ULTRAVIOLET CROSSLINKING;

A COST EFFECTIVE ALTERNATIVE TO E-BEAM CROSSLINKING OF PE AND HFFR

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AMI "Polymer in Cables" Conference

Virtual Summit 22-24th June 2021

Chemical Crosslinked cables: what crosses your mind?

PLEXCHEM Technologies
Chemistry for Good

- Pre-crosslinking - *lumpy surface*
- Punctures - *cable failures*
- Under-crosslinking - *poor hot set*
- Shrinkage - *choosing the right tools*
- Orange Skin - *unacceptable appearance*
- The outcome of extrusion - *finding out too late*
- Operating conditions - *leading to poor test results*
- Special storage conditions - *Shelf life*

Because the crosslink chemicals interfere with the extrusion process

An introduction to Photochemistry

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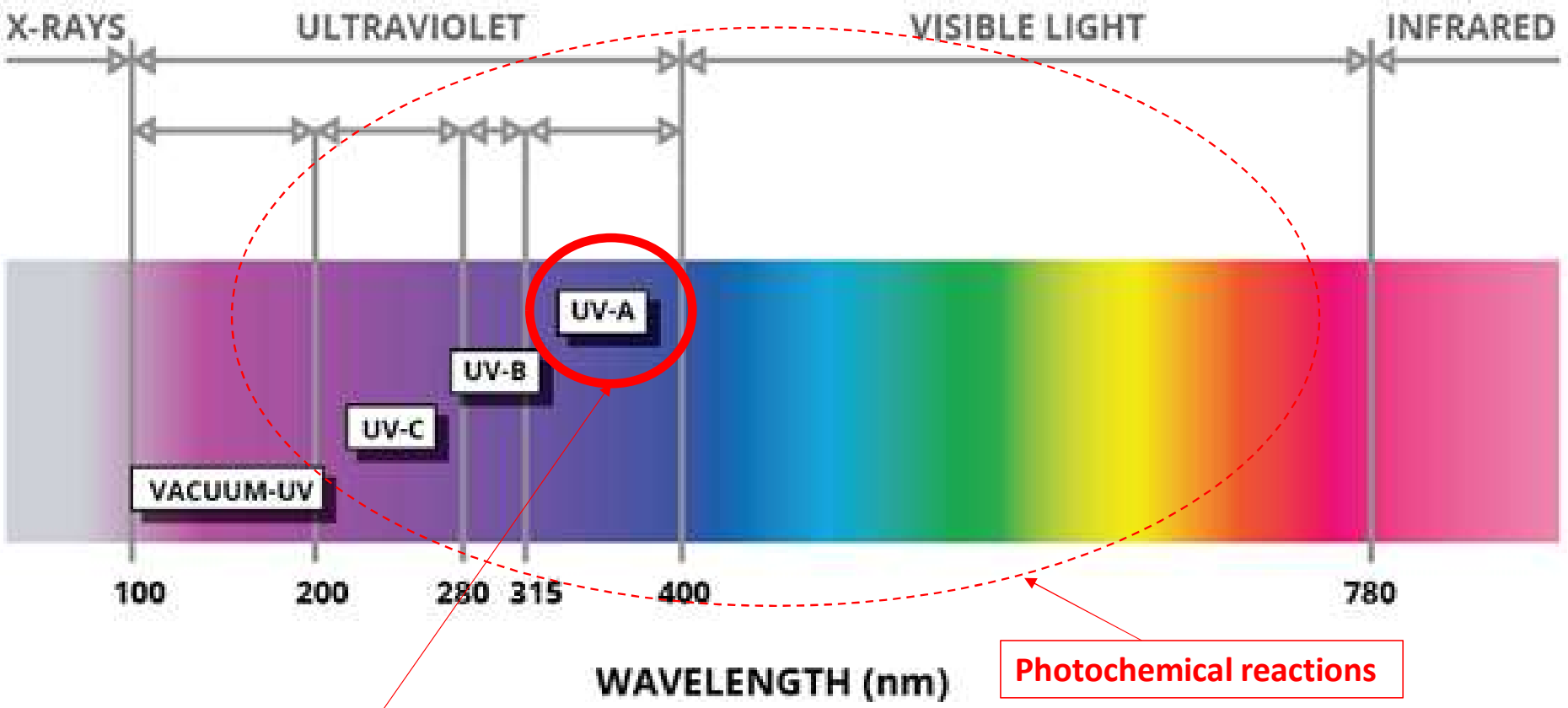
Chemistry for Good

