

2

FILE COPY

AD-A214 212

Second Quarterly Technical Report

Analysis and Evaluation of Technical Data
on the
Photochromic and Non-Linear Optical
Properties of Materials

June 1, 1989

George Mason University

Robert F. Cozzens, Principal Investigator

ARPA Order#: 6631

Contract#: DAAB07-89-C-F404

Project #: CJ829178CJCA

Program Code #: 8E20

DTIC
ELECTE
NOV 08 1989
S B D

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

89 11 06 008

Background

The overall goal of this relatively small contractual effort is to provide technical assistance to Dr. Frank Patten (DARPA) in evaluating data on materials, especially polymers, that may be useful in the development of optical limiters for the protection of eyes and electro-optic sensors from exposure to damaging levels of laser radiation. A major task is to assist in the development of a predictive capability in assessing the viability of various protective approaches and to determine the theoretical limitations which may exist in the use of organic materials as optical switches and limiters.

Progress to Date

A search of the literature has been initiated in an attempt to gather into one table the magnitude of the non-linear optical properties of various organic materials as a function of molecular structure. The first quarterly technical report (March 1989) included a partial list of references being reviewed in order to document reported NLO properties of a variety of molecules and systems. Attached as Appendix A to this, the second quarterly report (June 1989) is a table of molecules and systems with values reported for their NLO properties; namely, values of $\chi^{(3)}$. It is anticipated that this table will represent the starting point for a "living document", continuously updated as new molecules are synthesized and properties measured.

The Principal Investigator attended the Lockheed-Celenese program review held at DARPA headquarters on 26 April. Written comments and suggestions were sent to Dr. Patten following the review.

At no travel expense to this contract, the Principal Investigator attended the "7th DOD Conference on DEW Vulnerability, Survivability and Effects" held in Monterey, CA 9-12 May. Several presentations and poster sessions related to eye and sensor protection or vulnerability to laser radiation. Of special note were the techniques using highly ordered smectic A films developed by Optical Shield, Ltd. and the superheated droplet power limiter reported by Science Applications International Corporation. No new or novel materials with large NLO properties were reported at the conference.

Initial discussions have been held with Mr. Marshal Sparks of BDM Corp. (Los Angeles, CA) and Scientific Research Center, (Playa Del Rey, CA) regarding a possible joint effort to initiate a theoretical study to predict the ultimate limit that may be obtained from an "ideal" NLO polymer or system used as an optical power limiter. These discussions were initiated at the request of Dr. Frank Patten, DARPA. Further discussions and a site visit are scheduled in the near future.

During the next quarter, tabulation of the NLO properties of material will continue and, if agreed to by Dr. Patten, DARPA, and the monitors of this contract, an effort will be initiated to identify the theoretical limitation to the optical switching ability of organic molecules and polymers. This effort would be joint with Mr. Sparks and perhaps others as noted above.

The Principal Investigator is coordinating his activities with the Chemistry Division of the Naval Research Laboratory in Washington, D. C., in order to avoid duplication of effort and to maximize research efficiency.

Accession For	
NTIS USA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By <i>per letter</i>	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
<i>A-1</i>	

APPENDIX A

To Accompany Second Quarterly Technical Report

LIST OF MATERIALS EXHIBITING
REPORTED NON-LINEAR OPTICAL RESPONSE

This tabulation has been generated in conjunction with Dr. Michael Boyle of the Naval Research Laboratory, Washington, D. C. and will appear as part of a formal NRL Report. Part of this contractual effort at George Mason University was in assisting in the development of that NRL Report and thus this tabulation of data is included here, prior to the distribution of the NRL Report.

LISTING OF X³ MATERIALS

THE FOLLOWING LIST OF ORGANIC AND INORGANIC X³ MATERIALS IS NOT AN EXHAUSTIVE COMPILATION OF REPORTED RESULTS. RATHER, IT IS AN ATTEMPT TO DEMONSTRATE THE WIDE VARIETY OF MATERIALS THAT HAVE OR ARE BEING EXAMINED AND THE MAGNITUDE OF THEIR RESPECTIVE NONLINEAR OPTICAL EFFECTS.

