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INFLUENCE OF NEUTRAL GAS ATMOSPHERES AND TEMPERATURE ON NEW LIQUID SCINTILLATORS LIGHT OUTPUTS

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Abstract

Golovkin S.V. et al. Influence of Neutral Gas Atmospheres and Temperature on New Liquid Scintillators Light Outputs: IHEP Preprint 97-12. – Protvino, 1997. – p. 8, figs. 8, tables 2, refs.: 10.

Vacuumed green emitting light liquid scintillators based on 1-methylnaphthalene and a new IPN solvent enhanced their scintillation efficiencies up to 21-32% relative to those at room temperature in air. These enhanced levels of scintillation efficiencies remained practically unchanged in Ne, Ar and CO_2. The intrinsic light outputs for our best liquid scintillators in vacuum up to 55-63 % in comparison with the anthracene have been attained. The light output temperature dependencies of liquid scintillators were studied. The light output of liquid scintillators based on 1-methylnaphthalene in air and on IPN solvent in vacuum were practically temperature independent in a temperature interval from -5^{o}C to +20^{o}C.

Аннотация

Головкин С.В. и др. Влияние атмосферы нейтральных газов и температуры на световыход новых жидких сцинтилляторов: Препринт ИФВЭ 97-12. – Протвино, 1997. – 8 с., 8 рис., 2 табл., библиогр.: 10.

Излучающие в зеленой области спектра жидкие сцинтилляторы на основе 1-метилнафталина и нового растворителя IPN после вакуумизации улучшили свою эффективность сцинтилляций на 21-32% по сравнению с их уровнями сцинтилляций на воздухе, а собственный световыход этих жидких сцинтилляторов в вакууме достиг 55-63% от световыхода антрацена. Эти повышенные уровни эффективности сцинтилляций остались практически без изменений в атмосферах нейтральных газов Ne, Ar и CO_2. Световыходы жидких сцинтилляторов на основе 1-метилнафталина на воздухе и новых жидких сцинтилляторов на основе IPN в вакууме практически не зависят от температуры в интервале от -5^{o}C до +20^{o}C. Жидкий сцинтиллятор на основе 1-метилнафталина с люминофором R6 при концентрации 3 г/л показал высокую стабильность своего световыхода +0.024%^{o}C в интервале температур от +20^{o}C до +60^{o}C.

During last few years very promising experimental results from tests of particle detectors based on capillary fibers filled with liquid scintillators (LSs) have been obtained [1-8]. The main advantages of such detectors are high levels of scintillation efficiency [2,3,8], large attenuation lengths >3 m in liquid-core fibers [2,3,8], relatively short decay time constants of about $6.2 - 7.6$ ns [3,8], high levels of radiation hardness > 100 Mrad [4], high spatial resolution ~ 14 μm for capillaries with small diameters [1]. For tracking detectors the main requirement is a high level of the light output from far ends of liquid core capillary fibers which provides a high level of the track hit density. In order to satisfy it a high level of LSs scintillation efficiency, large Stocks shift between the emission and absorption spectra and high optical transparency of LSs for their emission spectra are needed. Such promising LSs have been found [8]. At present time liquid-core capillary fibers filled with an our best LS (in air) provided a track hit density of about 6.5 photoelectrons per millimetre (p.e./mm) at a distance of 20 cm from the readout system and ~3 p.e./mm at a distance of 1.5 m from the readout system for $\oslash 20 \mu m$ capillaries.

It is well known that many vacuumed LSs have different scintillation properties relative to those in air [9]. This is due to the influence of O_2 in air on LSs luminescence. Besides, for the above applications there is a need to find a neutral gas atmosphere without losing LSs light outputs. This work is devoted to the investigation of influence of different neutral gas atmospheres and vacuum on our LSs light outputs.

1. Experimental technique

The light output I of our LSs was measured by exciting LSs samples ($\oslash$ 1.6 $\times$ 1.0 cm^3) with a ^{90}Sr radioactive β-source. The source and samples were fixed upon the entrance window of a photomultiplier (PM) FEU-84-3. The quantum efficiency Y of the PM multialkaline photocathode is presented in Fig. 1. The light output of our LSs was measured in comparison with a crystal anthracene (having the maximum of wavelength emission λ_{em}=447 nm) and in some cases, with a standard polystyrene (PS) scintillator ($\oslash$ 1.6 $\times$ 1.0 cm^3) containing 1.5% pTP + 0.01% POPOP. The luminescent spectrum L of POPOP is presented in Fig. 1. Abbreviations and known to us formulae of the used solvents, fluors and their maximum of wavelength emission λ_{em} in 1MN are listed in Appendix. We also measured λ_{em} in IPN for our fluors. It was found that they were close to the data presented in Appendix.