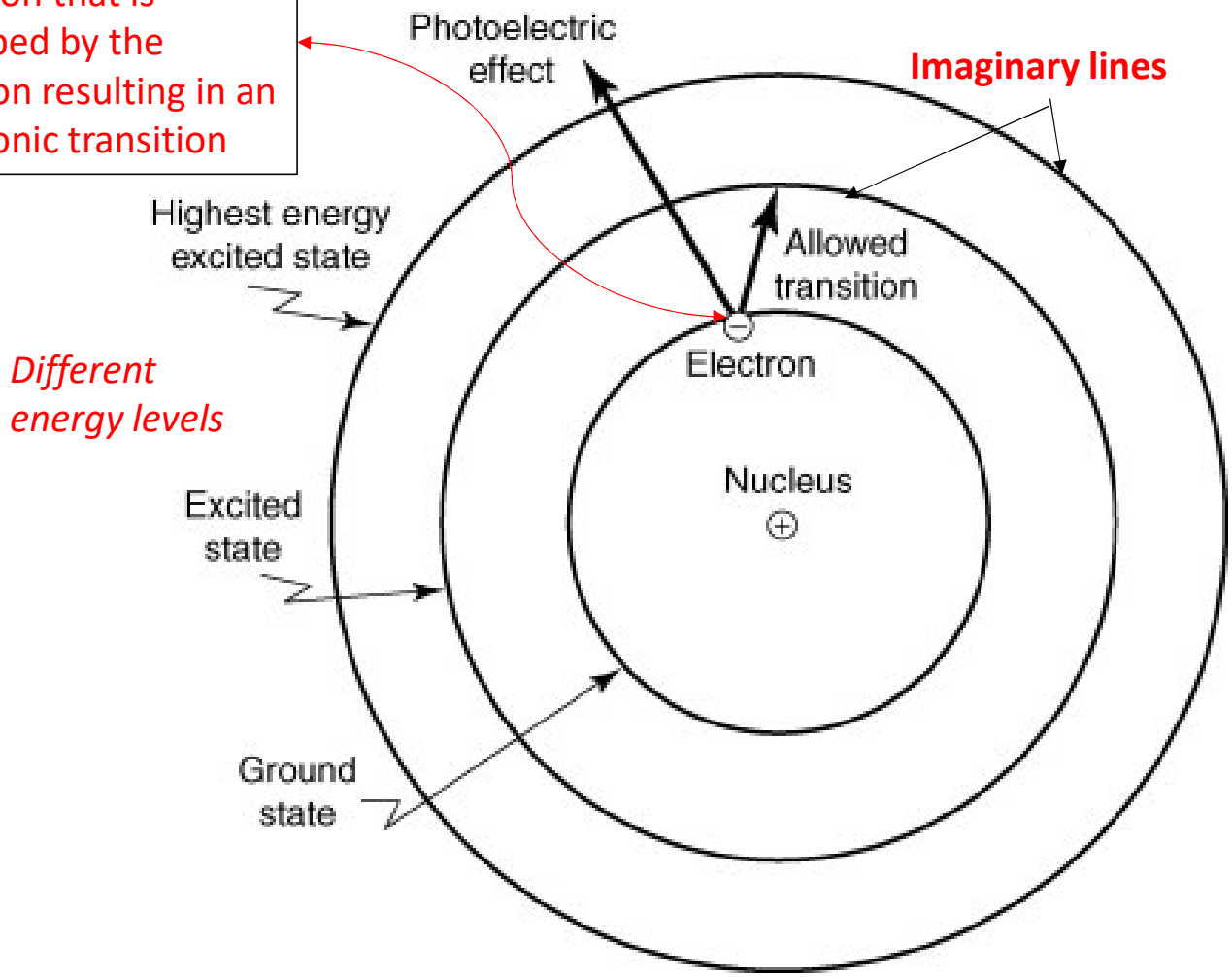
The study of chemical reactions and physical behaviour that may occur under the influence of visible and/or ultraviolet light is called **Photochemistry**

