Development of Liquid Scintillator containing Zirconium Complex for Neutrinoless Double Beta Decay Experiment

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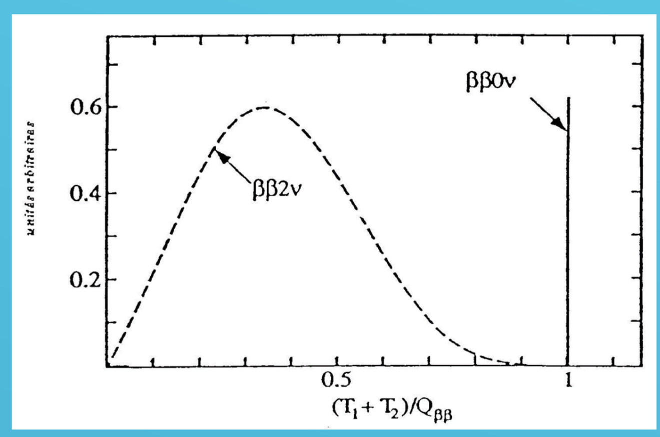
1. Neutrinoless Double Beta Decay

◆ **Neutrinoless double beta decay**

- Lifetime and neutrino mass
  $[T_{1/2}^{0\nu}(0^+ \to 0^+)]^{-1} = G_{0\nu}(E_0,Z)|M_{0\nu}|^2 \langle m_\nu \rangle^2$
- Energy spectrum and lifetime measurement
  - ・monochromatic energy = Q-value
  - ・$T_{1/2} \sim a(Mt/\Delta EB)$ a: abundance M: mass t: meas.time ΔE: energy res. B: BG rate



Requirement : Low background rate, Large target mass and High energy resolution.

◆ **Double beta decay candidates**

$\beta\beta$ emitters with $Q_{\beta\beta}$ >2 Mev

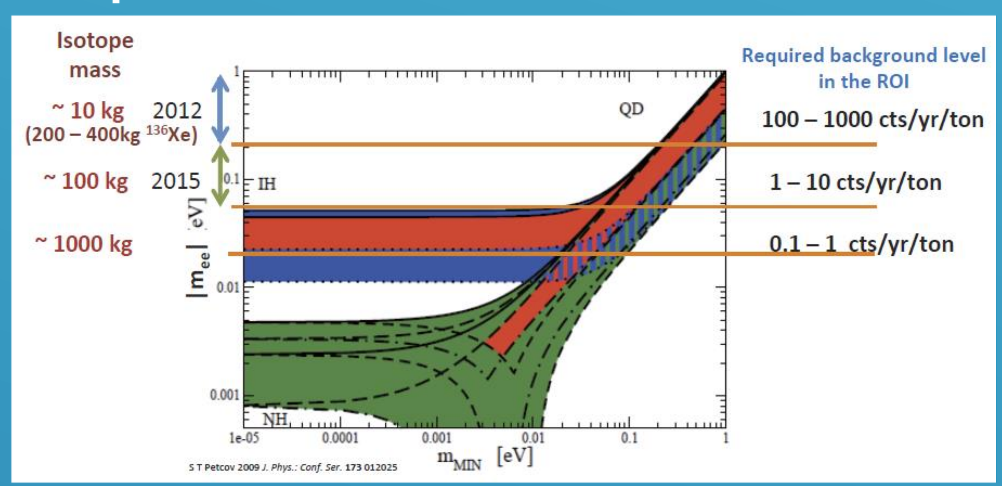
Transition	$Q_{\beta\beta}$ (keV)	Abundance (%) (^{232}Th = 100)
$^{110}Pd \to ^{110}Cd$	2013	12
$^{76}Ge \to ^{76}Se$	2040	8
$^{124}Sn \to ^{124}Te$	2288	6
$^{136}Xe \to ^{136}Ba$	2479	9
$^{130}Te \to ^{130}Xe$	2533	34
$^{116}Cd \to ^{116}Sn$	2802	7
$^{82}Se \to ^{82}Kr$	2995	9
$^{100}Mo \to ^{100}Ru$	3034	10
$^{96}Zr \to ^{96}Mo$	3350	3
$^{150}Nd \to ^{150}Sm$	3667	6
$^{48}Ca \to ^{48}Ti$	4271	0.2

- above ^{208}Tl γ line (2.614MeV) : ^{48}Ca, ^{150}Nd, ^{96}Zr, ^{100}Mo, ^{82}Se…
- large abundance : ^{100}Mo, ^{82}Se, ^{150}Nd, ^{96}Zr
- solved in liquid scintillator formed as metal complex

⇩

Zirconium (^{96}Zr) is possible candidate.

