PROPERTIES OF SCINTILLATOR SOLUTES

June 1998

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

SPECIAL TECHNOLOGIES LABORATORY
Santa Barbara, California
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
PROPERTIES OF SCINTILLATOR SOLUTES

John M. Flournoy

June 1998

This document is UNCLASSIFIED

S. G. Iversen, Classifier

Work performed under Contract No. DE-AC08-96NV11718
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, or representation, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.
PROPERTIES OF SCINTILLATOR SOLUTES

This special report summarizes measurements of the spectroscopic and other properties of the solutes that were used in the preparation of several new liquid scintillators developed at EG&G/Energy Measurements/Santa Barbara Operations (the precursor to Bechtel Nevada/Special Technologies Laboratory) on the radiation-to-light converter program. The data on the individual compounds are presented in a form similar to that used by Prof. Isadore Berlman in his classic handbook of fluorescence spectra.\(^1\) The temporal properties and relative efficiencies of the new scintillators are presented in Table 1, and the efficiencies as a function of wavelength are presented graphically in Figure 1. In addition, there is a descriptive glossary of the abbreviations used herein. Figure 2 illustrates the basic structures of some of the compounds and of the four solvents reported in this summary.

The emission spectra generally exhibit more structure than the absorption spectra, with the result that the peak emission wavelength for a given compound may lie several nm away from the wavelength, \(\lambda_{\text{avg}}\), at the geometric center of the emission spectrum. Therefore, we have chosen to list absorption peaks, \(\lambda_{\text{max}}\), and emission \(\lambda_{\text{avg}}\) values in Figures 3 - 30, as being most illustrative of the differences between the compounds.

The scintillation efficiencies were measured relative to that of the commercial plastic scintillator BC-422, which is available from Bicron Corporation. Although p-terphenyl was not developed on this program, data for this compound are also included, because its solution in pseudocumene (PC) makes a very bright, fast scintillator, against which the others can also be compared. In addition, data for di-propyl-TPB (DPTPB) are included, because its solution in PC makes the fastest scintillator ever observed in this laboratory, although it is too inefficient to be very useful.

The compounds, BHTP, BTPB, ADBT, and DPTPB were all developed on this program. P-terphenyl, PBD, and TPB are commercially available blue emitters. C-480 and the other longer-wavelength emitters are laser dyes available commercially from Exciton Corporation.

---

### SCINTILLATOR FORMULATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Formula/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid A</td>
<td>PC with 8 g/l PBD and 8g/l TPB</td>
</tr>
<tr>
<td>L-460</td>
<td>PC with 0.1 M BHTP and 0.02 M BTPB</td>
</tr>
<tr>
<td>L-460A</td>
<td>PC with 0.05 M BHTP and 0.02 M ADBT</td>
</tr>
<tr>
<td>L-650A</td>
<td>BA with 0.1 M C-480 and 0.03 M DCM</td>
</tr>
<tr>
<td>L-660</td>
<td>BA with 0.02M C-540A and 0.002M SR-640</td>
</tr>
<tr>
<td>L-735</td>
<td>BN with 0.10 M C-540A and 0.02 M LDS-722</td>
</tr>
<tr>
<td>L-841</td>
<td>BA with 0.10 M Rh-610 and 0.005 M LDS-821</td>
</tr>
</tbody>
</table>

### SOLUTES

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADBT</td>
<td>1,1-diphenyl-4,4-di-(p-bromophenyl)-1,3-butadiene</td>
</tr>
<tr>
<td>BHTP (4-BHTP)</td>
<td>4-bromo-4&quot;-(5-hexadecyl)-p-terphenyl</td>
</tr>
<tr>
<td>BTPB (bromo-TPB)</td>
<td>1,4,4-triphenyl-1-(p-bromophenyl)-1,3-butadiene</td>
</tr>
<tr>
<td>C-480</td>
<td>Coumarin 480 (or Coumarin 102)</td>
</tr>
<tr>
<td>C-540A</td>
<td>Coumarin 540A (or Coumarin 153)</td>
</tr>
<tr>
<td>DCM</td>
<td>red-emitting styryl laser dye</td>
</tr>
<tr>
<td>DPTPB</td>
<td>1,1-diphenyl-4,4-di-(4-(n-propylphenyl))-1,3-butadiene</td>
</tr>
<tr>
<td>LDS-722</td>
<td>far-red-emitting styryl laser dye (Exciton)</td>
</tr>
<tr>
<td>LDS-821</td>
<td>near-infrared-emitting styryl laser dye (Exciton)</td>
</tr>
<tr>
<td>PBD</td>
<td>2-phenyl-5-(4-biphenyl)-1,3,4-oxadiazole</td>
</tr>
<tr>
<td>Rh-610</td>
<td>Rhodamine 610 (or Rhodamine B)</td>
</tr>
<tr>
<td>SR-640</td>
<td>Sulforhodamine 640</td>
</tr>
<tr>
<td>TP</td>
<td>p-terphenyl</td>
</tr>
<tr>
<td>TPB</td>
<td>1,1,4,4-tetraphenyl-1,3-butadiene</td>
</tr>
</tbody>
</table>

### SOLVENTS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BA</td>
<td>benzyl alcohol (alpha-hydroxy toluene)</td>
</tr>
<tr>
<td>BN</td>
<td>benzonitrile (phenyl cyanide, cyanobenzene)</td>
</tr>
<tr>
<td>CH</td>
<td>cyclohexane</td>
</tr>
<tr>
<td>DIN</td>
<td>di-isopropynaphthalene (mixed isomers)</td>
</tr>
<tr>
<td>PC</td>
<td>pseudocumene (1,2,4-trimethylbenzene)</td>
</tr>
</tbody>
</table>
Table 1. Properties of eight liquid scintillators excited by $^{90}$Sr beta particles.

