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Abstract

A comparison is made between the light yield, attenuation length, time response and light propagation speed in plastic scintillating fibres (SCSF-38 and Kuraray-3HF) and quartz capillaries filled with liquid scintillator (LS) 1-methilnaphthalene ($1MN$) doped with new dyes $R45$ and $R39$. The inner diameter of capillaries and diameter of plastic fibres is 0.5 mm.

The number of photoelectrons detected at the far end (2 meters) was 2.9 for capillaries filled with $1MN + 3\ g/l\ R45$ while it was 1.8 times smaller in the case of SCSF-38 and 3 times smaller in the case of Kuraray 3HF plastic fibres. Taking into account the quantum efficiency of the photodetector used these reduction factors became 3.0 and 2.0, respectively.

Good attenuation length, high light output and also excellent radiation resistance of capillaries filled with LS (> 60 Mrad) show that they are a very promising alternative to plastic scintillating fibres for future application in tracking detectors and calorimeters.

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1 Introduction

The use of detectors based on scintillating fibres has been proposed [1] for particle tracking in experiments that will be performed at future high energy and high luminosity colliders.

It will be shown in the following that capillaries filled with liquid scintillator [1, 2, 3, 4] could be a better choice than commonly used plastic fibres.

The capillaries used were made of quartz glass with a low refractive index (n_{gl} = 1.46). In order to increase the trapping efficiency K by total internal reflection on the LS-capillary interface ($K \simeq 0.5(1 - n_{gl}^2/n_{ls}^2)$) a LS with a high refractive index n_{ls} was used. An excellent LS based on the 1-methylnaphthalene (n_{ls} = 1.617) with new dyes $R39$, $R45$ emitting in the green region has been developed by our collaboration.

These capillaries with LS have some important advantages:

1. Owing to the large light yield and excellent trapping efficiency the number of photolectrons is about 1.5 - 3 times larger than in plastic fibres. In capillaries trapping efficiency is $K = 9.2\%$, while for conventional polystyrene fibres ($n_{core} = 1.59$, $n_{clad} = 1.49$) $K = 6.1\%$.

2. Because of the high reflection coefficient at the LS-glass interface the attenuation in capillaries is determined by the LS bulk transparency for diameters greater than 30 μm. The attenuation length is $l_{att} = 1.8\ m$ for 28 μm diameter capillaries and $l_{att} = 3\ m$ for 500 μm diameter capillaries.

3. According to our measurements [5] the radiation resistance of the capillaries filled with LS was greater than 60 Mrad. The scintillation efficiency of our LS did not undergo substantial changes for doses up to 64 Mrad, and at the same dose the light output was reduced to approximately half the original value (without changing the LS). In addition the replaceability of the LS significantly increases the radiation resistance of the detector itself.

2 Measurements of scintillating fibres

A comparison has been made between capillaries filled with LS and two of the best plastic fibres actually available (SCSF-38 and Kuraray-3HF). The inner diameter of capillaries and diameter of plastic fibres was 0.5 mm. The following properties of the fibres were investigated:

1. The number of photoelectrons ($N_{p.e.}$) produced by a minimum ionising particle and the attenuation length (l_{att}).

2. The fluorescence decay time (τ) and propagation speed of scintillating light (v).

3. The influence of dye concentration in the LS on the attenuation length and on the fluorescence decay time.

For the above items an Hamamatsu photomultiplier (PM) R1635 with maximum sensitivity in blue region was used.

For some measurements of the attenuation length of capillaries and fibres an image intensifier (II) 40-25 with peak sensitivity in the green region was used. Signals from the II were amplified by the R1635 PM placed on the II output window.

The measurements were performed at the INFN laboratories in Pisa, and a detailed description of measurements and analysis procedure can be found in [6]. A summary of the main parameters is given in Table 1.

2.1 Number of photoelectrons and attenuation length

Attenuation curves were obtained by measuring the anode current of the PM as a function of position of the radioactive source (^{90}Sr) along the fibre under test. In order to obtain an absolute normalisation the number of photoelectrons was determined by fitting the charge distributions taken at several points.

At distances L greater than 0.5 m from the PM photocathode the number of photoelectrons $N_{p.e.}(L)$ was fitted by the formula:

$$N_{p.e.}(L) = N_0 \cdot exp(-L/l_{att}),$$

where l_{att} is the fibre attenuation length and N_0 is the number of photoelectrons extrapolated at zero distance.

