Overview about the Work with Liquid Scintillators

Today: Experimental Setups to determine the properties of liquid scintillators
Overview

- Global overview of the usage and work with liquid scintillators
  - Scintillation process
  - Proper Usage
  - Production
  - Testing

- Experimental Setups of the TUM / E15 (institute for astroparticle physics)
  - Absorption Length  M. Wurm
  - Light yield        P. Pfahler, M.Wurm
  - Fluorescence time  T.Marrodán
  - Radio purity       M.Hofmann
  - Purification of Liquid Scintillator P.Pfahler
Scintillator and its Properties

• A Scintillator is a mixture of a solvents and at least one wavelength shifter
  – In example: 20% PXE
  80% Dodecan
  3g/L PPO
  20mg Bis/Msb

• The amount & fraction of ingredients in a Sc. determines its Light output (light yield)
  – The Light yield of each Scintillator has therefore to be determined
  – Depending on the Solvents the answer time (Fluorescents time) of a Sc. is different
    • The exact knowledge of this Fluorescents time helps to get more detailed information

• The emitted scintillation light is proportional to the deposited energy
  – If we know the produced amount of light exactly, we know the deposited energy!
    • What we can measure is the light that is detected by the PMT's
      – All light “consuming” processes obscure a correct interpretation
        » Absorption
        » Scattering of light

• Scintillators are sensitive to O₂, heat, UV-light, (Metall in case of heavy metal doped Sc.)

• To maximize the information output of the Scintillator we measure its properties
Experimental Setups to determine the properties of liquid scintillators

- Experimental Setups
  - Absorption length
  - Light yield
    - Light emission of a Scintillator
      - Absolute Light yield
    - Relative Light yield
  - Time constants
  - Time of Information output
    - Information loss due to lost light
  - Absorption length
  - Attenuation length
    - Light scattering
  - Radio purity
    - To lower the impurities in a Sc.
    - Identify the Artificial radioactive impurities
      - Germanium detector
    - Chromatography column
      - Al₂O₃ // Silica Gel
  - Purification
    - Ingredients/ Materials
      - Al₂O₃ // Silica Gel

To lower the impurities in a Sc.

Identify the Artificial radioactive impurities

Radio purity

Chromatography column

Time of Information output

Absorption length

Attenuation length
Attenuation length measurement

The total intensity loss is given by sum of all partial light losses

- The total loss of light intensity is given by the attenuation length

The partial losses have 2 main reasons

1. Absorption
2. light scattering

\[
I(x) = I_0 e^{-\frac{x}{\lambda_{\text{abs}}}} e^{-\frac{x}{\lambda_{\text{scat}}}} = I_0 e^{-\frac{x}{\lambda_{\text{att}}}} = I_0 e^{-x\left(\frac{1}{\lambda_{\text{abs}}} + \frac{1}{\lambda_{\text{scat}}}ight)}
\]

- Idea of Measurement (Attenuation length & light scattering)
  - We measure the total loss of light intensity, the attenuation length
  - We measure the light scattering of the Scintillator
  - The absorption length can then be calculated

- To know the partial losses can help to improve the situation
  - Light scattering has 2 reasons
    - Mie-Scattering due to Impurities! ---we can get rid of---this will improve the quality of the Sc.
    - Rayleigh-Scattering due to the bound electrons off the Sc. the scattered light is polarized (max.90°)—possibility to distinguish
Attenuation length

The total intensity loss is measured in three different tubes 100cm 50cm 25cm in length.

A LED puts in a defined intensity.

The PMT detects all photons that not scattered or absorbed.

Problems:
Reflection on entrance glass and Tube walls will obscure the interpretation → scattered light partially seen.
Light scattering

2 main reasons for light scattering

Rayleigh - Scattering : Photons scatter on bound electrons of the Molecules.
                   : scattered light is polarized

Mie - Scattering : Photons scatter on suspended particles

Polarization for the scattered light is maximal for 90° scattering angle. This scattering is an intrinsic property of this Scintillator. The non-polarized part is due to Mie-scattering. This impurities can be filtered.

-> this helps to improve the Sc. properties.

LED produces Light pulses
Converging lens and aperture and polarization filter
Absorption length

Measuring attenuation length

Calculating Absorption length

Measuring scattering length

Older measurement by Michael Wurm
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- Light scattering
- Information loss due to lost light
- Radio purity
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- Ingrediences/Materials
- Germanium detector
- Chromatography column
- Al₂O₃ / Silica Gel
- Time of Information output
- Tool to enlarge the attenuation length

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Light yield Measurements

• Relative light yield measurements
  – Comparing the self made Sc. probe with a well known standard Scintillator (BC505, etc.)
  – Gives a percentage of the Light yield i.e. (The Sc. probe has 80% Light yield of BC505)
  – To test this
    • we need to excite a small fixed Volume of Scintillator by a radiating source or UV-light.
    • We try to get as much light out of the probe as possible
      – Scintillator probe holder should be highly reflective to avoid absorption in the Sc.
        probe holder
  
