 10^{-6}\) s
given:

\[ v = 3 \times 10^8 \text{ m/s} \]\n\[ t = 0.0000022 \text{ s} \]\n\[ h = 20 \text{ km} \]

average lifetime

distance from the earth in production

wanted: \( s \)

\[ s = v \cdot t \]
\[ s = 3 \times 10^8 \cdot 2.2 \times 10^{-6} \text{ m} \cdot \text{s} \cdot \text{s}^{-1} \]

\[ s = 660 \text{ m} \]

distance that the muon can travel during its average lifetime

Even if individual muons have a slightly longer life, they should not reach the earth (660 m \(<\) 20000 m)
muon counter in Bern

Experiment to demonstrate Einstein's special theory of relativity

Click here for explanation...

<table>
<thead>
<tr>
<th>Bern, Events since 15.04.2011 00:00:35</th>
<th>Events per minute</th>
<th>15.04.2011, 14:38:47</th>
<th>Jungfraujoch, Events since 27.10.2010 00:00:45</th>
<th>Events per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>15764</td>
<td>19</td>
<td>20483</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

[Image of Bern cityscape and Einstein poster]
Reasoning with Einstein

For very fast moving particles the time passes very slowly.

resting muon

Does not reach the earth

very fast muon

reaches the earth
Why are the muons reaching the earth?

- The answer comes from the special theory of relativity, discovered by Einstein.
- For fast moving bodies, time passes slower (time dilation).
- For a muon travelling close to light speed the clock moves slower than for a resting muon.
- As a result the fast moving muon can reach the Earth.
- This effect is also known as the twin paradox.
Where are current limits of our knowledge?

The protons from space have an extremely high energy.

The mechanism by which they get this energy is still unknown.

There are many possibilities:

- sun eruption
- supernova
- black hole
How does this radiation affect us?
Overview in the video

Start
Estimation of the cosmic radiation exposure

- typical energy of muons: \( E \sim 1 - 10 \text{ GeV} \)
- particle flow: a muon per cm² per minute (fingernail)
- energy loss \( \sim 2.5 \text{ MeV per cm (in water)} \)
- consider a volume of 1 cm³ of water:
  - 1 g of water takes 2.5 MeV (ionisation-) energy per minute
  - 1 year has \( \sim 526 \text{ 000 minutes (60 x 24 x 365.25)} \)
  - 1 kg water absorbs \( 2.5 \times 1000 \times 526 \text{ 000 MeV} = 1.3 \times 10^9 \text{ MeV} = 0.00021 \text{ J} \)
How does that effect us?
We consist

- essentially of water
- Each kilogram of our body takes about the same amount of energy every year like a kilogram of water (in reality about 0.0003 J per year)

\[ 1 \text{ Kg} \quad 0.0003 \text{ J/yr} \]
Comparison of loads: energy dose $D$

\[
\frac{\text{absorbed energy}}{1 \text{ kg of irradiated body}} = \text{energy dose } [D]
\]

unit: \[\frac{1 \text{ Joule}}{1 \text{ Kilogram}} = 1 \text{ Sievert } [1\text{Sv}]\]

- Comparative value for radiation exposure
- Cover Size: 1 kg of the irradiated body
Annually each kilogram of our body absorbs about 0.0003 J energy from cosmic radiation. The absorbed dose $D$ is:

$$0.0003 \text{ Sv/yr} = 0.3 \text{ mSv/yr}$$

The equivalent dose $H$ makes adjustments for different forms of is radiation by applying a factor $Q$:

$$H = D \cdot Q$$

$Q=1$ for gamma-ray and muons, $Q= 1-30$ for alpha radiation, protons and neutrons

The sizes $D$ and $H$ are also used to assess the danger of other forms of radiation.
artificial and natural radiation exposure

Average equivalent dose $H$ in mSv in 2006

- Cosmic: 0.3
- Earth: 0.4
- Food: 0.3
- Radon: 1.1
- Medicine: 1.9
- all other sources < 0.1
What is the effect of the radiation on our bodies?
effect on DNA

DNA molecule
Emergence of defects in DNA
What exactly is happening?

- Ionization, free radical
- Bug in DNA
- Repair by the body?
  - Yes → Fixed bug
  - No → Bug not fixed
- Mutations and cancer
What exactly is happening?

The energy of the particles in cosmic radiation releases electrons from their correct place in the molecule (ionization). A defect is created in the molecule.

The body can usually repair itself because humans have adapted to the presence of natural radiation in the course of evolution. However, the possibilities for repairing are limited.

If the number of defective places is too great due to caused a high energy dose then permanently altered sections of the DNA may result. These alterations are responsible for genetic changes (mutations) as well as for development of cancer cells.
What consequences does it have for us?

- Cosmic radiation is part of nature
- The human body can deal with a natural dose of radiation
- An estimation of any specific health risk requires the consideration of any additional sources of ionizing radiation
- Currently a limit of 1 millisievert per year has been established by law in Germany as an upper limit for any additional radiation dose.
to remember.....