Electromagnetic Spectrum



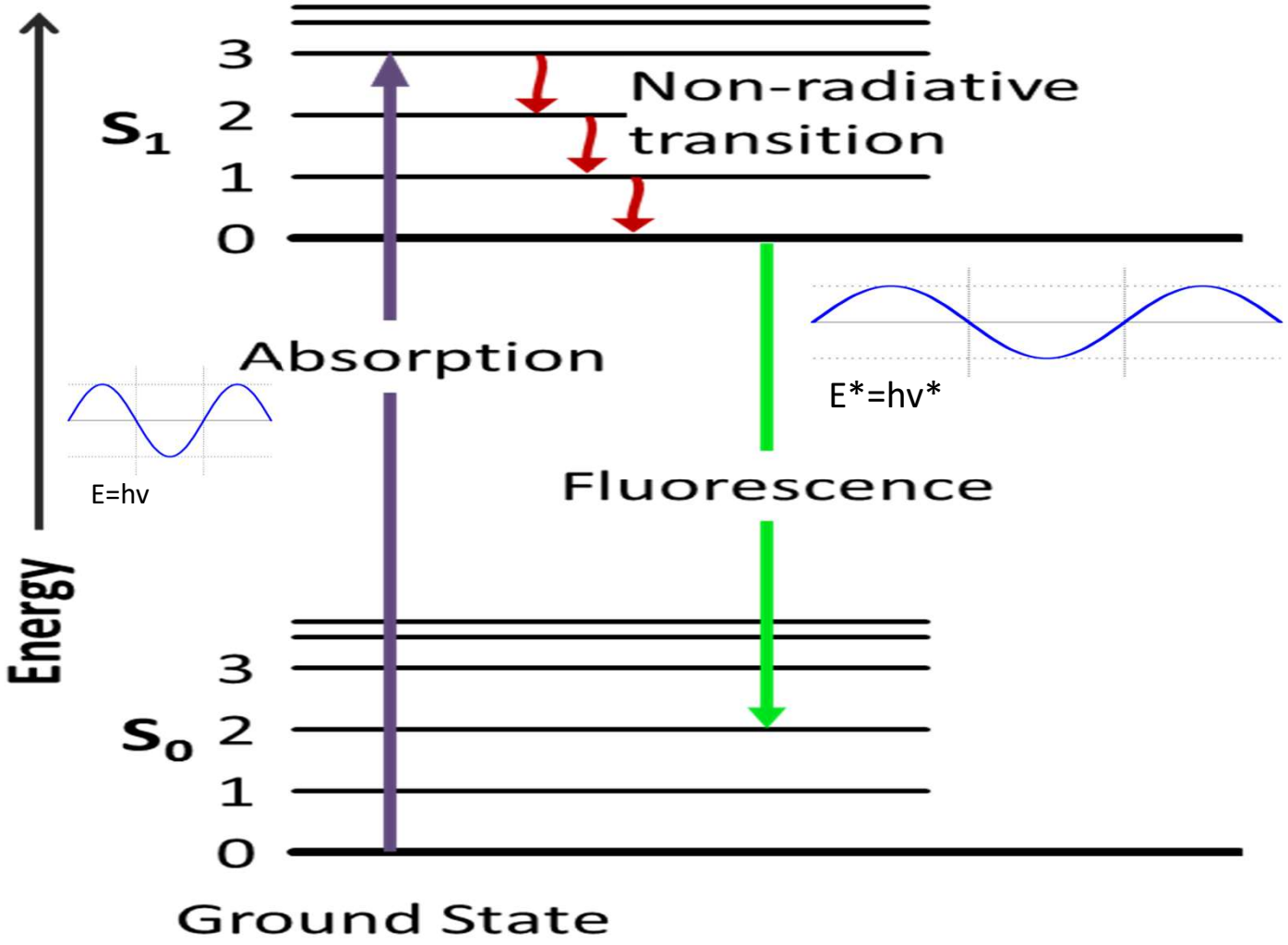
Electronic transitions

Specific frequency of radiation that is absorbed by the electron resulting in an electronic transition



Note:
Orbitals are pictorial representation of wave functions that describe the probability of a electron's quantum