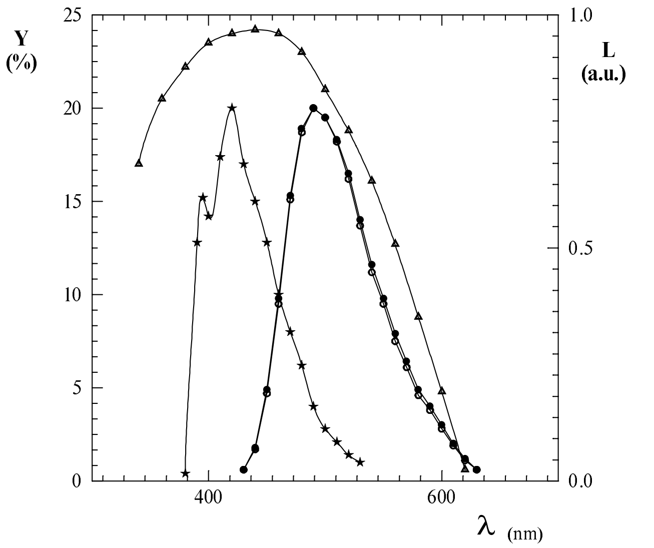

Fig. 1. Quantum efficiency Y of our PM (△) and luminescent spectra L of POPOP (⋆), 1MN + R6 in air (•) and 1MN + R6 in vacuum (∘) for the excitation at 365 nm.

Taking into account the above application, first of all, the amount of light from LSs received by the PM should be measured. The PM photocurrent was measured. The experimental error of such relative light outputs measurements was about ±2% and with a possible systematic error of their values determination was about ±5%. The concentration of scintillating fluors in our LSs was about 3 g/l. Other levels of concentrations will be especially mentioned further on.

The crystal anthracene light output was set equal to 100%. The light output of our 1.0 *cm* thick PS scintillator was found to be about 25% in comparison with the anthracene. There is need to compare the intrinsic light output of our green LSs with the standard PS or anthracene scintillators that have their maximum light outputs in the blue region.

2. Results

2.1. Influence of vacuum and neutral gasses on liquid scintillators light outputs

We investigated the light output of LSs in different neutral atmospheres. Some results of this investigation for 1MN + R6 are presented in Figs. 2-4. Note that the luminescent spectrum L of R6 in 1MN in air is presented in Fig. 1. In Fig. 2 the initial light output of this LS in air was taken as 1. After three hours of pumping out the light output of the LS increased up to a level of 1.27 relative to that in air. Then during two hours we kept the LS in Ar or Ne atmosphere at a pressure of about 1.1 atm.

At the moment of Ar or Ne introduction the light output of the LSs slightly dropped to a level of 1.24, but then increased to a level of 1.26. The nature of these effects is not understood yet and needs explanation. After two hours of the LS saturation in Ar and Ne atmosphere we exposed them to the air. The LS light output began dropping quite fast and in 24 hours attained practically its initial light output level in air.

As is clear from Fig. 2 the similar behaviour was observed with the introduction of CO_2 in the vacuumed LS.

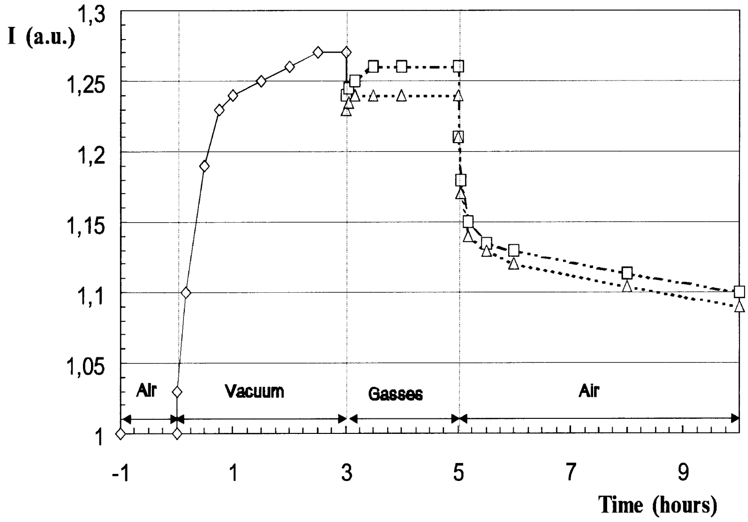

Fig. 2. Light output of 1MN + R6 in different neutral atmospheres. This LS light output in air was taken as 1. ◊ – in vacuum, □ – for Ar and Ne, △ – for CO_2.