Attenuation of scintillating light in capillaries and plastic fibres are shown in fig. 1. The attenuation length in capillaries is quite good ($l_{att} = 289 \pm 6\ cm$ for $1MN + 3\ g/l\ R45$) and the number of photoelectrons at a distance $L = 2\ m$ is much higher for capillaries ($N_{p.e.} = 2.9$) than for plastic fibres ($N_{p.e.} = 1.63$ for SCSF-38 and only $N_{p.e.} = 0.98$ for Kuraray-3HF).

The PM used has peak sensitivity in the blue region (fig. 2). In order to correctly compare blue and green fibres the number was recomputed of photons using the sensitivity spectrum of the PM. The number of photons at the input of the PM as a function of radioactive source position is shown in fig. 3, and it was approximately 2 - 3 times larger in capillaries than in plastic fibres. This could be explained by the higher trapping efficiency in capillaries and by the larger light yield of the LS.

2.2 Time response and propagation speed of scintillating light

Measurement of the decay time of the scintillating light has shown to be well represented by an exponential, as it can be seen in fig. 4 for a capillary filled with $1MN$ + 3 g/l $R45$. This green LS has a decay constant of 6.8 ns, to be compared with 8.0 ns of Kuraray-3HF green plastic fibres. On the other side the blue plastic fibre SCSF-38 is one of the fastest (τ = 3.7 ns).

It should also be mentioned that the decay time of the LS depends on the dye concentration (see Table 1.).

The propagation speed of the scintillating light was practically the same in plastic fibres and in capillaries (about 6.5 ns/m).

2.3 Influence of dye concentration

The properties of a LS depend on the dye concentration. We measured the attenuation length and decay time for the 3 g/l, 1.5 g/l and 0.75 g/l concentrations of the $R39$ dye, and also for 3 g/l and 1.5 g/l concentrations of the $R45$ dye. With an increase of the dye concentration the attenuation length decreased (fig. 5 and fig. 6), and otherwise the decay time became shorter (Table 1). Light yield of LS versus dye concentration is presented in fig. 7 and increases with concentration.

2.4 II + PM readout scheme

The influence of the type of photodetector used on the attenuation length has been verified. If a photodetector having maximum sensitivity at longer wave length is used it is possible to get larger attenuation length.

Instead of the PM which has peak sensitivity in the blue region (420-430 nm), use was made as a first stage of an II 40-25 with a sensitivity matched to the emission spectrum (see fig. 2) of the green fibres (500 nm).

A readout scheme consisting of an II 40-25 + PM R1635 was studied and the attenuation of scintillating light in capillary with $1MN$ + 3 g/l $R45$ and in plastic fibre Kuraray-3HF was measured. The attenuation length remains practically the same for the capillary (l_{att} = 2.8 m) but changes slightly for plastic Kuraray-3HF fibre (l_{att} = 3.7 to 4.2 m) (fig. 8).

3 Conclusions

In this work a comparison has been made of the main properties of two of the best plastic scintillating fibres SCSF-38, Kuraray-3HF with quartz capillaries filled with liquid scintillator 1-methilnaphthalene doped with the new dyes $R45$ and $R39$. The main results of the measurements are summarised in Table 1.

Attenuation lengths $l_{att} = 289 \pm 6\ cm$ for capillaries filled with $1MN + 3\ g/l\ R45$ and $l_{att} = 372 \pm 8\ cm$ for plastic fibre Kuraray-3HF have been measured.

Capillaries have a significantly higher light output than plastic fibres. At a distance of 2 m from where the scintillating light is produced the signal in capillaries filled with $1MN + 3\ g/l\ R45$ is 2.9 photoelectrons, while in plastic blue SCSF-38 fibres is 1.63 and in plastic green Kuraray-3HF fibres is 0.98.

The decay time of capillaries filled with LS ($\tau = 6.8$ ns) is similar to the one of green plastic Kuraray-3HF fibres (8 ns).

The parameters of capillaries filled with LS, number of photoelectrons, attenuation length and decay time depend on the concentration of the dye, and it is possible to find an optimal concentration for each specific application.

These results and also the excellent radiation resistance of capillaries filled with LS ($>$ 60 Mrad) show that they are very promising for future applications in tracking detectors and calorimeters.