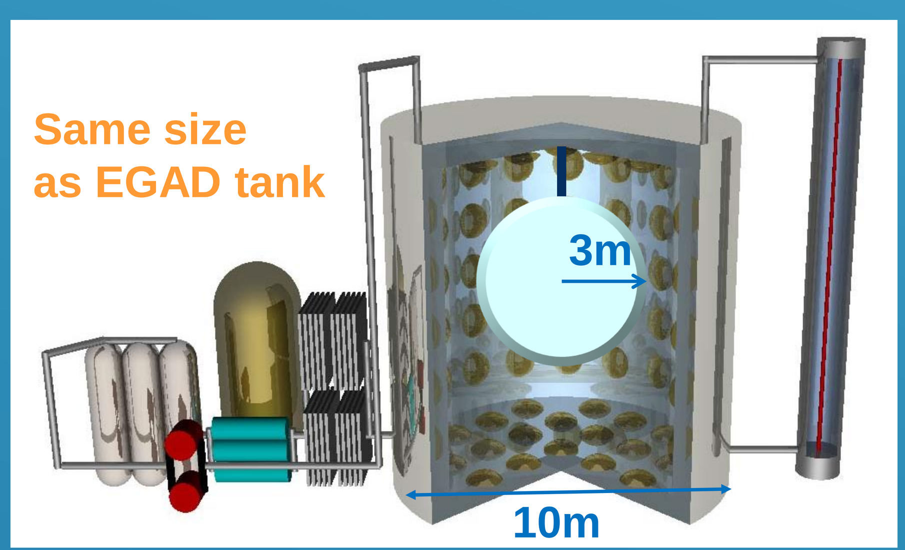
◆ **Experimental limits for neutrino mass**



- high energy resolution : **4%@2.5MeV = 100keV**
- low background rate : **0.01count kg^{-1} y^{-1}**
- large target mass : **~ ton scale**

Goal: $\langle m_\nu \rangle$~10meV

◆ **Detector design for Zr loaded liquid scintillator**



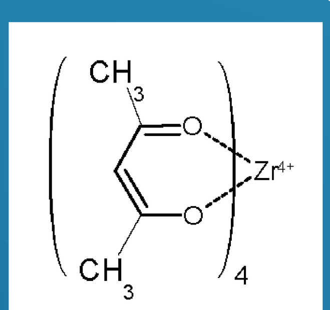
Assuming 10w.t.% solubility

- high energy resolution : **4%@2.5MeV = 100keV**
- low background rate : **0.01count kg^{-1} y^{-1}**
- large target mass : **~ ton scale**

Zirconium Complex in Organic liquid Scintillator (ZICOS) experiment

2. Zirconium complex

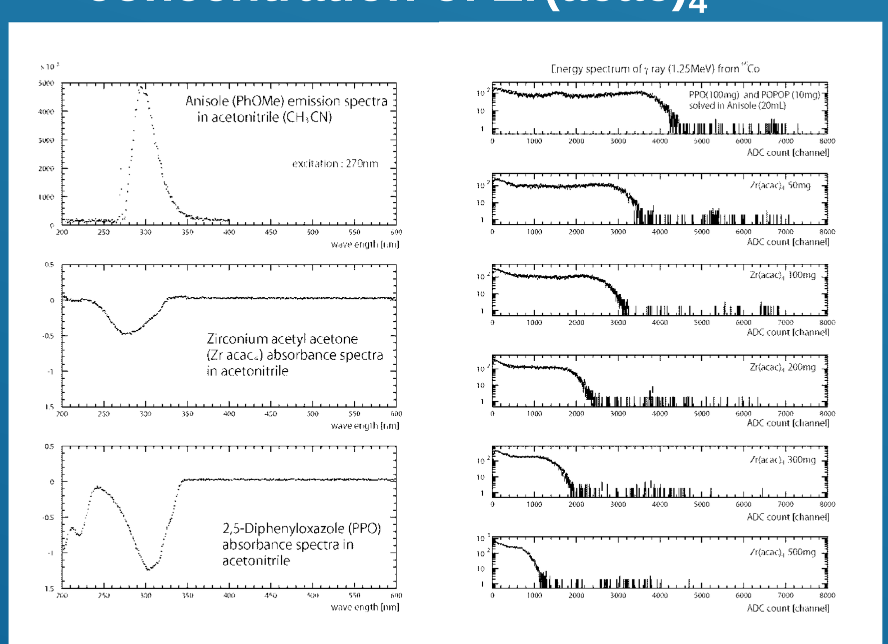
◆ **Zirconium (IV) acetylacetonate**



- good solubility (over 10w.t.% in Anisole)
- stable and cheep (commercial product)