state as a function of position, time, momentum, and spin.

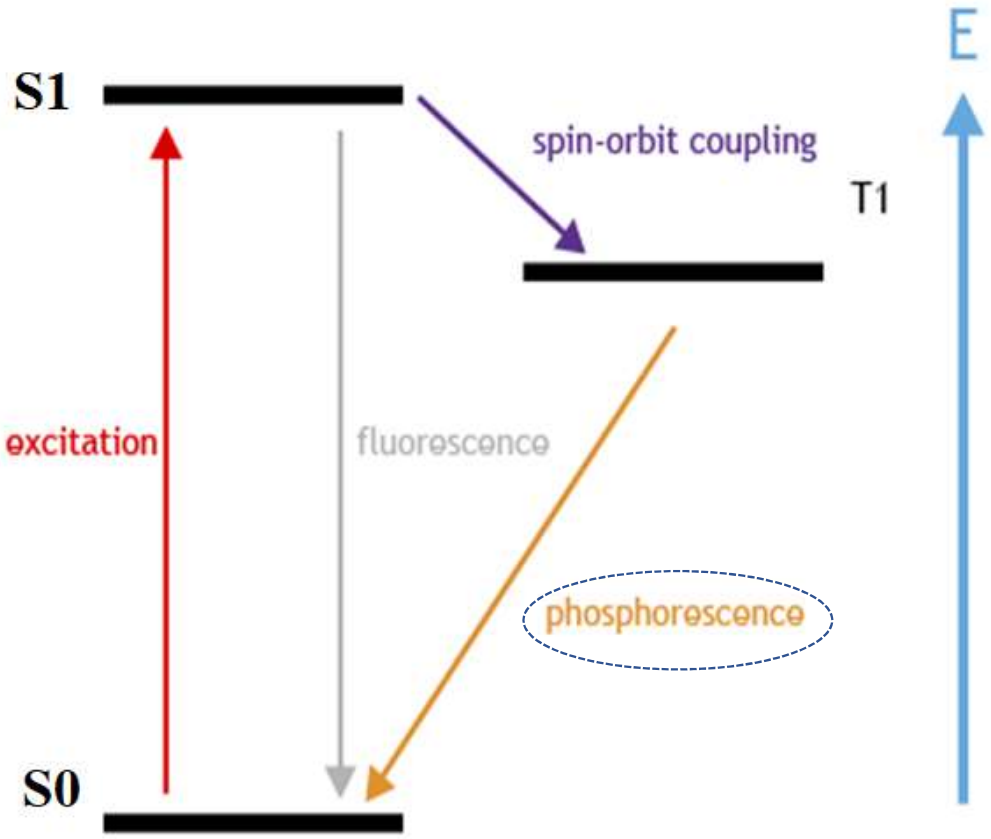
Fluorescence



After an electron absorbs a high-energy photon,
E=hv the system is excited electronically and vibrationally.

The system relaxes vibrationally, and eventually fluoresces at a longer wavelength E*=hv*.