Average equivalent dose $H$ in mSv in 2006

Natural sources

- Cosmic: 0.3
- Earth: 0.4
- Food: 0.3
- Radon: 1.1

Technology

- Medicine: 1.9
- all other sources < 0.1
artificial vs. natural radiation

Alltägliche Strahlenbelastung

- künstliche Strahlenbelastung
- natürliche Strahlenbelastung

- sonstige innere Strahlung 8,0%
- kosmische Strahlung 8,0%
- Einatmen von Radon 27,1%
- von Außen 14,0%

- Medizinische Anwendungen 41,1%
- Folgen des Tschernobylunfalls 0,6%
- Kernkraftwerke (Normalbetrieb) 0,3%
- Atombombenversuche 0,3%
- sonstige künstliche Strahlung 0,6%
# Altitude dependence of cosmic rays

<table>
<thead>
<tr>
<th>Height above the earth</th>
<th>Effective dose per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 km (outside of the Space Shuttle)</td>
<td>400...500 mSv (quiet sun)</td>
</tr>
<tr>
<td>300 km (in Space Shuttle)</td>
<td>100...200 mSv (quiet sun)</td>
</tr>
<tr>
<td>10 km (plane cruising altitude)</td>
<td>40 mSv (with permanent residence)</td>
</tr>
<tr>
<td>3800 m</td>
<td>1.8 mSv</td>
</tr>
<tr>
<td>3000 m</td>
<td>1 mSv</td>
</tr>
<tr>
<td>2000 m</td>
<td>0.6 mSv cosmic + ca. 1 mSv terrestrial</td>
</tr>
<tr>
<td>0 m</td>
<td>0.3 mSv cosmic + 2 mSv terrestrial</td>
</tr>
</tbody>
</table>
Load at different heights

www.helmholtz-muenchen.de/epcard
Risk during flying?

- **Effektive Dosis (linke Skala)**
- **Flugdauer (rechte Skala)**

Flüge ab Frankfurt

EPCARD V3.2

- Brüssel
- Rom
- Bukarest
- London
- Athen
- Dublin
- Madrid
- Moskau
- Tel Aviv
- Kairo
- Lissabon
- Kuwait
- Abu Dhabi
- New York
- San Francisco
- Sao Paulo
- Buenos Aires

0 10 20 30 40 50 60 70 80

0 5 10 15

Dosis (µSv)

Dauer (Std.)
load at the next flight

www.helmholtz-muenchen.de/epcard

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt

epcard-portal

Flugdosimetrie
Risk during flying?

- Short distance flight: less than 1% of the annual natural load
- Long-haul flight: Approx. 5% of the annual natural load
- "Occasional flyer": very low risk
- Risk control necessary for „frequent flyers" and aircrews

<table>
<thead>
<tr>
<th>Reiseziel</th>
<th>Dosisbereich* [μSv], etwa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rom</td>
<td>3 – 6</td>
</tr>
<tr>
<td>Gran Canaria</td>
<td>10 – 18</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>17 – 28</td>
</tr>
<tr>
<td>Johannesburg</td>
<td>18 – 30</td>
</tr>
<tr>
<td>Singapur</td>
<td>28 – 50</td>
</tr>
<tr>
<td>New York</td>
<td>32 – 75</td>
</tr>
<tr>
<td>San Francisco</td>
<td>45 – 110</td>
</tr>
</tbody>
</table>

(flights from Frankfurt)
Manned flight to Mars - a reality soon?

1. 4 Ares-V Cargo Launches
2. Cargo: ~350 days to Mars
3. Aerocapture Habitat Lander into Mars Orbit
4. Aerocapture / Entry, Descent & Land Ascent Vehicle
5. In-Situ propellant production for Ascent Vehicle
6. 3 Ares-V Cargo Launches
7. Ares-I Crew Launch
8. Crew: Jettison drop tank after trans-Mars injection ~180 days out to Mars
9. Crew: Use Orion to transfer to Habitat Lander; then EDL on Mars
10. ~500 days on Mars
11. Crew: Ascent to high Mars orbit
12. Crew: Prepare for Trans-Earth Injection
13. Crew: ~180 days back to Earth
14. Orion direct Earth return
Challenges

- Flight duration: over 2 years
- Distance: > 200,000,000 km
- Massive exposure to cosmic radiation
- Tremendous driving power required
- No reversal possible
- No assistance from Earth
- Cancer risk
- Psychological distress (isolation)
Test of radiation exposure on ISS
Doll gets suit with hundreds of sensors!
... and is fixed at the outside of the station
Manned flight to Mars - a reality soon?
Thanks...

To the members of the „Physic- Education“ group at CERN for their help and support

One special „Thank You“ to Rolf Landua for his ideas and critical coaching during the project!