Scintillation of liquid neon
Photon Detection at 27 K

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Jin Ping Solar Neutrino Workshop
June 9, 2014
Why neon?

- Scintillates efficiently (of order 20 photons/keV or more)
- No long lived isotopes
- Easily purified of radioactive contaminants
  - Charcoal extremely effective at liquid neon temperatures (Harrison et al., NIM A 570 (2007) 556-560)
- 1.2 g/liter
- Not cheap, although not as expensive as xenon (~few hundred USD/kg)
- Can detect neutrino-electron and neutrino-nucleus scattering

### Table 3.1: Some physical properties of noble elements [182, 183]

<table>
<thead>
<tr>
<th>Property</th>
<th>He</th>
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Liquid noble gas detectors reminder

- Radiation (gamma, electron, neutron, neutrino) collides with electron or nucleus, depositing energy
- Recoiling electrons or nuclei excite other atoms
- Leads to scintillation via metastable molecules (in two states, singlet and triplet) and ionization

\[
\begin{align*}
\text{electron recoil} & \rightarrow \text{excitation} + \text{ionization} \\
\text{nuclear recoil} & \rightarrow \text{atomic motion} \\
\text{Xe}_2^* + \text{Xe} & \rightarrow \text{Xe}_2^+ + \text{e}^- \\
\text{Xe}_2^* & \rightarrow 2\text{Xe} + \text{hv} \\
\text{scintillation light (175 nm)} & \rightarrow S1 \\
\text{S2} & \rightarrow \text{recombination}
\end{align*}
\]
History

- 1970 - Packard, Surko and Reif measure scintillation spectrum in solid and liquid neon
- 1979 - Suemoto and Kanzaki measure absorption spectra in liquid and solid neon, and observe both molecular and atomic transitions
  - Atomic states have very long radiative lifetimes (~600 us), but also have non-radiative decays
- 2002 - Michniak et al. observe 7.4 photons/keV for electrons and a lifetime of 4 us
- 2008 - Yale group (James Nikkel) observes 15 us lifetime, disagreement attributed to purity, first observation of pulse shape discrimination (PSD)
- 2009-2010 - MicroCLEAN measurements at Yale
Neon scintillation probably more complicated than standard picture

- Small hump in molecular potentials could lead to longer lived atomic species
- Free electrons form bubble states (as in helium)
  - If molecules do as well (as in helium), that can change interactions


FIG. 3. Potential curves for the excited states of Ne$_2$ formed in the interaction of Ne(3s, $^1P$) with ground-state Ne, not including spin–orbit coupling. The zero of the energy scale is the separated-atom limit of ground-state Ne$_2$. 
MicroCLEAN

- 3.14 liter detector
- Optimize light collection
- Two 20 cm Hamamatsu R5912-02MOD PMTs
- Inner surfaces of active region are coated with TPB
- Neon data comes primarily from 2009-2010 run
MicroCLEAN

- Pulse tube refrigerator
- Liquefier cell
- PMTs
- Active volume defined by PTFE cylinder
- Inner vessel top plate with feedthroughs
- Inner vessel
MicroCLEAN

- Sample scintillation trace in neon (significant slow component)
MicroCLEAN

- $^{83}\text{Kr}^m$ source calibration - some krypton does diffuse into the bulk
MicroCLEAN

- Maximum light yield of (3.5 +/- 0.4) pe/keV (after circulation through internal charcoal trap that could not be purged)
  - Identical detector saw 6 pe/keV in argon
  - Light scavenging impurities may be more of an issue than in argon
MicroCLEAN

- Time dependence is more involved than just 2 or 3 exponentially decaying species (singlet, triplet, atomic, ?)
MicroCLEAN

- Time dependence also changes with pressure and temperature

![Graph showing voltage vs. time with different temperatures and corresponding time constants.]

- 26.7 K, \( \tau_1 = 21.5 \pm 1.5 \mu s \)
- 27.8 K, \( \tau_1 = 18.2 \pm 0.4 \mu s \)
- 28.8 K, \( \tau_1 = 12.12 \pm 0.05 \mu s \)
MicroCLEAN

- Both time constant and relative intensity are affected

- Results of fitting to a 4 component exponential model ($t_1,t_2$ correspond to the nominal triplet and singlet states)

- Increase in intensity of long lived component matched by a decrease in the time constant with increasing temperature
• Slight increase in signal with temperature

• Will need to be well understood for a large solar neutrino detector with non-uniform thermodynamics
- Temperature/Pressure dependence remains largely unexplored
  - Measurements on saturation line (T and p went together)
  - No electric field
  - Might have something to do with bubble states

\[ T_f = 29 \text{ K}. \]

\[ T_0 = 26.7. \]

\[ \beta = 2, \] the model is quite capable of matching the observed triple life time data as shown in Fig. 6.33. Given our lack of theoretical guidance for whether neon molecules truly do form bubbles and the potential stability of those bubbles, this model is purely speculative.

Neon temperature (K)

\[
\begin{align*}
26.5 & 27 & 27.5 & 28 & 28.5 & 29 \\
\end{align*}
\]

\[
\begin{align*}
\tau_1 & \quad \text{Time constant (\(\mu\text{s}\))} \\
22 & 20 & 18 & 16 & 14 & 12 \\
\end{align*}
\]

Figure 6.33: The observed triplet lifetime along with a fit to the bubble-mixture model of Eq. 6.10, where \(\beta = 2\).

Moving next to the power-law behavior between 50 ns and 1 \(\mu\text{s}\), we can again draw a parallel to the situation in liquid helium and attribute this component to collisions between triplet molecules seeding the creation of singlet molecules that immediately decay. The data in Figure 6.29 are suggestive of a transition from \(\alpha \sim 0.5\) to \(\alpha \sim 1\) around 28.5 K, and two would be interested to discover whether \(\alpha\) remains close to 1 for temperatures above 29 K. Such a transition comes naturally out of the King and Voltz theory as a consequence of changing the geometry of the recoil track; for example, King and Voltz predict an exponent of 1 for spherical track geometry and an exponent of 1.5 for a cylindrical geometry [311]. As has already been discussed, the recoil track geometry would be influenced by a change in the diffusion constant of excited species within the track. Given the correlation between the intermediate exponential component and the power-law behavior, however, the evidence for a phase transition is not conclusive.

Lastly, the KV theory cannot account for the intermediate exponential behavior, even if one modifies the KV model to include the decay of the triplet state. Therefore, we attribute the intermediate component to either excited atomic states producing singlet molecules that immediately...
MicroCLEAN

- Response to nuclear recoils and potential for pulse shape discrimination (not nearly as good as in liquid argon)

- 26.7 K data
- Statistical model (fitted parameters)
- Statistical model (additional noise set to 0)

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PMT considerations

- All studies done with Hamamatsu R5912-02MOD with the platinum underlay to allow use at cryogenic temperatures and two extra dynode stages
PMT considerations

- Gain drops by factor of 100 at liquid neon temperatures
PMT considerations

• Dark current increases at lowest temperatures
  – Also observed by Hans-Otto Meyer at Indiana for Hamamatsu R7725 down to 4 K

![Graph showing the dark count rate as a function of temperature.](image-url)
PMT considerations

- While single PE pulses can still be identified in the traces, the SPE distribution loses coherence
  - At neon temperatures, we could not resolve the SPE response for one of our 2 PMTs
  - Tried tuning first dynode voltage with limited improvement

![Graphs showing pulse area distribution](image)

- Terrible SPE dispersion