Phosphorescence



Examples of Phosphorescence

Glow in the dark stick

signage

Amount of Time for Interactions

Process	Transition	Timescale (sec)
Light Absorption (Excitation)	$S_0 \rightarrow S_n$	10^{-15} (instantaneous)
Internal Conversion	$S_n \rightarrow S_1$	10^{-14} to 10^{-11}
Vibrational Relaxation	$S_n^* \rightarrow S_n$	10^{-12} to 10^{-10}
Intersystem Crossing	$S_1 \rightarrow T_1$	10^{-11} to 10^{-6}
Fluorescence	$S_1 \rightarrow S_0$	10^{-9} to 10^{-6}
Phosphorescence*	**$T_1 \rightarrow S_0$**	**10^{-3} to 100**
Non-Radiative Decay**	$S_1 \rightarrow S_0$	10^{-7} to 10^{-5}
	$T_1 \rightarrow S_0$	10^{-3} to 100

Just for perspective:

The time the insulation spends in 1 meter UV chamber at a speed of 300m/min is 0.2 sec, and in that time there would have been at least 10^6 interactions some resulting in crosslink reactions

**The singlet to triplet (or reverse) transition involves a change in electronic state. For this reason, the lifetime of the triplet state is longer the singlet state and this allows the unpair electron to undergo chemical reactions*

*Non-radiative decay** may take place by intermolecular energy transfer to a different molecule in a process called **quenching***

Summary of the process

2nd step; Free radical generation with Carbon monoxide formation

UV radiation

Ketone e.g. Benzophenone

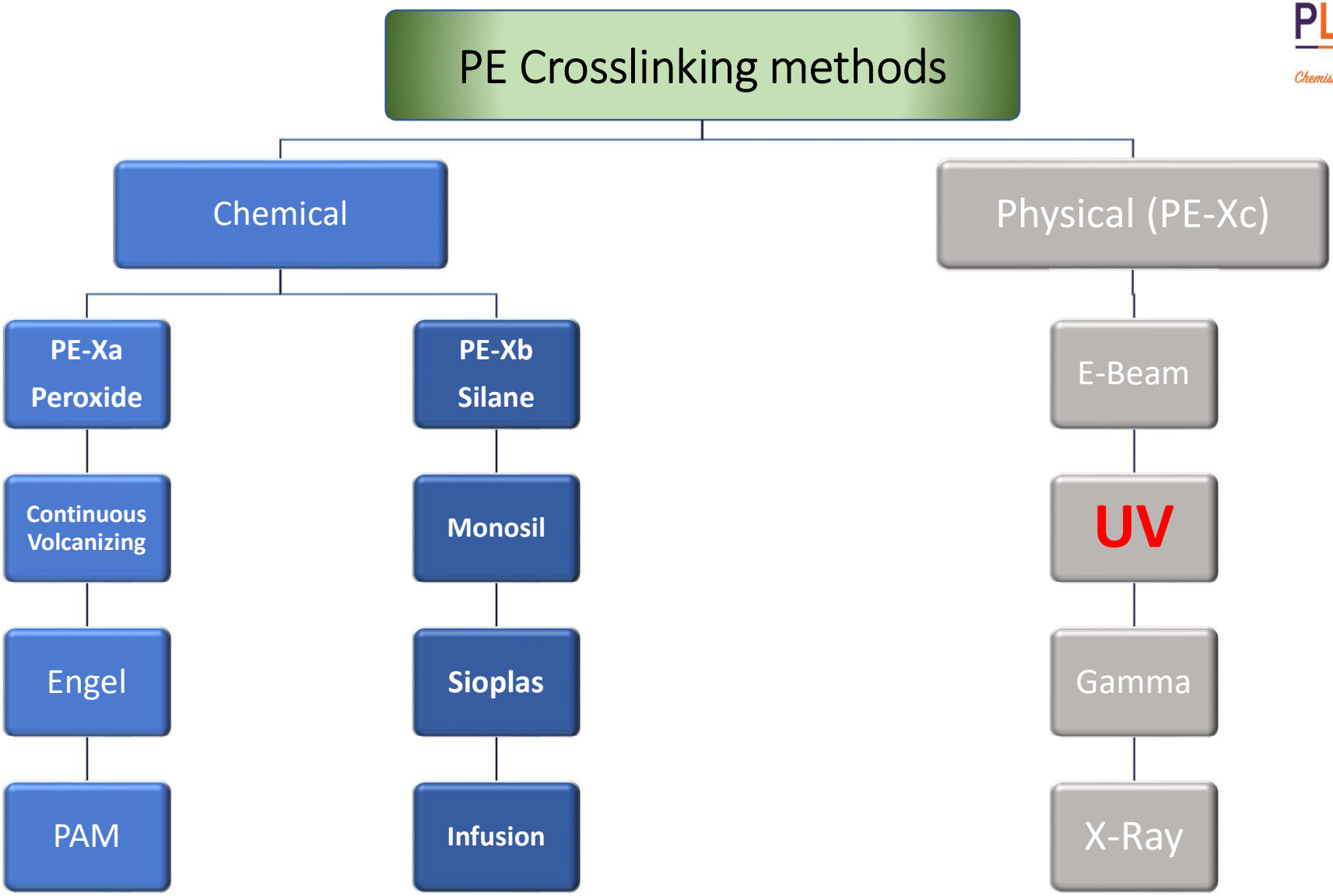
3rd step; Free radical extraction of Hydrogen atom to produce polymeric free radicals