THE FOLLOWING ABBREVIATIONS ARE USED FOR MATERIAL NAMES:

PMMA	POLY (METHYL METHACRYLATE)
MBA	M-(P-METHOXYBENZYLIDENE)-P-BUTYLAMINE
PBT	POLY(P-PHENYLENEBENZOBISTHIAZOLE)
4-RCHU	4-METHOXYCARBONYLMETHYLURETHANE
PTS	POLY(BIS(P-TOLUENE SULFONATE))
DMA-HS	PARADIMETHYLAMINO-B-NITROSTYRENE
DMA-FMD	PARADIMETHYLAMINO-L-PHENYL, 4-NITROBUTADIENE
PC	PHTHALOCYANINE
MA	METHYLITROAMINE
DMSO	DIMETHYLSULFOXIDE
PPV	POLY(P-PHENYLENE VINYLENE)
TCMQ	TETRACYANOQUINODIMETHANE
PDA	POLYDIACETYLENE
PBO	POLY(P-PHENYLENE-2,6-BENZOBISTHIAZOLE)
POIAB	
PBI	POLY(BENZIMIDAZOLE)
BBB	POLY(6,9-DIHYDRO-6,9-DIOXOBENZENZIMIDAZO(2,1-B:1',2'-J)BENZO(LMN)PHEMANTRIDOLINE-2,13-DIYL)
BBL	POLY(7-OKO-7,10-BENZO(DEF)IMIDAZO(4',5':5,6)-BENZIMIDAZO(2,1-A)ISOCQUINOLONE-3,4:10,11-TETRAYL)-10-CARBONYL)
POL	POLY(1,4-DIHYDROPYRAZINO(2,3-C)-QUINOLINE-2,3,8-TRIVYL-7(ZN)-YLIDENE-7,8-DIMETHYLIDENE)
POL	POLY(2H,11H-BIS(1,4)OXAZINO(3,2-B:3',2'-N)TRIPHENODITHIAZINE-3,12-DIYL-2,11-DIYLIDENE-11,12-BIS(METHYLIDINE))
PTL	POLY(2H,11H-BIS(1,4)TRIAZINO(3,2-B:3',2'-N)TRIPHENODITHIAZINE-3,12-DIYL-2,11-DIYLIDENE-11,12-BIS(METHYLIDINE))
DTFP	
BTTP	

THE FOLLOWING ABBREVIATIONS ARE USED IN DESCRIBING THE MATERIAL/MOLECULAR FORM:

TF	THIN FILM
LB	LANGMUIR/BLODGETT FILM
SOLN	SOLUTION
LIQU	LIQUID
MLTN	MOLTEN
LC	LIQUID CRYSTAL
CRYS	CRYSTAL
PLAT	CRYSTAL PLATLETS
MONO	MONOMER
POLY	POLYMER

THE FOLLOWING ABBREVIATIONS ARE USED IN DESCRIBING THE EXPERIMENTAL METHOD FOR DETERMINING THE NONLINEAR OPTICAL EFFECT:

DFWM	DEGENERATE FOUR WAVE MIXING
THG	THIRD HARMONIC GENERATION
RMG	REFLECTION WAVEGUIDE
OKE	OPTICAL KERR EFFECT
EFISH	ELECTRIC FIELD INDUCED SECOND HARMONIC GENERATION
SATIN	SATURATION INTENSITY
SP	SURFACE PLASMON
ETAL	NONLINEAR ETALON EXPERIMENT

NOTES

- (1) IN THE COLUMN DESCRIBING THE MAGNITUDE OF THE χ^3 EFFECT, QUANTITIES ENCLOSED IN PARENTHESSES ARE MOLECULAR HYPERPOLARIZABILITIES, γ . UNLESS OTHERWISE INDICATED, THE REPORTED VALUE IS AN EXPERIMENTAL MEASUREMENT.
- (2) THE COLUMN LABELED TIME REFERS TO THE RESPONSE TIME OF THE NONLINEAR OPTICAL MATERIAL.
- (3) DATA OBTAINED FROM NON-REFEREED SOURCES SUCH AS ORAL PRESENTATIONS AND CONFERENCE LECTURE NOTES ARE INDICATED IN THE REFERENCE COLUMN USING A SUPERSCRIPIT *.

CLASS: BOND ACTIVATION (LADDER AND RIGID ROD)

NAME	POLYMER	FORM	NONLINEAR OPTICAL EFFECT				REFERENCES				
			χ^3 or γ (esu)	n_2 (cm^2/MW)	λ (μm)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
PXL											
PQL	X=NR; R=H R=[CH=CHN(CH ₂ CH ₃) ₂]; PREPARATION A R=[CH=CHN(CH ₂ CH ₃) ₂]; PREPARATION B	TF	3E-10 2.8E-9 5E-11		0.53	R	ps	DFWM	DALTON † DALTON † DALTON †	80 80 193	1988 1988 1988
	R=[CH=CHN(CH ₂ CH ₂ CH ₃) ₂] R=[CH=CHN(C ₆ H ₅) ₂] R=[CH=CHN(C ₆ H ₄) ₂]	TF	2.8E-10 1.3E-9 7E-10 1.1E-9		0.53	R	ps	DFWM	DALTON † DALTON † DALTON †	80 80 193 80	1988 1988 1988 1988
PXL	I-CB; PRISTINE		5E-10						ULRICH † DALTON †	37 80	1988 1988
PDL	I-CB; BIPOLARON		1E-7						ULRICH † DALTON †	37 80	1988 1988
PDL	I-CB; PROTONATED		2E-13						ULRICH † DALTON †	37 80	1988 1988
PBT		TF	50-100E-12 9E-12 1E-10		1.90 0.58 & 0.60	NR NR	<ps	THG DFWM	GARITO RAO † ULRICH † DOMASH †	10 13 37 187	1986 1986 1988 1988