Molecular weight (M.W.) : 487.66

◆ **Scintillation yield with respect to concentration of $Zr(acac)_4$**



◆ **Quenting**

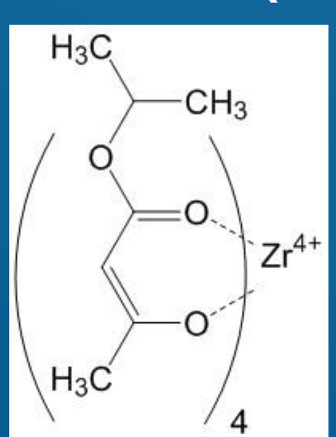
- Expected light yield

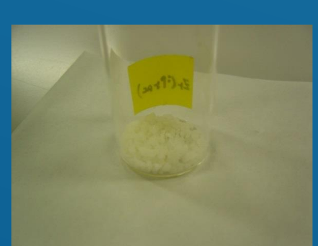
$$\text{Light yield} = L_0 \times \frac{\sigma_1 N_{ppo}}{\sigma_1 N_{ppo} + \sigma_2 N_{Zr}}$$

L_0 : Light yield of anisole
N_{ppo} : No. of PPO molecular
N_{Zr} : No. of $Zr(acac)_4$ molecular
σ_1: absorbance of PPO
σ_2 : absorbance of $Zr(acac)_4$

concentration of $Zr(acac)_4$	Observed ADC channel	Expected ADC channel
0 mg	3850	3850
50mg	3175	3138
100mg	2800	2651
200mg (1 w.t.%)	2000	2018 (52%)
300mg	1600	1613
500mg	900	1178
1000mg (5 w.t.%)	——	695 (18%)