Fig. 3 presents the light output of 1MN + R6 in vacuum and different gasses under nearly normal condition: 1.1 atm and room temperature. The introduction of N_2 and Freon-12 significantly decreased the light output of the vacuumed LS to levels of 1.16 and 1.13, respectively.

We also measured the emission spectra for our most efficient LSs in vacuum. So, the emission spectrum L of 1MN + R6 in vacuum is presented in Fig. 1. As is clear from Fig. 1 the emission spectrum in vacuum is close to that in air.

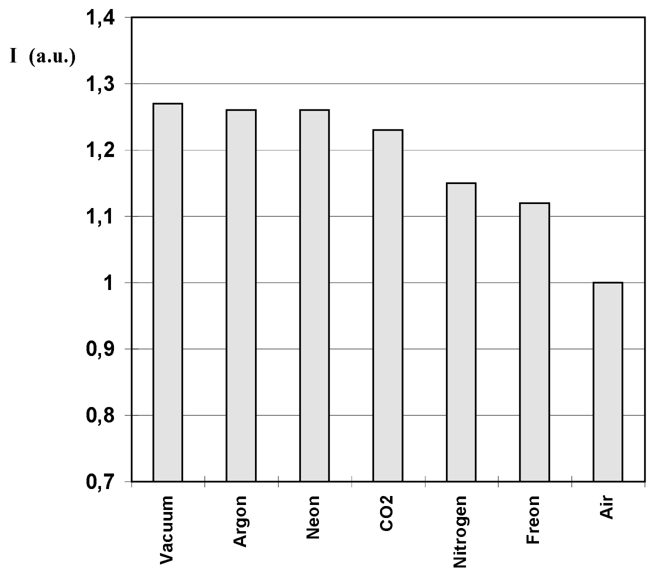

Fig. 3. Light output of 1MN + R6 in vacuum and in different gas atmospheres at room temperature. This LS light output was taken as 1.

The green emitting light vacuumed 1MN + R39 LS showed the maximum light output in air I_{la}=38.0 % and in vacuum I_{lv}=50.3 % in comparison with the anthracene. The corresponding effect of evacuation on the LS light output at room temperature is k=I_{lv}/I_{la}=1.32. The scintillation properties for our most efficient LSs are summarized in Table 1.

Taking into account the PM quantum efficiency Y, experimental data on I_{la} and I_{lv} from Table 1 and known to us the LSs emission spectra we can determine for our most efficient LSs their intrinsic light outputs in air I^y_{la} and vaccum I^y_{lv}. These results are also presented in Table 1. The error of I^y_{la} and I^y_{lv} estimations is about ±10 %. As is clear from Table 1 their maximum light outputs have reached levels of ∼55-63 % (in vacuum) in comparison with the anthracene.

Scintillation properties for some less efficient LSs are summerized in Table 2.

Table 1. Scintillation properties of our best liquid scintillators in air and vacuum at T=20^{o}C.

N	scintillator	I_{la},%	I^y_{la},%	I_{lv},%	I^y_{lv},%	k	ΔI_a %/^{o}C
1	1MN + R6	36.3	46.8	46.0	59.2	1.27	+0.024
2	1MN + R45	35.8	47.3	44.3	58.6	1.24	-0.125
3	1MN + R39	38.0	47.9	50.3	63.2	1.32	-0.042
4	1MN + 3M-15	33.5	44.2	41.5	54.9	1.24	-0.024
5	IPN + R6	36.3	46.7	47.8	61.8	1.32	-0.054
6	IPN + R45	33.8	44.6	42.8	56.6	1.27	-0.149
7	IPN + R39	36.8	46.4	47.3	59.5	1.28	-0.058
8	IPN + 3M-15	37.5	49.5	45.5	60.0	1.21	-0.060

Table 2. Scintillation properties of liquid scintillators in air and vacuum at T=20^{o}C.