Table 1: Main parameters of capillaries filled with LS and plastic scintillating fibres (0.5 mm in diameter).

Item	λ	l_{att}	N_0	$N_{p.e.}(L)$		τ	v^{-1}
	nm	cm	$p.e.$	$L = 15cm$	$L = 2m$	ns	ns/m
$1MN + 3\ g/l\ R45$	500	289	5.69	6.11	2.90	6.8	6.8
$1MN + 1.5\ g/l\ R45$	500	296	5.33	5.57	2.74	9.8	-
$1MN + 3\ g/l\ R39$	500	162	6.59	7.78	1.97	6.9	7.0
$1MN + 1.5\ g/l\ R39$	500	200	6.96	7.53	2.60	9.2	-
$1MN + 0.75\ g/l\ R39$	500	239	5.62	5.81	2.51	14.2	-
$SCSF - 38$	430	207	4.23	4.62	1.63	3.7	6.4
$Kuraray - 3HF$	530	372	1.69	1.87	0.98	8.0	6.3

λ - wave length at the peak of emission spectrum.

References

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[3] M.Adinolfi et al., Nucl. Instr. and Meth. A315(1992)177.

[4] N.I.Bozko et al., Nucl. Instr. and Meth. A317(1992)97.

[5] S.V. Golovkin et al., Proceedings of II workshop 'Physics at VLEPP', 2-4 June 1992, Protvino, Russia, vol. II, p. 117.

[6] D.Autiero et al., Preprint INFN PI/AE 06/93.

A Figure caption

Fig.1 Attenuation length in plastic fibres and in capillaries filled with LS. Amplitude in photoelectrons. Attenuation lengths l_{att} were calculated in the region 60-200 cm.

Fig.2 Quantum efficiencies of photocathodes of PM R1635 and II 40-25.

Fig.3 Attenuation length in plastic fibres and in capillaries filled with LS. Amplitude in photons. Attenuation lengths l_{att} were calculated in the region 60-200 cm. The quantum efficiency of the photocathode is taken into account.

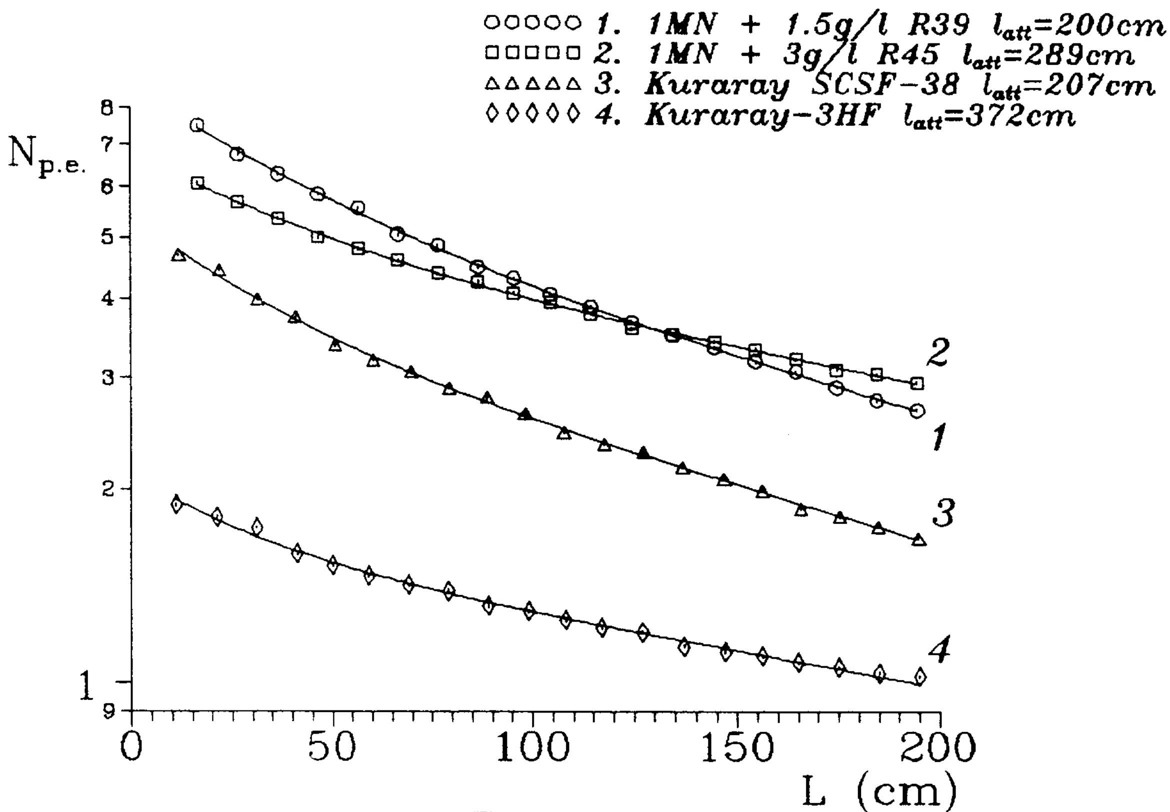
Fig.4 Decay time of the scintillating light from a capillary filled with $1MN$ + 3 g/l $R45$.