4th step; Polymeric free radical combine to form crosslink chains

How is chemical and radiation crosslinking similar?

-Both require the formation of free radicals that extract hydrogen atoms from polymers to be crosslinked

-After hydrogen extraction, the polymeric free radicals will react with other polymers to form crosslink chains


PE Crosslinking methods
Chemical
Physical (PE-Xc)
PE-Xa
Peroxide
PE-Xb
Silane
E-Beam
Continuous
Volcanizing
Monosil
UV
Engel
Sioplas
Gamma
PAM
Infusion
X-Ray

Main UV crosslinking equipment

UV Radiator

Purpose: To provide the required amount (intensity) of the threshold frequency (UV radiation) that will promote Electrons to the anti bonding energy level (singlet & triplet) in order to produce free radicals that results in crosslinking reactions

Chiller

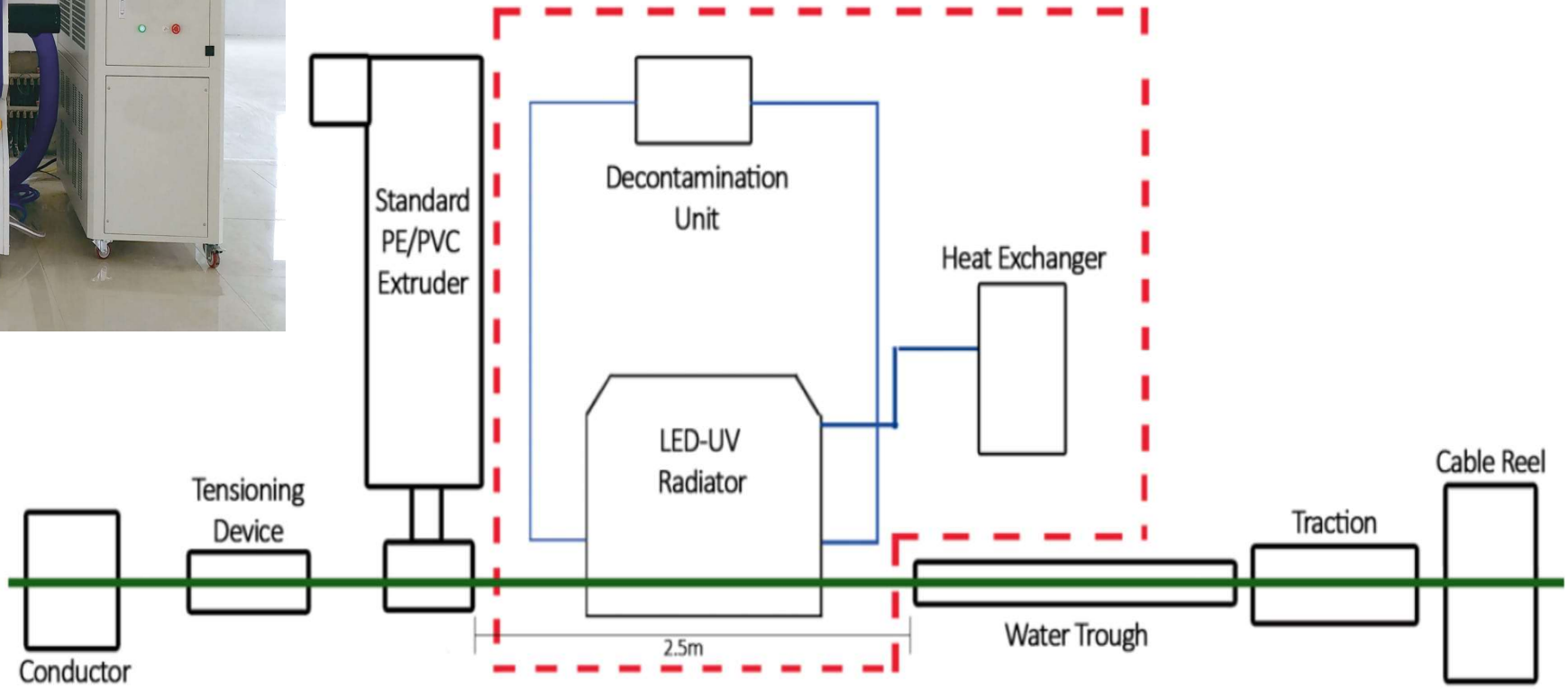
Purpose: The amount of heat generated would eventually lead to the damage of the LED lamps and the electronic components. It is imperative that the system be kept below 50° C.

Extractor

The excitation of electrons into free radicals would produce trace amount of toxic gases e.g. Ozone, Oxides of N2, Carbon Monoxide. Such gases are harmful to the operators as well as the equipment.

Equipment setup in Extruder Line

No special construction or renovation of existing layout



UV vs E-Beam - Physical method

Typical 2.5 MeV system