N	scintillator	I_{la},%	I_{lv},%	k	ΔI_a %/^{o}C
1	DIPN + R6	29.6	37.4	1.27	-0.024
2	DIPN + 3M-15	27.8	33.8	1.22	-0.092
3	DIPN + R39	27.8	34.7	1.25	-0.072
4	DIPN + R45	25.5	32.2	1.26	-0.038
5	1PN + R6	27.0	29.0	1.07	-0.028
6	1PN + R45	20.0	22.0	1.10	-0.083
7	1PN + R39	25.3	28.0	1.11	-0.068
8	1PN + 3M-15	23.5	26.3	1.12	-0.030
9	LS-13	21.0	25.4	1.21	+0.008
10	CLN + R6	16.3	19.5	1.20	+0.095
11	TOL + 50g/l PPO	11.5	-	-	-0.031
12	50% TOL + 50% IPN + R6	23.0	-	-	-0.024

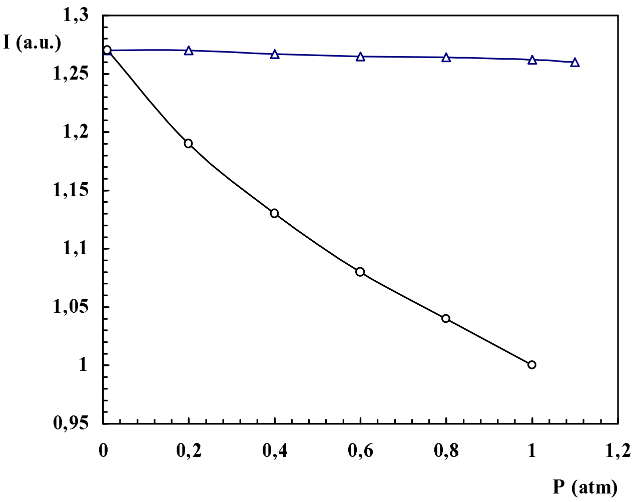

Fig. 4. Light output of 1MN + R6 versus pressure: △ – in Ar and ◯ – in air. Light output of our LS was taken as 1.

Fig. 4 shows 1MN + R6 light output as a function of Ar and air pressures. Note that at each level of the pressure we waited for some time till the LS light output stabilized. As is clear from Fig. 4, the vacuum pump should maintain a level of the vacuum better than 0.01 atm in order to provide the maximum LSs light output. Due to the daily variation of atmospheric pressure, the light output of LSs in air may change up to ±1% while these changes are less than ± 0.04% for LSs saturated with Ar. As expected, small variations of pressure are not important for LSs light output in neutral gasses.

2.2. Influence of temperature on LSs light output

For some applications (for example, electromagnetic calorimeters based on LSs, etc.) the temperature stability of the light output of LSs is an important factor. We investigated the light output of LSs based on 1MN, IPN, 1PN, etc. in air and vacuum with our promising fluors versus the temperature T in an interval from -16^{o}C to +80^{o}C. This interval was limited at low T by the LSs freezing temperature and for high T − by the process of the LSs evaporation.

Some results of this investigation are presented in Figs. 5-7. As is clear from Figs. 5-7 and the data presented in Table 1 and Table 2, the maximum light output and good temperature stability have LSs based on 1MN and IPN. Figs. 5-6 show some results of the light output temperature dependencies measurements for LSs based on 1MN and IPN. The light output of all our LSs based on 1MN in air and LSs based on IPN in vacuum are practically temperature independent in an interval from -5^{o}C to +20^{o}C. The light output of 1MN + R39 in vacuum and air and 1MN + R6 in air is very stable in a temperature interval from +20^{o}C to +60^{o}C. For example, 1MN + R6 revealed a level of the light output temperature stability of about ΔI_a=+0.024%/^{o}C in an interval from +20^{o}C to +60^{o}C which is a little better than the temperature stability of commonly used NE-102a plastic scintillators having ΔI_a=- 0.031%/^{o}C in the same temperature interval [10]. The temperature stability for 1MN + R45 is about 5.3 times worse in comparison with 1MN + R6 and 1MN + 3M-15. Experimental results on the LSs temperature stabilities are summarized in Table 1 and Table 2.