<table>
<thead>
<tr>
<th>Scintillator</th>
<th>$\lambda_{\text{max}}$ (nm)</th>
<th>FWHM (ns)</th>
<th>-3 dB Freq. Response (MHz)</th>
<th>Relative Efficiency*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.015 M TP in PC</td>
<td>342</td>
<td>2.9</td>
<td>125</td>
<td>1.4</td>
</tr>
<tr>
<td>0.14 M BHTP in PC</td>
<td>358</td>
<td>0.6</td>
<td>475</td>
<td>0.32</td>
</tr>
<tr>
<td>Liquid A</td>
<td>438</td>
<td>1.2</td>
<td>270</td>
<td>0.20</td>
</tr>
<tr>
<td>L-460</td>
<td>446</td>
<td>0.8</td>
<td>395</td>
<td>0.12</td>
</tr>
<tr>
<td>L-460A</td>
<td>450</td>
<td>0.7</td>
<td>483</td>
<td>0.06</td>
</tr>
<tr>
<td>L-650A</td>
<td>642</td>
<td>1.8</td>
<td>167</td>
<td>0.09</td>
</tr>
<tr>
<td>L-660</td>
<td>648</td>
<td>13.0</td>
<td>25</td>
<td>0.18</td>
</tr>
<tr>
<td>L-735</td>
<td>725</td>
<td>1.6</td>
<td>215</td>
<td>0.08</td>
</tr>
<tr>
<td>L-841</td>
<td>838</td>
<td>1.6</td>
<td>246</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*Tabulated efficiencies are relative to BC-422 = 1.00. The absolute energy conversion efficiency of BC-422 is about 1.9 percent.
Figure 1. Beta-excited emission spectra of nine liquid scintillators and BC-522 plastic.

Figure 2. Chemical structures of some basic blue emitters and four scintillator solvents.
Figure 3.

Figure 4.
Figure 5.

Figure 6.
Figure 7.

PBD
Solvent: Cyclohexane
Absorption max.: 298 nm
Emission (λem): 362 nm
Quantum yield: 1.00
Decay time: --- ns

Figure 8.

PBD
Solvent: Pseudocumene
Absorption max.: --- nm
Emission (λem): 372 nm
Quantum yield: 0.83
Decay time: 1.00 ns

Strong absorption by the solvent prevented taking the absorption spectrum of PBD in pseudocumene.
**Figure 9.**

**Figure 10.**
ABSORPTION
EMISSION

Mono-bromo-TPB (BTPB)
Solvent: Cyclohexane
Absorption max.: 348 nm
Emission ($\lambda_{em}$): 456 nm
Quantum yield: 0.32
Decay time: 1.38 ns

Figure 11.

Mono-bromo-TPB (BTPB)
Solvent: Pseudocumene
Absorption max.: 351 nm
Emission ($\lambda_{em}$): 467 nm
Quantum yield: 0.09
Decay time: 0.46 ns

Figure 12.
Figure 13.

Figure 14.
Figure 15.

Di-propyl-TPB (DPTPB)
Solvent: Cyclohexane
Absorption max.: 349 nm
Emission (λmax): 468 nm
Quantum yield: 0.09
Decay time: 0.55 ns

Figure 16.

Di-propyl-TPB (DPTPB)
Solvent: Pseudocumene
Absorption max.: 353 nm
Emission (λmax): 473 nm
Quantum yield: 0.03
Decay time: 0.17 ns
Coumarin 480
Solvent: Benzyl Alcohol
Absorption max.: 399 nm
Emission (\(\lambda_{em}\)): 477 nm
Quantum yield: 0.67
Decay time:
- 0.01 M: 4.8 ns
- 0.10 M: 3.3 ns

Coumarin 540A
Solvent: Cyclohexane
Absorption max.: 392 nm
Emission (\(\lambda_{em}\)): 458 nm
Quantum yield: 0.97
Decay time: --- ns

Figure 17.

Figure 18.
Figure 19.

Figure 20.
Figure 21.

Figure 22.
Figure 23.

Figure 24.
Rhodamine 610
Solvent: Benzyl Alcohol
Absorption max.: 560 nm
Emission (λem): 600 nm
Quantum yield: 0.73
Decay time:
0.001 M 6.5 ns
0.10 M 2.2 ns

Figure 25.

SR-640
Solvent: Benzyl Alcohol
Absorption max.: 586 nm
Emission (λem): 624 nm
Quantum yield: 0.74
Decay time: 10. ns

Figure 26.
Figure 27.

Figure 28.
Figure 29.

Figure 30.
DISTRIBUTION LIST

DOE Nevada Operations Office
Technical Information Resource Center
P.O. Box 98518
Las Vegas, NV 89193-8518

U. S. Department of Energy
Office of Scientific and
Technical Information
P. O. Box 62
Oak Ridge, TN 37831

DOE/NV Public Reading Facility
NLV 040