CALCULATED

5E-7

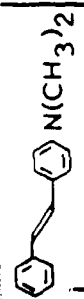

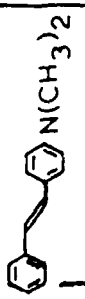
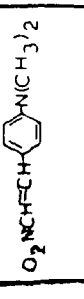
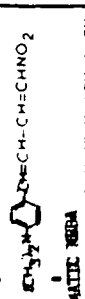



GLASS: LONG CHAIN UNSATURATED

NAME	VEHICLE MATERIAL	STRUCTURE	FORM	NONLINEAR OPTICAL EFFECT				REFERENCES							
				χ^3 or (γ) (esu)	n_2 (cm ² /Mw)	λ (μ m)	Res/NonRes	TIME	METHOD	AUTHOR	REF #	YEAR			
POLYDIACETYLENE															
PDA-PDS:		$R^1R^2CH_2OSO_2C_6H_4CH_3$	TF PLAT PLAT CRYS CRYS CRYS TF TF	9E-9 5E-10 1.6E-10 8.5E-10 3E-9 1.1E-11 1E-9	3E-6 1.8E-6 1E-6	0.70 0.65 0.70 2.62 1.89 >0.70 1.94	NR R NR NR R NR NR R	1ps <6p <6ps <3ps	DFWM DFWM DFWM THG THG ETAL RWG DFWM	CARTER CARTER CARTER SAUTERET SAUTERET HERMANN CARTER NAKANISHI PRASAD*	122 133 133 125 125 180 136 131 82	1985 1985 1985 1976 1976 1980 1984 1988 1988			
PDA-TCDE:		$R^1R^2(CH_2)_xOCOC_6H_4H_3$	PLAT MONO POLY POLY	1.2E-13 7.5E-11 3.7E-11	1E-6	>0.70 1.89 2.62	NR near R near R NR		RWG THG THG THG	CARTER SAUTERET SAUTERET SAUTERET	136 125 125 125	1984 1976 1976 1976			
PDA-ABCUL:		$R^1R^2(CH_2)_xOCOC_6H_4COOC_6H_4$	TF RED TF YLW COMPOSITE/PMMA COMPOSITE/PMMA	4E-10 2.5E-11 3E-10 3E-9	1E-6	0.58 & 0.61 0.58 & 0.61 0.53 1.06	R(?) R(?) R NR	<ps <ps 10ps <ps	DFWM DFWM OKE OKE	RAO RAO HO HO	16 16 137 137	1986 1986 1987 1987			
POLY-DFMP:			(1.09 μ)TF (0.98 μ)TF (1.05 μ)TF (0.98 μ)TF (1.05 μ)TF	2.4E-11 3.7E-11 2.6E-11 2.4E-11 3.5E-11		1.83 1.83 1.94 1.94 1.88				NAKANISHI† NAKANISHI† NAKANISHI† NAKANISHI† NAKANISHI†	131 131 131 131 131	1988 1988 1988 1988 1988			
POLY-BIFF:			(0.07 μ)TF (0.05 μ)TF (0.07 μ)TF (0.05 μ)TF (0.07 μ)TF	2.8E-10 2.6E-10 1.3E-10 1.5E-10 3.2E-10		1.83 1.83 1.94 1.94 1.88				NAKANISHI† NAKANISHI† NAKANISHI† NAKANISHI† NAKANISHI†	131 131 131 131 131	1988 1988 1988 1988 1988			

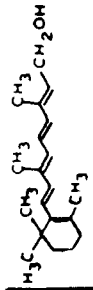
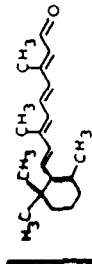
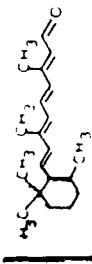
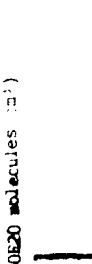
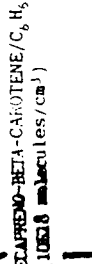
CLASS: LONG CHAIN UNSATURATED