Fig.5 Influence of the $R45$ dye concentration on the attenuation length in capillaries filled with LS. Amplitude in photoelectrons. Attenuation lengths l_{att} were calculated in the region 60-200 cm.

Fig.6 Influence of the $R39$ dye concentration on the attenuation length in capillaries filled with LS. Amplitude in photoelectrons. Attenuation lengths l_{att} were calculated in the region 60-200 cm.

Fig.7 Light yield of LS versus concentration of the dye.

Fig.8 Attenuation length in plastic fibres and in capillaries filled with LS.



ooooo 1. 1MN + 1.5g/l R39 l_{att}=200cm
□□□□□ 2. 1MN + 3g/l R45 l_{att}=289cm
△△△△△ 3. Kuraray SCSF-38 l_{att}=207cm
◊◊◊◊◊ 4. Kuraray-3HF l_{att}=372cm
$N_{p.e.}$
8
7
6
5
4
3
2
1
9
0
50
100
150
200
L (cm)
2
1
3
4

Fig.1.

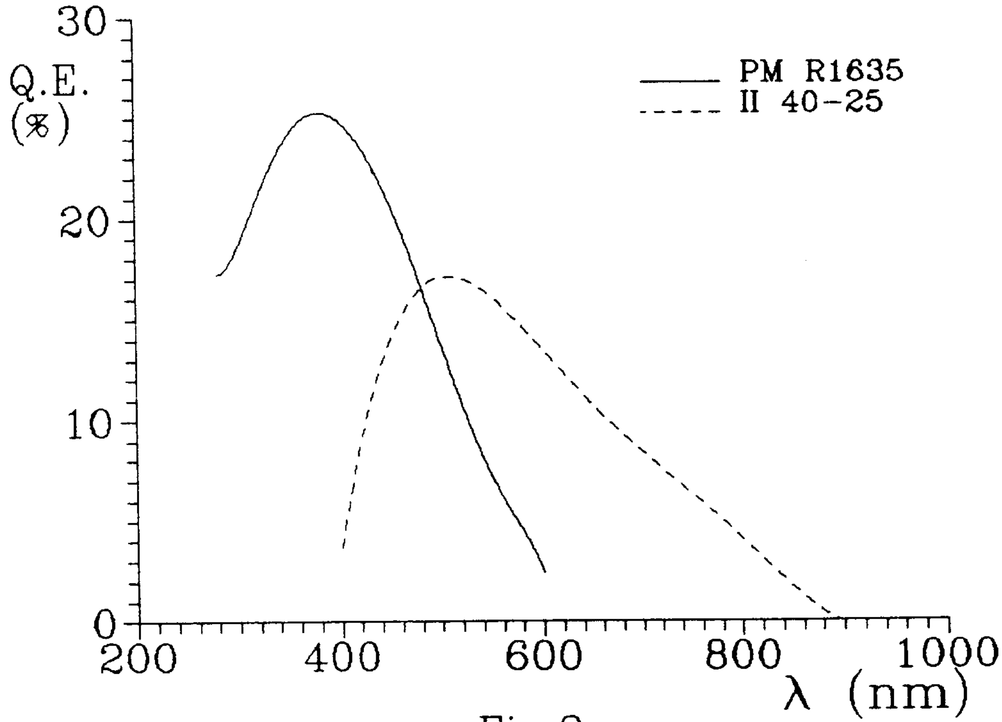
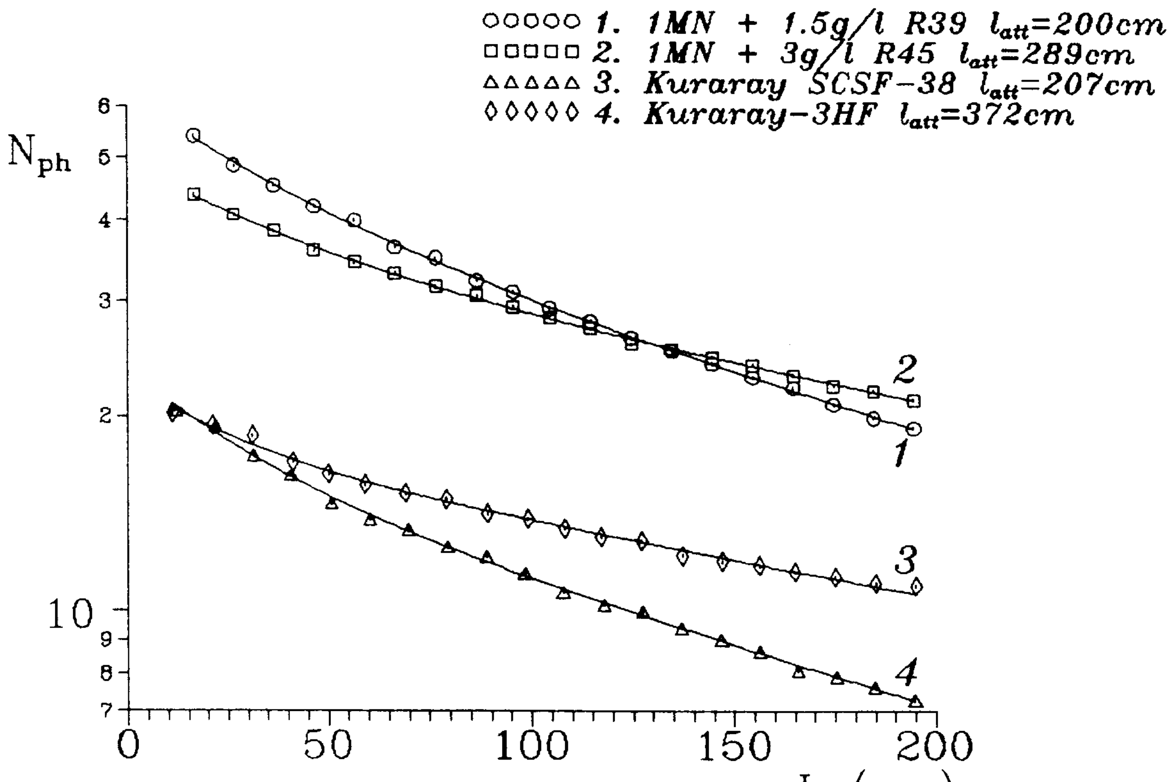


Fig.2.


○○○○○ 1. 1MN + 1.5g/l R39 l_att=200cm
□□□□□ 2. 1MN + 3g/l R45 l_att=289cm
△△△△△ 3. Kuraray SCSF-38 l_att=207cm
◊◊◊◊◊ 4. Kuraray-3HF l_att=372cm
N_ph
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9
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L (cm)
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4

Fig.3.