Fig. 7 shows the temperature dependencies for LSs based on DIPN with our promising fluors. These LSs are not so efficient as the LSs based on 1MN and IPN presented in Figs. 5-6. Experimental data on scintillation properties of some home-made LSs based on other solvents like IBP [1], TOL, CLN and a complex one consisting of 50% IPN + 50% TOL, are presented in Table 2 for comparison.

One can see from Fig. 8 that our pure solvents 1MN, IPN, DIPN and 1PN show low levels of the light outputs. They are strongly temperature dependent reducing their light outputs with the temperature increases. The levels of their light output enhancements under evacuation are k=1.22-2.56 and the light outputs are I_{la}=3.3-8.5 % in air at T=20^{o}C in comparison with the anthracene.

In contrast to the negative light output temperature dependencies for pure solvents both in air and vacuum, many LSs based on them and presented in Figs. 5-7 have shown the positive light output temperature dependencies for the same temperature interval. The nature of this effect needs explanation.

[1] LS-13 - a LS based on IBN with λ_{em}=420 nm and light output of I_{la}=21 % manufactured by NPO Monocrystal, Khar'kov, Ukraine

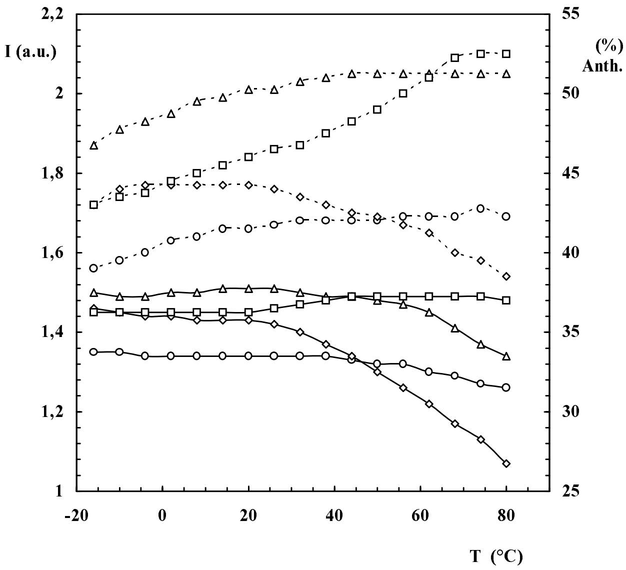

Fig. 5. Light output of some LSs based on 1MN versus temperature: □ – IPN + R6; ◊ – IPN + R45; △ – IPN + R39; ◯ – IPN + 3M-15. Solid line – in air, dashed line – in vacuum. Light output of our PS scintillator was taken as 1.

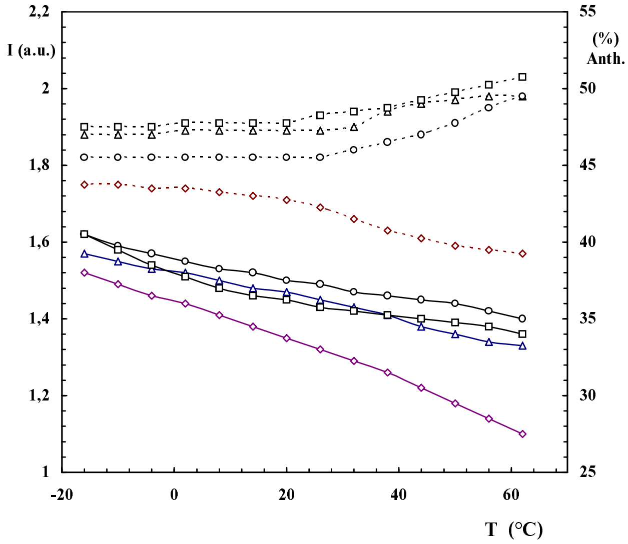

Fig. 6. Light output of some LSs based on IPN versus temperature: □ – IPN + R6; ◊ – IPN + R45; △ – IPN + R39; ◯ – IPN + 3M-15. Solid line – in air, dashed line – in vacuum. Light output of our PS scintillator was taken as 1.