NAME	MOLECULE MATERIAL		NON-LINEAR OPTICAL EFFECT					REFERENCES			
	STRUCTURE	FORM	χ^3 OR $\chi^{(r)}$ (esu)	n_2 (cm ² /MW)	Δ (μ m)	Res/NonRes	FINE	METHOD	AUTHOR	REF #	YEAR
cis-STILBENE		LIQU	(1.7E-35)		1.06			FWM	OUDAR	75	1977
trans-STILBENE/C ₆ H ₆		SOLN	(4.8E-35)		1.06			FWM	OUDAR	75	1977
p-NITROSTILBENE/C ₆ H ₆		SOLN	(7.5E-34)		1.06			EFISH	OUDAR	75	1977
p-AMINOSTILBENE/C ₆ H ₆		SOLN	(2E-34)		1.06			EFISH	OUDAR	75	1977
p-DIMETHYLAMINOSTILBENE/C ₆ H ₆		SOLN	(4.7E-34)		1.06			EFISH	OUDAR	75	1977
p-CHLOROSTILBENE/C ₆ H ₆		SOLN	(2.7E-35)		1.06			EFISH	OUDAR	75	1977
p-CHLORO-p'-NITROSTILBENE/CHCl ₃		SOLN	(6.9E-34)		1.06			EFISH	OUDAR	75	1977

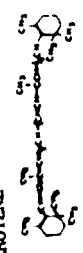
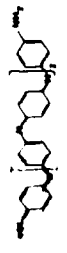
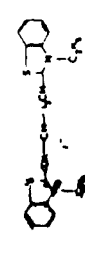

TABLE I. POLYMER UNSATURATED

MOLECULE MATERIAL	FORM	NONLINEAR OPTICAL EFFECT			REFERENCES					
		$\chi^{(3)}$ or (r) (esu)	n_2 (cm ² /MW)	λ (μ m)	Res/Nonres	TIME	METHOD	AUTHOR	REF #	YEAR
<p>4-DIMETHYLAMINOSTILBENE/CH₂Cl₂ SOLN</p> 	SOLN	(1E-33)		1.06			EFISH	OUДАР	75	1977
<p>4-NITRO-4'-AMINOSTILBENE/CH₂Cl₂ SOLN</p> 	SOLN	(9.9E-33)		1.06			EFISH	OUДАР	75	1977
<p>4-DIMETHYLAMINOSTILBENE/CH₂Cl₂ SOLN</p> 	SOLN	(1.7E-32)		1.06			EFISH	OUДАР	75	1977
<p>4-NITRO-4'-AMINOSTILBENE/CH₂Cl₂ SOLN</p> 	SOLN	(8.8E-32)		1.06			EFISH	OUДАР	75	1977
<p>4-DIMETHYLAMINOSTILBENE/CH₂Cl₂ SOLN</p> 	SOLN	(2.8E-32)		1.06			EFISH	OUДАР	75	1977
<p>4-DIMETHYLAMINOSTILBENE/CH₂Cl₂ SOLN</p> 	LC	6E-13(z)		1.91			THG	WONG	153	1986
<p>4-DIMETHYLAMINOSTILBENE/CH₂Cl₂ SOLN</p> 	LC	3E-14(x)		1.91			THG	WONG	153	1986
<p>4-DIMETHYLAMINOSTILBENE/CH₂Cl₂ SOLN</p> 	LC			0.69			DFWM	FEKETE	159	1980
<p>4-DIMETHYLAMINOSTILBENE/CH₂Cl₂ SOLN</p>	LC	3E-13		1.91			THG	WONG	153	1986

CLASS: LONG CHAIN UNSATURATED

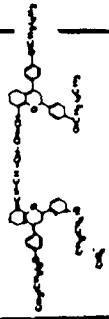
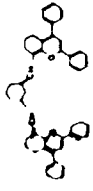
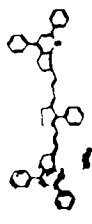
NAME	MOLECULE MATERIAL	FORM	NONLINEAR OPTICAL EFFECT					REFERENCES		
			χ^3 or (γ) (esu)	n_2 (cm^2/MW)	λ (μm)	Res/NonRes	TIME	METHOD	AUTHOR	REF#
RETINOL		MLTN	5.0E-13 (4.6E-35)		1.89 1.89			HERMANN HERMANN	86 86	1974 1974
RETINAL		MLTN	1.1E-12 (9E-35)		1.89 1.89			HERMANN HERMANN	86 86	1974 1974
trans-RETINAL/DMSO (10E20 molecules/cm ³)		SOLN	(1.3E-34)		1.89			HERMANN	86	1974
cis-trans BIKINE/DMSO (10E20 molecules/cm ³)		SOLN	(3E-34)		1.89			HERMANN	86	1974
DOBELAPHEMO-BETA-CAROTENE/C ₆ H ₆ (10E18 molecules/cm ³)		SOLN SOLN	(1.7E-32) (4E-33)		1.89 2.47			HERMANN HERMANN	86 86	1974 1974