  • If needed (due to background) we trigger the data acquisition through a coincidence.
  • The PMT is sensitive to Magnetic fields $\rightarrow$ $\mu$-metal shielding
Light yield Measurements

- Relative light yield measurement

Compton backscattering method
Light yield Measurements

• Absolute light yield Measurement
  – Determining the absolute number of Photoelectrons (pe) emitted by the Sc.probe per deposited MeV
  – Gives a number (i.e 5.3x10^3 pe/MeV)
  – To measure this
    • We need to measure the single photo peak (Area)
    • We need to excite a Sc. Probe with a well defined Energy and measure the Area of this Signal aswell.
      – Possible Excitations that allow a coincidence are
        » Cosmic muons – using the known Energy deposition per cm Target
        » e⁺-emitter (^{22}Na) – using annihilation of e⁺- e⁻ emitting 2 x 511keV (180°)
        » γ-ray-emitter – using the compton back scattering method
  • Knowing the Energy and the emitted light we can make an Energy calibration
  • To be sure that excitation and light out put are connected a coincidence is needed
  • We try to get just the light that is emitted in the direction of the PMT
    – We want to scale up to 4π--- Reflection has to be surpressed or known
    – Measurement of light reflection properties of the Sc. probe holder are necessary
  • In addition we simulated the Sc.probe holder with Geant 4 (difficult geometry)
    – Measurement and Simulation were compared.
• Scintillator Research Tank (SRT)
Absolute light yield Measurement

Gamma ray spectroscopy

Coincidence with cosmic muons

2 x 511 keV spectroscopy ($^{22}\text{Na}$)

Compton recoil spectroscopy
Experimental Setups to determine the properties of liquid scintillators

- **Radio purity**
  - Identify the Artificial radioactive impurities
  - Germanium detector
  - Ingridences/ Materials

- **Purification**
  - Tool to enlarge the attenuation length
  - Chromatography column
  - Al₂O₃ / Silica Gel

- **Fluorescents time**

- **Absorption length**

- **Light yield**
  - Time of Information output
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  - Light emission of a Scintillator
  - Relative Light yield
  - Absolute Light yield

- **Information loss due to lost light**

- **Attenuation length**

- **Light scattering**
Florescence time Measurements

- Determining the light output time constants of the Scintillator molecules
- Aim is a deeper understanding of the fluorescence time
  - Future aim is to manipulate the Sc. and to optimize it for fast measurement
    - Developing a new Scintillator
  - To measure this
    - We need to excite a small Volume of Scintillator with a γ-Source
    - We set up 2 very fast PMT’S
      - One in contact with the Probe
      - One in 60cm distance of the Probe
    - The near PMT acquires a pulse and triggers the far detector to acquire data within a certain time period. [0-450ns] ; Starts a clock
    - The far PMT runs in Single photon detection mode
      - Seeing a single photon during this time window
        » Stops the clock.
    - This acquired time [start-stop] is the stored
    - With enough statistics we get a time distribution of this Sc. probe
Fluorescence time

Coincidence measurements

Single Photon time distribution

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Experimental Setups to determine the properties of liquid scintillators
Purification of Liquid Scintillator

- Column chromatography
  - Aim is to purify the Scintillator
  - Gives a Scintillator of higher purity, lesser light Scattering, higher Attenuation length
  - To purify a Scintillator
    - We used a chromatography column
    - As purifying Material
      - $\text{Al}_2\text{O}_3 \rightarrow$ filters for polar impurities
      - Silica Gel $\rightarrow$ was used in BOREXINO to filter radioactive impurities
    - The Scintillator is sent through the column which holds the purifying Material
      - The powder offers a huge surface to all polar impurities/ingredients
        » All polar impurities will remain in the powder
        » The powder itself is held back by a small pore sized filter
    - This process has 2 modes (Loop/Batch mode)
      - Loop mode: the Scintillator is pumped in a circle $\rightarrow$ only good at the beginning
      - Batch mode: each batch of Sc has its own batch of powder $\rightarrow$ better but expensive & time intensive
  - During all processes the Scintillator should not be contaminated with $\text{O}_2$, heat, or UV-light
Purification system & Liquid handling

Reinigungssystem

Liquid Handling System
Purification system
Experimental Setups to determine the properties of liquid scintillators

Radio purity

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- Absorption length

- Absorption length
Radio Purity

- Identify all radioactive sources
- Aim is to recognize all radioactive backgrounds
  - Either in the used Detector materials or in the ingredients
    - PPO has sometimes U, Th, impurities and (if badly stored) Radon
  - To measure this
    - We use a Germanium detector (150%)
    - In an underground lab of the TUM with an overburden of 6m soil ~15 MWE
    - The detector is equipped with
      - An active Muon veto
      - An anti compton shield
      - Held under N₂-Atmosphere
      - Shielded with
Gamma-Spectroscopy with a 150 % Ge-Detector

UGL reduces cosmic muons by a factor of 3
Nearly complete shielding of the hadronic components
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Thank you for listening