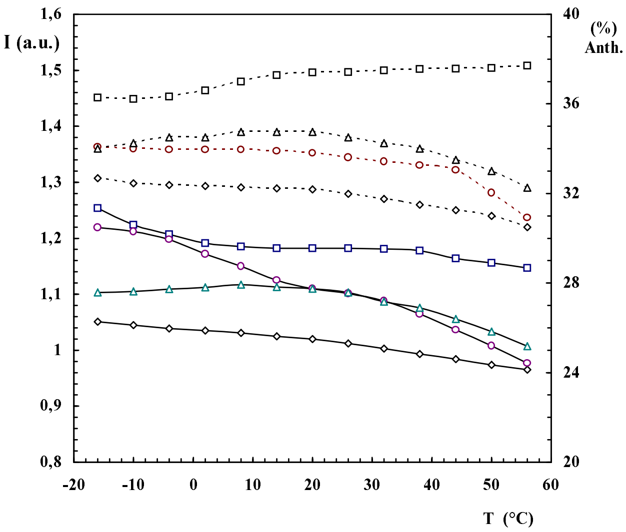

Fig. 7. Light output of some LSs based on DIPN versus temperature: □ – DIPN + R6; ◊ – DIPN + R45; △ – DIPN + R39; ◯ – DIPN + 3M-15. Solid line – in air, dashed line – in vacuum. Light output of our PS scintillator was taken as 1.

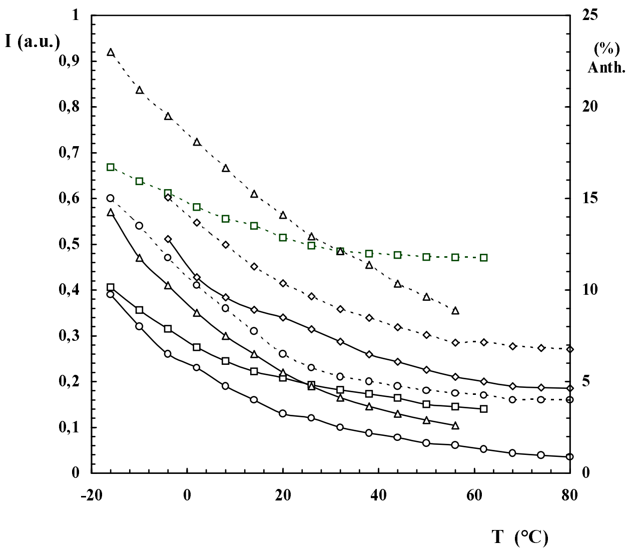

Fig. 8. Light output of pure 1MN, IPN, DIPN and 1PN solvents versus temperature: ◯ – MN; □ – IPN; △ – DIPN; ◊ – 1PN; Solid line – in air, dashed line – in vacuum. Light output of our PS scintillator was taken as 1.

Conclusion

The influence of vacuum and some neutral gasses on LSs light output at room temperature has been investigated. Vacuumed green emitting light LSs based on 1MN and IPN enhanced their scintillation efficiency up to 21-32% relative to those in air. These enhanced levels of scintillation efficiencies remained practically unchanged in Ne, Ar and CO_2 atmospheres. Intrinsic light outputs of our best LSs in vacuum up to ~55-63 % in comparison with the anthracene were attained.

We also studied the temperature influence on liquid scintillators light outputs. It was found that some LSs, for example 1MN + R6, were practically temperature independent in a temperature interval from - 5^oC to $+20^o$C and had good temperature stability of about $+0.024\%/^o$C in an interval from $+20^o$C to $+60^o$C.

The use of our best vacuumed LSs based on 1MN or IPN in neutral gas atmospheres like Ne or Ar will improve the hit density in our tracking detectors up to 21-32% in comparison with those levels in air.

Acknowledgements

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List of investigated solvents and dopants

1MN	- 1-methylnaphthalene
IPN	- naphthalene derivative
1PN	- 1-phenylnaphthalene
DIPN	- 1,4-diisopropylnaphthalene
IBP	- 1-isopropylbiphenyl
CLN	- 1-clornaphthalene
TOL	- toluen
PPO	- 2,5-diphenyloxasole, λ_{em}=365 nm
pTP	- paraterphenyl, λ_{em}=340 nm
POPOP	- 1,4-bis-(2-(5-phenyloxazolyl))- benzene, λ_{em}=420 nm
R6	- pyrazoline derivative, λ_{em}=490 nm
R39	- pyrazoline derivative, λ_{em}=485 nm
R45	- pyrazoline derivative, λ_{em}=500 nm
3M-15	- pyrazoline derivative, λ_{em}=500 nm

С.В.Головкин и др.
Влияние атмосферы нейтральных газов и температуры на световыход новых жидких сцинтилляторов.

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