CLASS: LONG CHAIN UNSATURATED

MOLECULE MATERIAL		NONLINEAR OPTICAL EFFECT				REFERENCES					
NAME	STRUCTURE	FORM	χ^3 or χ^2 (esu)	n_2 (μm)	λ (μm)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
BETA-CAROTENE		GLASS SOLN	1E-12 (1.4E-33)	8.1E-8*	1.89	NR		THG	HERMANN	87	1973
(10E19/cm ³) / C ₂ H ₆		SOLN	(1.1E-33)		1.89			THG	HERMANN	86	1974
(10E19/cm ³) / C ₂ H ₆		SOLN	1.4E-13*		2.47	R		DFWM	HERMANN	86	1974
/ETHANOL		SOLN	(7.6E-31)**		1.064	R		DFWM	MALONEY	83	1987
		SOLN			1.064	R		DFWM	MALONEY	83	1987
XANTHINE/WATER		SOLN	1.9E-12** (5.2E-30)***		1.064	R		DFWM	MALONEY	83	1987
		SOLN			1.064	R		DFWM	MALONEY	83	1987
DITC/ETHANOL		SOLN	5.7E-13** (3.5E-29)***		1.064	R		DFWM	MALONEY	83	1987
		SOLN			1.064	R		DFWM	MALONEY	83	1987
DMTC/ETHANOL		SOLN	7.3E-13** (2.3E-29)***		1.064	R		DFWM	MALONEY	83	1987
		SOLN			1.064	R		DFWM	MALONEY	83	1987

* CONVERTED FROM esu TO cm²/MW USING: 1 esu = 8.1 x 10³ cm²/MW.^{1,2,7}
 ** CONVERTED FROM MKS(m²/V²) TO esu USING: 10⁻¹⁴ esu = 1.4 x 10⁻²² MKS.^{5,7}
 *** CONVERTED FROM MKS(m²/V²) TO esu USING $\gamma_{esu} = \gamma_{MKS} \times 7.16 \times 10^{11}$.^{8,9}

CLASS: LONG CHAIN UNSATURATED

MOLECULE/MATERIAL		NONLINEAR OPTICAL EFFECT					REFERENCES				
NAME	STRUCTURE	FORM	χ^3 OR γ (esu)	n_2 (cm ² /MW)	λ (μ m)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
A9860/1,2 DICHLOROETHANE		SOLN	1.3E-12* (1.9E-28)**		1.064 1.064	R R		DFWM DFWM	MALONEY MALONEY	83 83	1987 1987
195/1,2 DICHLOROETHANE		SOLN	1.5E-12* (1.4E-28)**		1.064 1.064	R R		DFWM DFWM	MALONEY MALONEY	83 83	1987 1987
5501/1,2 DICHLOROETHANE		SOLN	8.9E-12* (9.1E-29)**		1.064 1.064	R R		DFWM DFWM	MALONEY MALONEY	83 83	1987 1987
BUTADIENE			(3.5E-36)		0.69			EFISH	GARITO†	78	1988
HEXADIENE (60:trans)			(1.1E-35)		0.69			EFISH	GARITO†	78	1988
OCTADIENE (cis)			(1.8E-36)		0.65			EFISH	GARITO†	78	1988

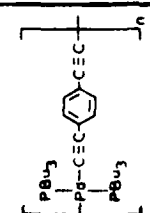
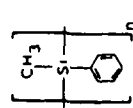
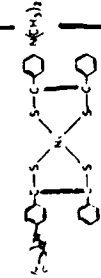
* CONVERTED FROM MKS(m²/V²) TO esu USING: 10⁻¹⁴ esu = 1.4 x 10⁻²² MKS^{-5,2}
 ** CONVERTED FROM MKS(m²/V²) TO esu USING $\gamma_{esu} = \gamma_{SI} \times 7.16 \times 10^{13.81}$