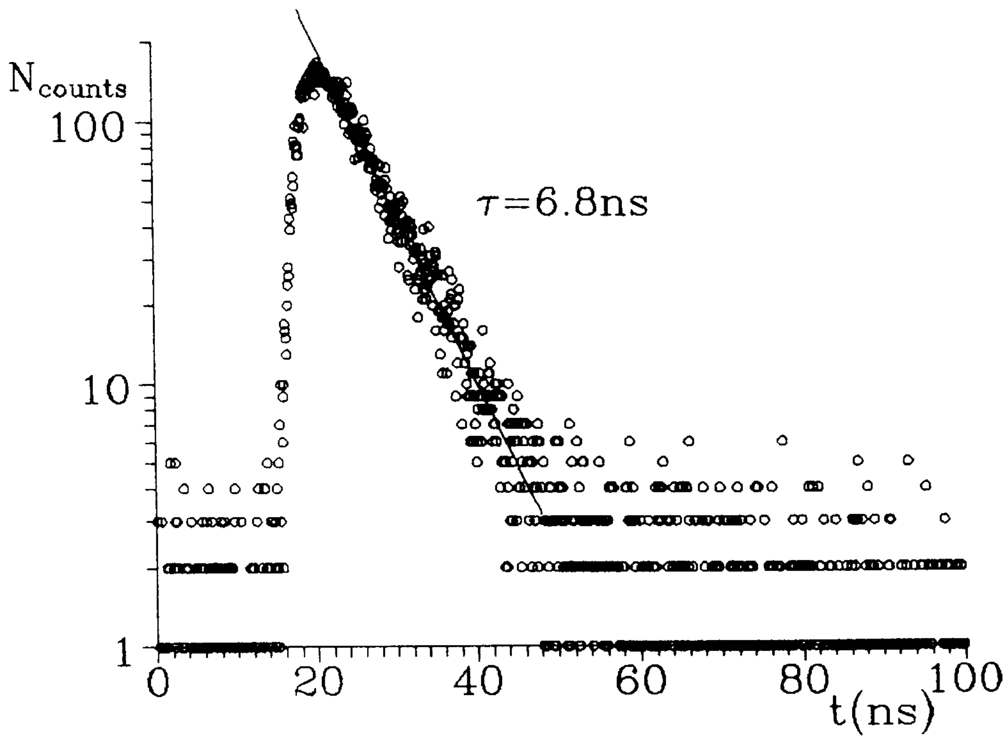
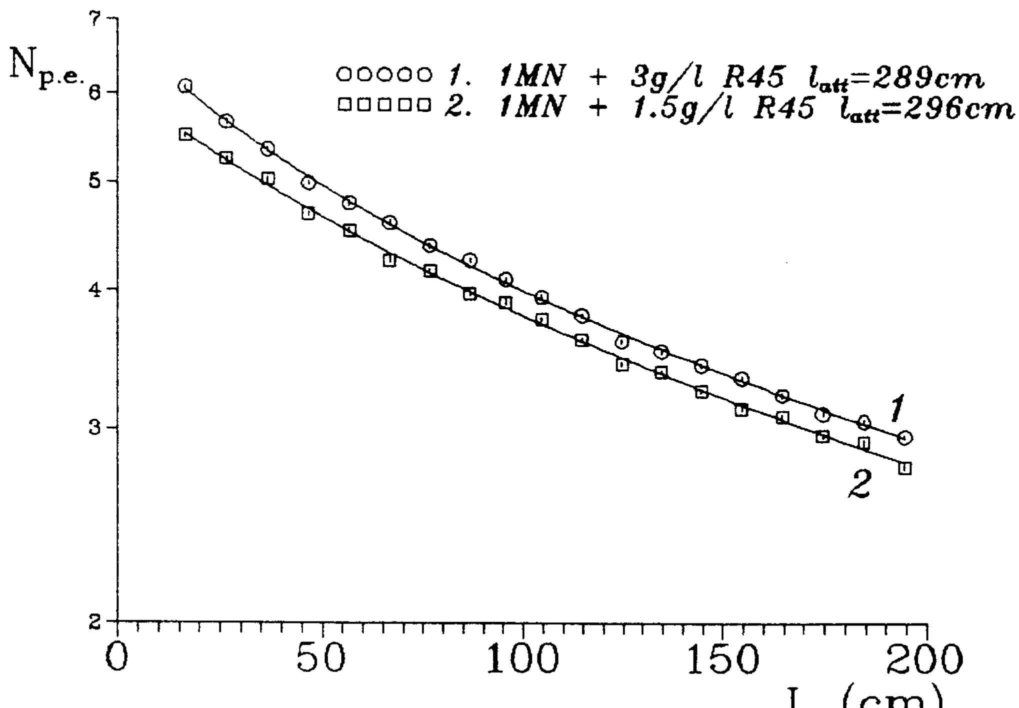


Fig.4.