◆ **tetrakis (isopropyl acetoacetate) Zr**

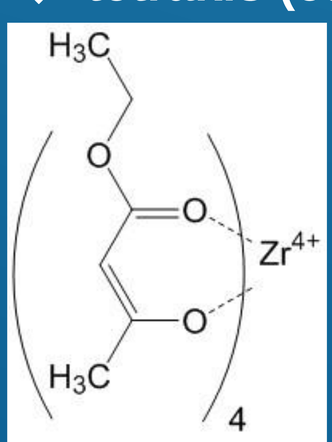


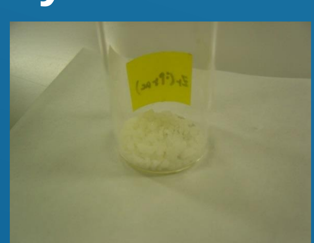


●solubility ~10w.t.%
●state : powder

$Zr(CH_3COCHCOOCH(CH_3))_4$ = $Zr(iprac)_4$
M.W. : 711.92

◆ **tetrakis (ethyl acetoacetate) Zr**





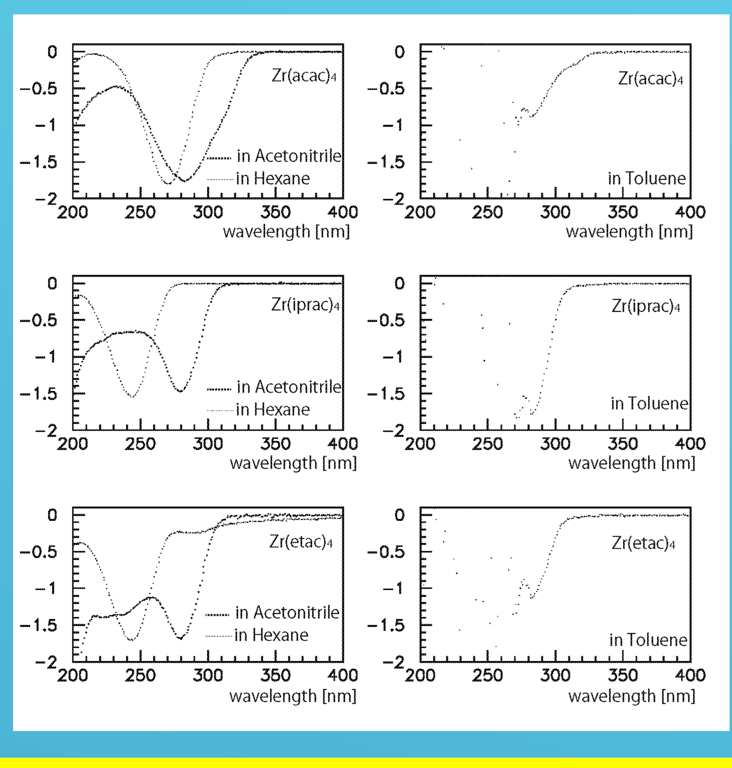
●solubility ~10w.t.%
●state : solid

$Zr(CH_3CCOCHCOOCH_3)_4$ = $Zr(etac)_4$
M.W. : 665.81

3. Scintillation yield with β-keto ester

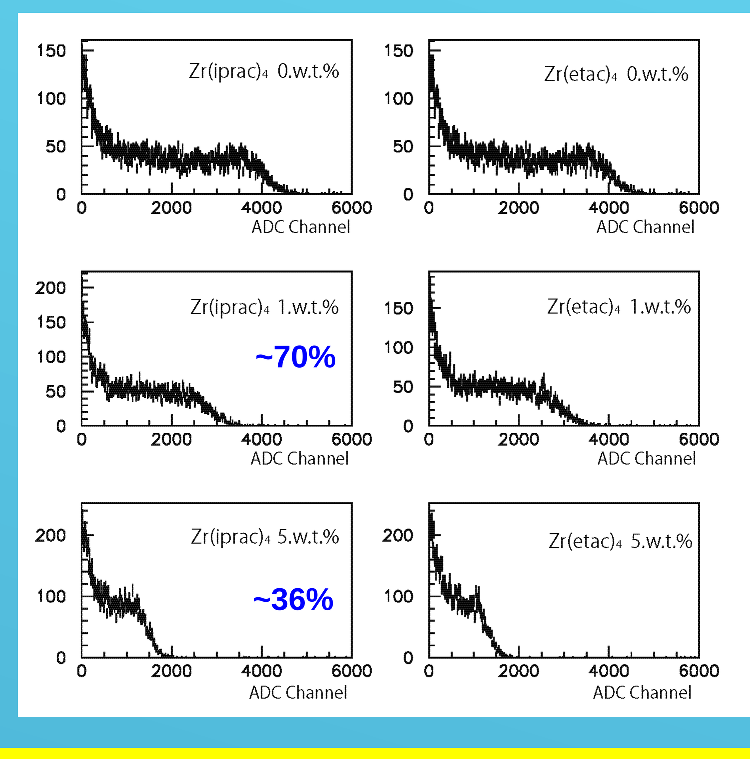
◆ **Liquid scintillator containing Zr β-keto-ester complex**

- **Absorbance**



Confirmed absorption peak moves 275nm → 245nm in Hexane, but in Acetonitrile .