CLASS: LONG CHAIN UNSATURATED

MOLECULE/MATERIAL		NONLINEAR OPTICAL EFFECT				REFERENCES					
NAME	STRUCTURE	FORM	χ^3 or n_2 (esu)	n_2 (cm^2/MW)	λ (μm)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
PC6S:	A BIPHENYL, SIDE-CHAIN LIQUID CRYSTAL POLYMER; A PROPRIETARY PRODUCT OF HOECHST-CELANESE CORPORATION		2.4E-11*	5.0E-6*	0.53	NR	ns	DFWM	LIPSCOMB	47	1986
			8E-13**	8.4E-7**	0.53	NR	ps	OKE	ALTMAN	116	1988
DVDA	LIQUID CRYSTAL		4E-12	8.1E-7***				THG	GARITO	85	1985

*REPORTED AS $3/6 \times \text{CS}_2$; OBTAINED THE TABLE VALUE USING A VALUE OF $\chi^3 = 6.8\text{E}-13$ esu AND $n_2 = 1.4\text{E}-7$ cm^2/MW FOR CS_2 , 185
 **REPORTED AS $6 \times \text{CS}_2$; OBTAINED THE TABLE VALUE USING A VALUE OF $\chi^3 = 6.8\text{E}-13$ esu AND $n_2 = 1.4\text{E}-7$ cm^2/MW FOR CS_2 , 185
 ***CONVERTED FROM esu TO cm^2/MW USING: 1 esu = 8.1×10^3 cm^2/MW , 127

CLASS: ORGANOMETALLICS

NAME	MOLECULE MATERIAL		NONLINEAR OPTICAL EFFECT					REFERENCES			
	STRUCTURE	FORM	χ^3 OF (esu)	n_2 (cm ² /MW)	λ (μ m)	Res/Nonres	TIME	METHOD	AUTHOR	REF #	YEAR
PALLADIUM POLY-YNE		TF	3.9E-11*	8.1E-6*	0.53	R		THG	FRAZIER	143	1987
POLYSILANE		TF	1.5E-12 TOO SMALL		1.06 1.91	R NR		THG THG	KAJZAR KAJZAR	145 145	1986 1986
IRON/TOLUENE		SOLN	1.2E-12** (6.2E-29)***		1.064 1.064	R R		DFWM DFWM	MALONEY MALONEY	83 83	1987 1987

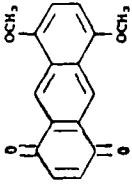
*REPORTED AS $50 n_1(CS_2)$. OBTAINED USING A VALUE OF $\chi^3 = 6.8E-13$ esu AND $n_2 = 1.4E-7$ cm²/MW FOR CS_2 .¹⁸⁵
 **CORRECTED FROM MKS(m²/V²) TO esu USING: 10^{-18} esu = 1.4×10^{-22} MKS.⁵²
 ***CORRECTED FROM MKS(m³/V²) TO esu USING $\gamma_{esu} = \gamma_{SI} \times 7.16 \times 10^{13}$.⁸³

CLASS: MISCELLANEOUS

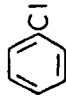


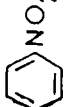
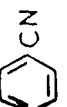
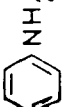

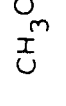
MOLECULE/MATERIAL		NONLINEAR OPTICAL EFFECT					REFERENCES				
NAME	STRUCTURE	FORM	χ^3 OR (γ) (esu)	n_2 (cm^2/MW)	λ (μm)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
CdS/NAFION (perfluorosulfonic acid ion exchange film); 50 Å CdS particles		TF	NOT GIVEN		0.51	R	10 ns	DFWM	WANG	182	1987
NMA/PMA: 17% NMA 10% PMA		TF	2.3E-12	2.5E-7	1.064 1.064			EFISH THG	GOODWIN KHANARIAN	11 175	1988 1986
AZO-DYE/COPOLYMER 25.9% DYE		TF	1.3E-12		2.050	NR		THG	MATSUMOTO	147	1987
[] GOLD COLLOID: 100 Å DIAMETER SILVER COLLOID: 100 Å DIAMETER			1.5E-8 2.4E-9		0.527 0.527	R R	<5ps <5ps	DFWM DFWM	HACHE HACHE	146 146	1986 1986
POLYSTYRENE LATEX MICROSPHERES IN WATER (-234 MICRON DIAMETER)		SOLN	6.8E-8*	3.6E-3	0.514	NR		DFWM	SMITH	170	1981
BEZENE		LIQU	1.0E-13 (3.9E-36)		1.9	R		THG	MEREDITH	115	1983
TOLUENE		LIQU	1.2E-13 1.1E-13		1.9 1.9	R R		THG THG	MEREDITH KAJZAR	115 34	1983 1987
FLUOROBENZENE		LIQU	9.8E-14 (4.6E-36)		1.9	R		THG	MEREDITH	115	1983
		LIQU	7.1E-14 (3.6E-36)		1.9	R		THG	MEREDITH	115	1983