$N_{p.e.}$
7
6
5
4
3
2
○○○○○ 1. 1MN + 3g/l R45 l_{att}=289cm
□□□□□ 2. 1MN + 1.5g/l R45 l_{att}=296cm
1
2
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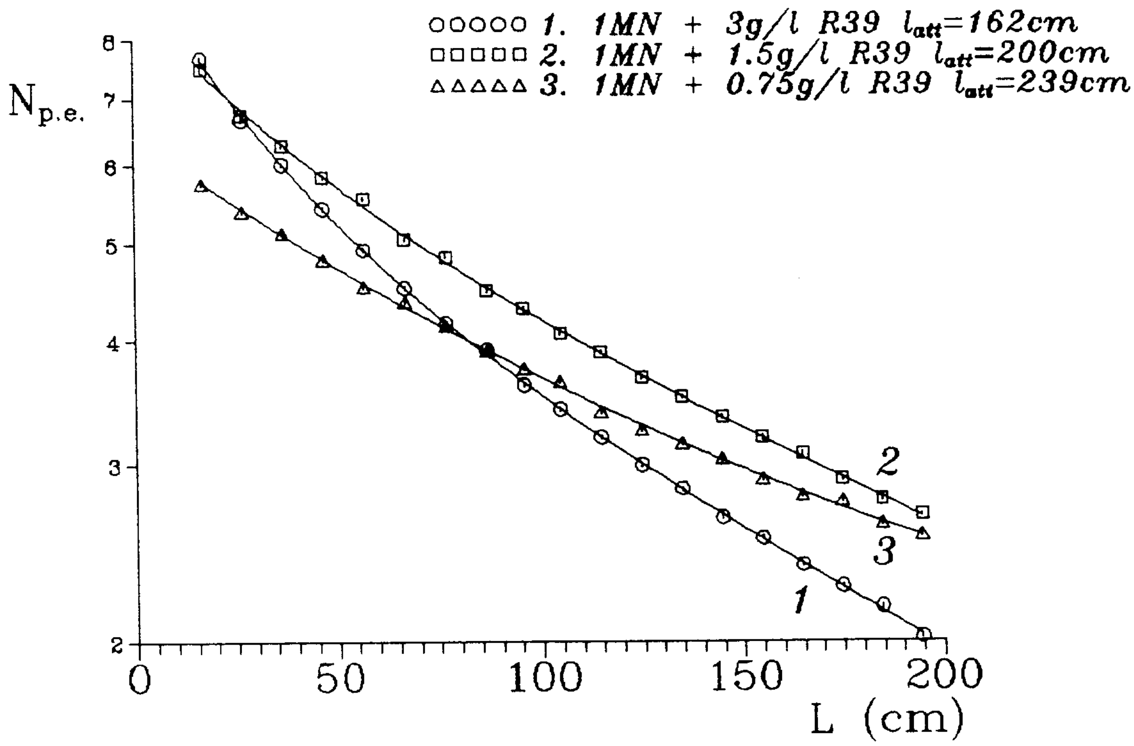
50
100
150
200
L (cm)

Fig.5.


○○○○○ 1. 1MN + 3g/l R39 l_{att}=162cm
□□□□□ 2. 1MN + 1.5g/l R39 l_{att}=200cm
△△△△△ 3. 1MN + 0.75g/l R39 l_{att}=239cm
$N_{p.e.}$
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7
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L (cm)

Fig.6.