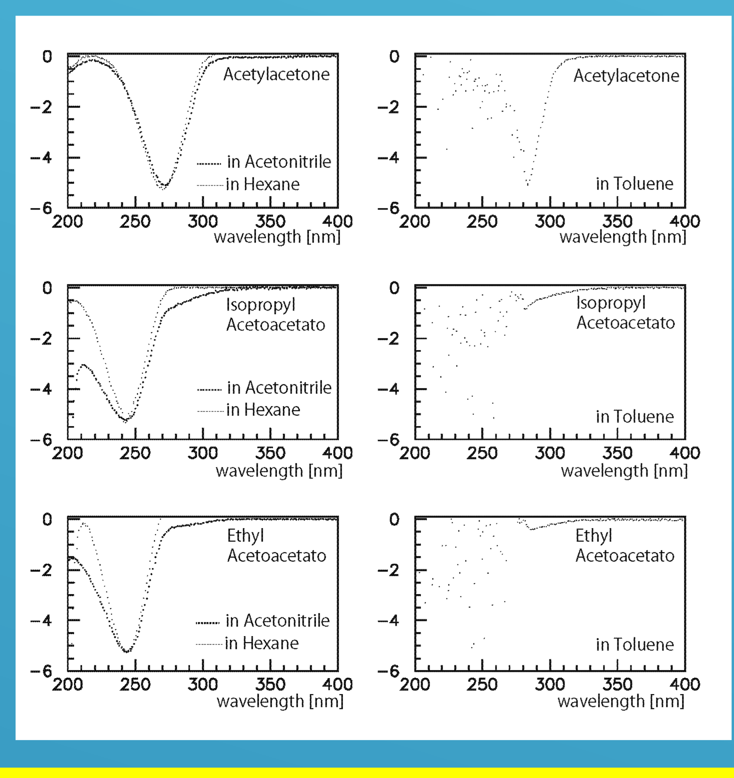
- **Scintillation light yield**



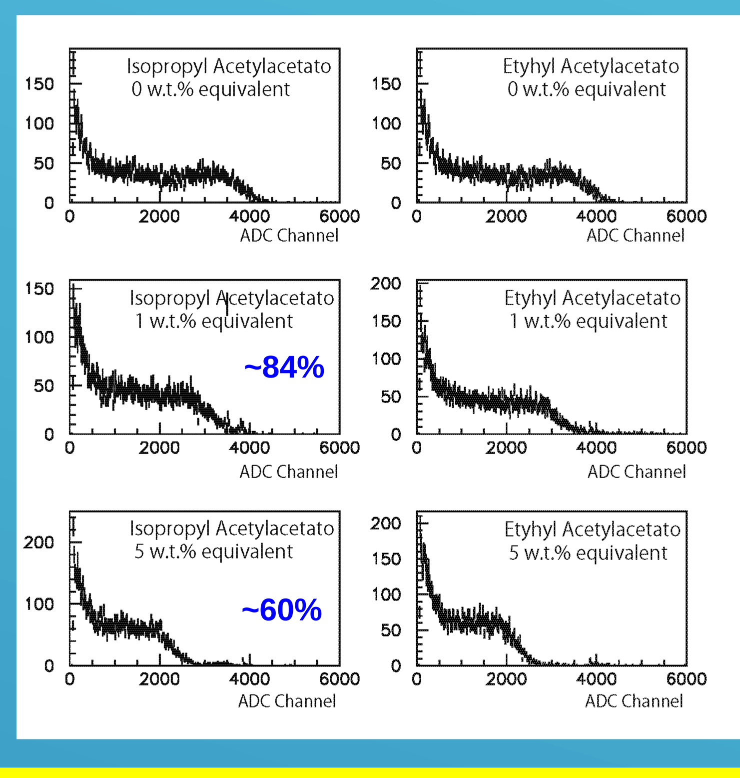
Observed scintillation light yield decreased (but improved). Still exist absorption peak around 270nm in Anisole.

◆ **Liquid scintillator containing β-keto ester ligand**

- **Absorbance**



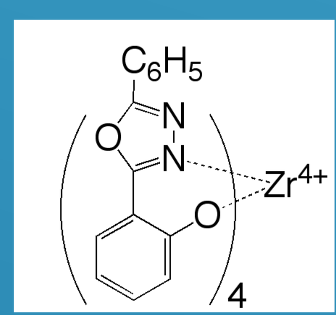
- **Scintillation light yield**



The absorption peak of β-keto ester ligands were found around at 240nm (not 270nm) even though in an aromatic solvent. Therefore the scintillation light yield recovers almost double @ 5w.t.%.