*REPORTED AS $\chi^{(3)}$ IN CS_2 . OBTAINED THE TABLE ENTRY USING $\chi^3 = 6.8 \times 10^{-13}$ esu FOR CS_2 .¹⁸

CLASS: MISCELLANEOUS

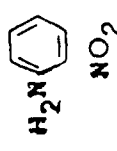
MOLECULE MATERIAL		NONLINEAR OPTICAL EFFECT				REFERENCES				
NAME	STRUCTURE	χ^3 OR (γ) (esu)	n_2 (cm ² /MW)	λ (μ m)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
POLYACENE QUINONE in POLY(VINYL CHLORIDE)	<p>104 by weight</p> 	1.12E-11		0.53		ps	DFWM	BARBARA	192	1988

CLASS: MISCELLANEOUS

MOLECULE MATERIAL		NONLINEAR OPTICAL EFFECT					REFERENCES				
NAME	STRUCTURE	FORM	χ^3 OR $\chi^{(3)}$ (esu)	n_2 (cm ² /MW)	λ (μ m)	Res./Nomiles	TIME	METHOD	AUTHOR	REF #	YEAR
CHLOROBENZENE		LIQU LIQU	1.1E-13 (4.3E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
BROMOBENZENE		LIQU LIQU	1.4E-13 (5.4E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
IODOBENZENE		LIQU LIQU	2.4E-13 (8.2E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
NITROBENZENE		LIQU LIQU LIQU	1.4E-13 (5.4E-36) 1.7E-13 (4.3E-35)		1.9 1.9 1.3 1.3	R R R R		THG THG EFISH EFISH	MEREDITH MEREDITH LEVINE LEVINE	115 115 54 54	1983 1983 1976 1976
CYANOBENZENE		LIQU LIQU	1.0E-13 (4.13E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
ANILINE		LIQU LIQU LIQU	1.7E-13 (5.7E-36) 3.3E-13 (7.8E-36)		1.9 1.9 1.3 1.3	R R NR NR		THG THG EFISH EFISH	MEREDITH MEREDITH LEVINE LEVINE	115 115 54 54	1983 1983 1976 1976
PYRIDINE		LIQU LIQU	9.9E-14 (3.4E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
ACETONITRILE		LIQU LIQU	2.5E-14 (8.7E-37)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983

CLASS: MISCELLANEOUS

NAME	MOLECULE/MATERIAL STRUCTURE	FORM	NONLINEAR OPTICAL EFFECT				REFERENCES				
			χ^3 or (γ) (esu)	n_2 (cm^2/MW)	λ (μm)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
METHANOL	<chem>CH3OH</chem>	LIQU LIQU	2.9E-14 (8.0E-37)		1.5 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
ETHANOL	<chem>CH3CH2OH</chem>	LIQU LIQU	3.7E-14 (1.3E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
2-PROPANOL	<chem>CH3CH(OH)CH3</chem>	LIQU LIQU	4.1E-14 (1.9E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
2-PROPANONE	<chem>CH3C(O)CH3</chem>	LIQU LIQU	4.4E-14 (2.0E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
TETRAHYDOPYRAN	<chem>C1CCOC1</chem>	LIQU LIQU	5.0E-14 (2.2E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
METHYL CYCLOHEXANE	<chem>CC1CCCCC1</chem>	LIQU LIQU	5.9E-14 (4.6E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
CARBON TETRACHLORIDE	<chem>CCl4</chem>	LIQU LIQU	6.7E-14 (3.1E-36)		1.9 1.9	R R		THG THG	MEREDITH MEREDITH	115 115	1983 1983
CHLOROFORM	<chem>CHCl3</chem>	LIQU	5.8E-14		1.9	R?		THG	MEREDITH	115	1983
TETRACHLOROETHYLENE	<chem>C2H2Cl4</chem>	LIQU	8.6E-14		1.9	R?		THG	MEREDITH	115	1983
O-NITROANILINE	<chem>Nc1ccc([N+](=O)[O-])cc1</chem>	LIQU LIQU	4.8E-12 (1.2E-34)		1.318 1.318	NR? NR?		BFISH BFISH	LEVINE LEVINE	54 54	1976 1976