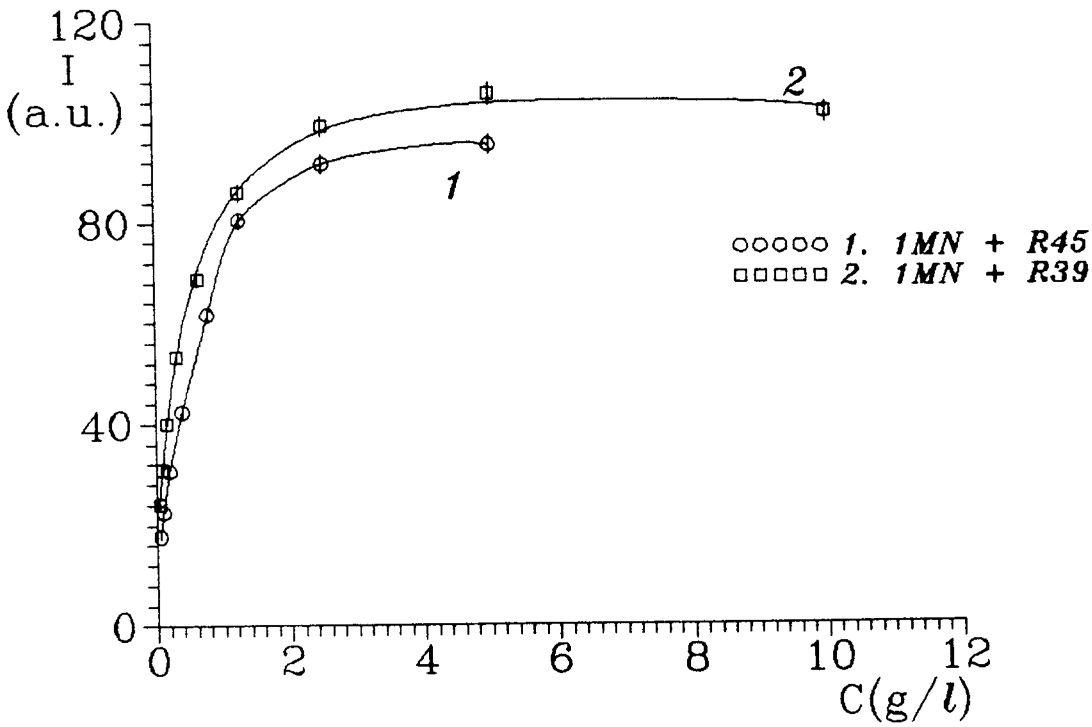

Fig.7.

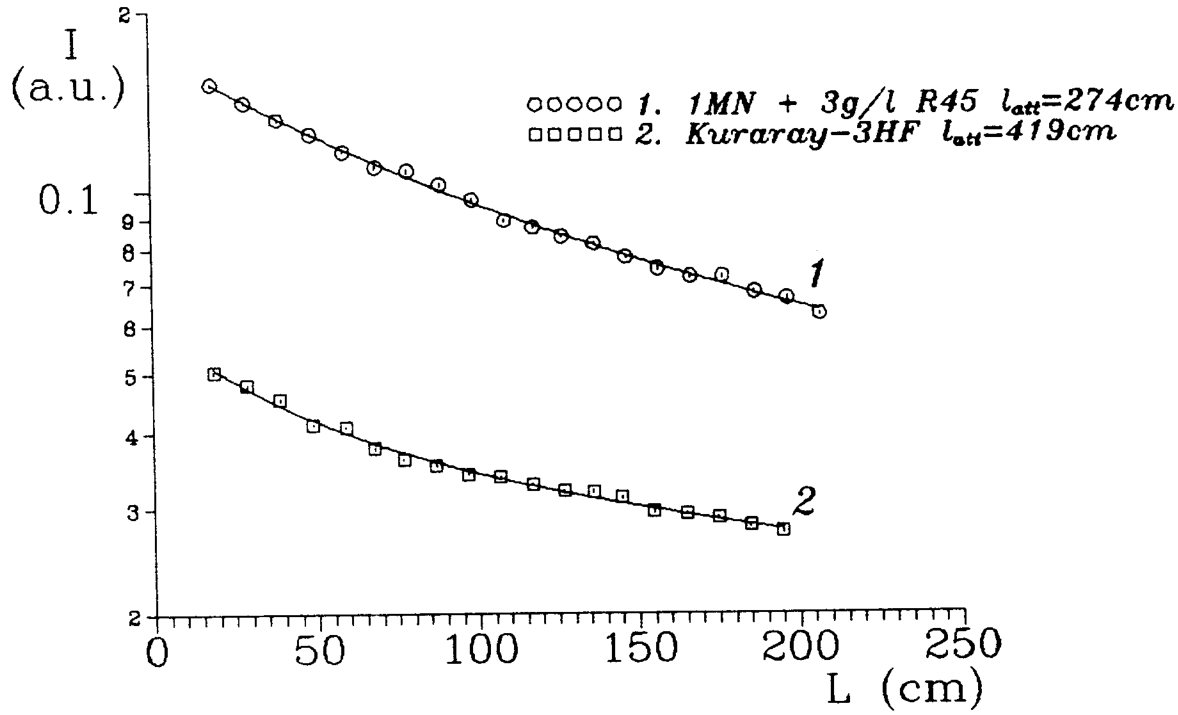
I
(a.u.)
0.1
ooooo 1. 1MN + 3g/l R45 l_{att}=274cm
□□□□□ 2. Kuraray-3HF l_{att}=419cm
1
2
0
50
100
150
200
250
L (cm)

Fig.8.