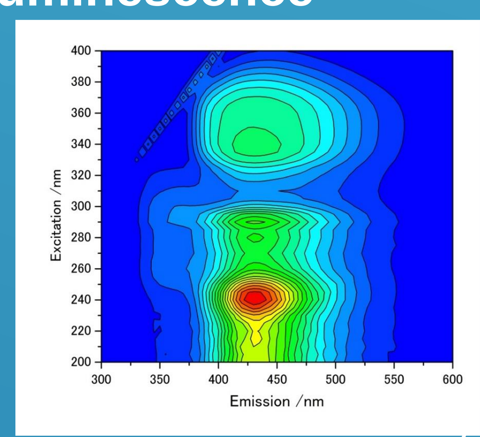
4. Zirconium complex with luminescence

◆ **Zirconium ODZ complex**

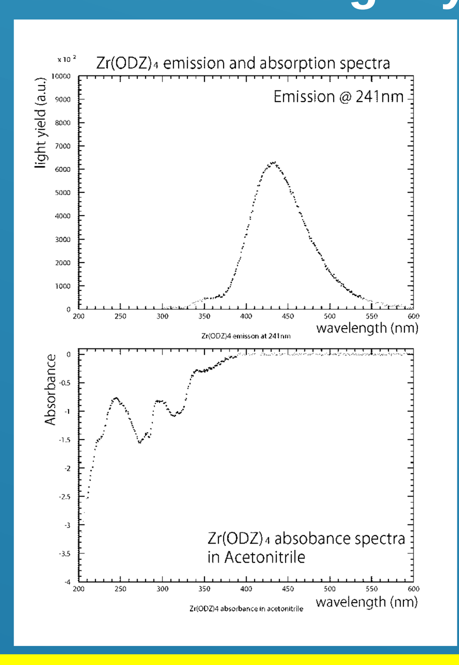


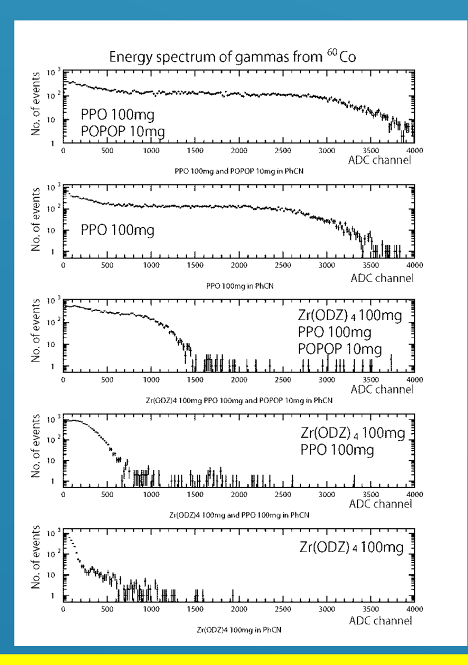
- good solubility (5w.t.% in Benzonitrile)
- **M.W. : 1040.18**
- state : yellow powder

◆ **Luminescence**



◆ **Scintillation light yield**



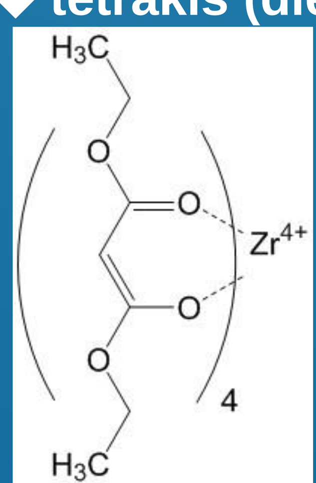


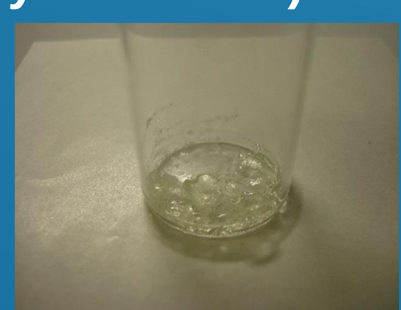
- **Emission wavelength : 430nm**
- **Absorption wavelength : 270nm and 320nm**
- **Third excitation (~340nm from PPO) was used for the emission of $Zr(ODZ)_4$.**
- **Quantum yield for first excitation (~240nm) was estimated as ~30%.**

Need another solvent which has shorter emission spectrum than Benzonitrile.

5. Other complex

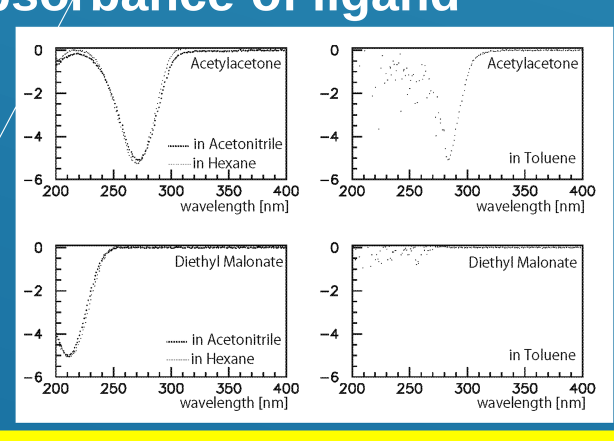
◆ **tetrakis (diethyl malonato) Zr**





$Zr(CH_3CH_2OCOCHCOOCH_2CH_3)_4$ = $Zr(deml)_4$
M.W. : 727.84

◆ **Absorbance of ligand**



short absorption peak (~210nm)

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