CLASS: MISCELLANEOUS

MOLECULE WATER:AL		NONLINEAR OPTICAL EFFECT					REFERENCES				
NAME	STRUCTURE	FORM	χ^3 or $\chi^{(3)}$ (esu)	n_2 (cm ² /MW)	λ (μ m)	Res/NonRes	TIME	METHOD	AUTHOR	REF#	YEAR
M-NITROANILINE		LIQU	3.3E-12		1.318	NR?		EFISH	LEVINE	54	1976
		LIQU	(8.5E-35)		1.318	NR?		EFISH	LEVINE	54	1976
P-NITROANILINE		LIQU	2.0E-11		1.318	NR?		EFISH	LEVINE	54	1976
		LIQU	(5E-34)		1.318	NR?		EFISH	LEVINE	54	1976
ALKANES	$\text{CH}_3(\text{CH}_2)_{n-2}\text{CH}_3$ n=6 n=8 n=10 n=16	LIQU	4.7E-14		1.064			THG	KAJZAR	52	1987
			5.0E-14		1.064			THG	KAJZAR	52	1987
			5.4E-14		1.064			THG	KAJZAR	52	1987
			6.0E-14		1.064			THG	KAJZAR	52	1987
$\text{CH}_3(\text{CH}_2)_{n-2}\text{CH}_2\text{Cl}$ n=6 n=10 n=12 n=14		LIQU	5.6E-14		1.064			THG	KAJZAR	52	1987
			6.1E-14		1.064			THG	KAJZAR	52	1987
			6.5E-14		1.064			THG	KAJZAR	52	1987
			6.7E-14		1.064			THG	KAJZAR	52	1987
$\text{CH}_3(\text{CH}_2)_{n-2}\text{CH}_2\text{Br}$ n=6 n=10 n=14		LIQU	7.5E-14		1.064			THG	KAJZAR	52	1987
			6.9E-14		1.064			THG	KAJZAR	52	1987
			6.9E-14		1.064			THG	KAJZAR	52	1987
$\text{CH}_3(\text{CH}_2)_{n-2}\text{CH}_2\text{I}$ n=6 n=8 n=10		LIQU	1.3E-13		1.064			THG	KAJZAR	52	1987
			1.2E-13		1.064			THG	KAJZAR	52	1987
			1.0E-13		1.064			THG	KAJZAR	52	1987

CLASS: INORGANICS

MOLECULE MATERIAL		NONLINEAR OPTICAL EFFECT				REFERENCES					
NAME	STRUCTURE	FORM	χ^3 OR γ (esu)	n_2 (cm ² /MW)	λ (μ m)	Res/Nonltes	TIME	METHOD	AUTHOR	REF #	YEAR
Pb/So FLUOROPHOSPHATE GLASS WITH ACRIDINE ORANGE (8E17 molecules/cm ³)			0.02	0.21	0.514	R	msec	SATIN	TOMPKIN	149	1987
ACRIDINE YELLOW (8E17 molecules/cm ³)			0.06	0.16	0.467	R	msec	SATIN	TOMPKIN	149	1987
BORIC ACID GLASS WITH FLUORESCEN (10E18 molecules/cm ³)			1		0.467	R	sec	DFWM	KRAMER	148	1986
CdS, Se _{1-x} DOPED GLASS			1E-8		0.588	R	ns	DFWM	ROSSIGNOL	30	1987
CRYSTALS											
NaF				7.7E-10*	1.060	NR			NASU	29	1987
NaCl				1.8E-9*	1.060	NR			NASU	29	1987
NaBr				7.8E-9*	1.060	NR			NASU	29	1987
KCl				2.7E-9*	1.060	NR			NASU	29	1987
KBr				1.1E-8*	1.060	NR			NASU	29	1987
CaF ₂				2.7E-9*	1.060	NR			NASU	29	1987
CaF ₂				1.2E-9*	1.060	NR			NASU	29	1987
CdS				1.9E-7	1.060	NR			NASU	29	1987
Dials			0.4	4E-4	0.820	NR			KOWEL	40	1987
			1.2E-11	1.1E-6**	1.3-13				CHANG	110	1981
Ins			1	3E-3 (77K)	5.4	NR			KOWEL	40	1987
			8E-10	6.5E-5**	9-24				CHANG	110	1981
Ins			1.8E-10	1.6E-5**	4-14	NR			CHANG	110	1981
Zn(II)D			1.5E-10	1E-5**	2-14	NR			CHANG	110	1981
Si(III)D			8.0E-12	7.1E-7**	1.3-7	NR			CHANG	110	1981
EpTe		TF	1.6E-4		10.6				WOLFF	181	1987
			-1E-4		10.6			non-DFWM	HOFFMAN	191	1988

* CONVERTED FROM esu TO cm²/MW USING: 1 esu = 8.1 x 10³ cm²/MW.¹²⁷
 ** CONVERTED FROM MKS(es²/V²) TO cm²/MW USING: 1 MKS = 7.3 x 10¹² cm²/MW.¹²⁷