インジウム錯体を用いた太陽ニュートリノ観測用液体シンチレータの開発

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宮城教育大学 福田善之、笠井香代子
東大宇宙線研 森山茂栄
Motivation

Allowed region obtained by combined results and KamLAND

Survival probability for solar matter oscillation below 1MeV

- Mixing angle $\theta_{12}$ is not well determined compared with $\theta_{23}$ obtained by Atm. $\nu$. 
- Survival probability could increase at $5\text{MeV}$ or less in case of LMA solution, and the value of probability depends on $\theta_{12}$.
- $\text{pp}/7\text{Be}$ solar neutrino spectrum gives us precise $\theta_{12}$
Capture of low energy solar neutrinos by $^{115}\text{In}$

Nuclear Physics A 748 (2005) 333-347

$$^{115}\text{In} + \nu_e \rightarrow ^{115}\text{Sn}^* + e^-$$

$$^{115}\text{Sn}^*(4.76\mu s) \rightarrow ^{115}\text{Sn} + \gamma_1(115\text{keV}) + \gamma_2(497\text{keV})$$


**Advantage**
- large cross section (~640SNU)
- direct counting for solar neutrinos
- sensitive to low energy region ($E_\nu \geq 125\text{keV}$)
- energy measurement ($E_e = E_\nu - 125\text{keV}$)
- triple fold coincidence to extract neutrino signal from huge BG ($e_1 + \gamma_2 + \gamma_3$)

**Disadvantage**
- natural $\beta$-decay of $^{115}\text{In}$ ($\tau_{1/2} = 4.4 \times 10^{14}\text{ yr}$ , $E_e \geq 498\text{keV}$)
- possible BG due to correlated coincidence by radiative Bremsstrahlung

**Requirement for the detector**

1. Good energy resolution : 10%(FWHM) $\rightarrow$ high light yield (BC505: 60%)
2. Fine segmentation ($10^4$–$10^5$) or **fine vertex resolution**
3. **High efficiency** $\gamma$ detection
4. Low Backgrounds $\rightarrow$ small detector (solubility : 5wt%)
Indium loaded Liquid scintillator

1. カルボン酸インジウム（In(RCOO)₃）をシュードクメンに8wt%（BC505比55%、透過長8m）
2. ジケトン錯体をアニソールに10wt%以上を溶解


錯体の吸収とアニソールの発光帯が重なり機能が低下
Liquid scintillator using Indium complex

- Indium complex tris(8-quinolinolate) indium (InQ$_3$)

- AlQ$_3$ has been established as Organic Electro Luminescence material (@~530nm)

- InQ$_3$ should also have a property of luminescence with same range WS

- It will be used for fluorescent object and help for light yield

molecular mass : 542.78
Synthesis of InQ$_3$
Luminescence of InQ$_3$ complex

- Measurement of photo luminescence
  - Device: HORIBA FluoroMax-4
  - Solvent: Toluene
  - Concentration: $10^{-4}$
  - Max. excitation wavelength: 320nm
  - Max. luminescence wavelength: 560nm
Solution on \( \text{InQ}_3 \) in organic solvent

- \( \text{InQ}_3 \) dissolved in some organic solvents with \(~1\%\)
  - Benzonitrile (\( \text{PhCN}: \text{C}_6\text{H}_5\text{CN} \))
    - density 1.0g/mL
    - flash point \( 75^\circ\text{C} \)
  - Acetophenone (\( \text{PhCOCH}_3 \))
  - benzyl alcohol (\( \text{PhCH}_2\text{OH} \))
Light absorption and fluorescence

Naphthalene Absorption

Naphthalene Fluorescence

PhCN Fluorescence

InQ3 Absorption

Transparency ~54cm @ 558nm

http://omlc.ogi.edu/spectra/PhotochemCAD/html/naphthalene.html
DAQ setup

- Photomultiplier: H3167 (400K)
- VME ADC: Lecroy 1182
- High voltage: Repic RPH-032
- Photocathode radiant sensitivity:
  - 30mA/W @ 291nm
  - 60mA/W @ 330nm
  - 40mA/W @ 560nm
Spectrum of γ’s for several solutions

InQ3 (20mg) + Naphthalen(0.3g) in PhCN

Photo luminescence due to γ radiation was confirmed

Fuji-film SC-48 (λ > 520nm)
Concentration dependence

\[ n = f \times \rho \times \sigma \]

- \( n \): number of events
- \( f \): photon flux
- \( \rho \): number of InQ3 molecular in 20mL
- \( \sigma \): cross section of photon absorption

- Linearity could be continued until \( \sim 0.75\% \), but saturation might occur above a few %.
Light yield and Quantum yield

BC-505 (4 times scale)

Quantum yield for InQ3

Relative yield: 10%
Quantum yield: ~1.0
Results

- tris(8-quinolinolate) indium complex (InQ₃) loaded liquid scintillator was made by PhCN as solvent and Naphthalen as fluorescent object.
- InQ₃ has photo luminescence for the \( \gamma \) radiation.
- Transparency: \( \sim 54 \text{cm} @ 558\text{nm} \) (1~2% dissolution)
- Light yield relative to BC505: 10%
- Quantum yield: \( \sim 1.0 \)
- First step for development of indium complex loaded liquid scintillator was successful.
- Next step: more light yield, solubility and transparency to modify complex.
Spectrum of $\gamma$’s for several solutions

**PhCN only**

**Naphthalen (0.3g) in PhCN**