Cost : more than 1 Million USD

Also building cost should be added

Required Space

Land : 230 m2

Building height : 20m

Required Power

100 kW

UV Crosslinking system

Cost : 60,000 USD

Required Space : 2.5 x 2 = 5 m2 ; Required Power : 20kW

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UV crosslinked XLPE Type tests

Supplier	Plexchem Technologies Pte Ltd
Grade	UV LVXLPE 818C
Lot No	190421 MC-3
Purpose	Ageing Properties Improvement

The cable extrusion parameters listed below :

a) Cable size	: 6.0 mm² (copper)
b) Screw Speed	: 20.0 rpm
c) Line Speed	: 30 m/min
d) UV Power	: 70%
e) Melt Temperature	: 170°C - 180°C

1. Tensile strength and Elongation at Break (Before Ageing)

No. of specimens / Colors	Sample 1 / Natural	Sample 2 / Natural	Sample 3 / Natural
Tensile Strength (>12.5 N/mm²)	19.76	21.91	20.44
Elongation at Break (> 200%)	454	447	489

2. After ageing without conductor (135°C, 168 hours)

Tensile Strength (>12.5 N/mm²)	22.81	22.55	21.19
Max. Variation ± 25%	15.44	2.92	3.67
Elongation at Break (> 200%)	441	420	486
Max. Variation ± 25%	-2.86	-6.04	-0.61

3. After ageing with conductor (150°C, 168 hours)

Tensile Strength (>12.5 N/mm²)	20.01	19.71	19.93
Max. Variation ± 30%	1.27	-10.04	-2.50
Elongation at Break (> 200%)	408	419	454
Max. Variation ± 30%	-10.13	-6.26	-7.16

...Type tests

4. Hot Set and Shrinkage Test

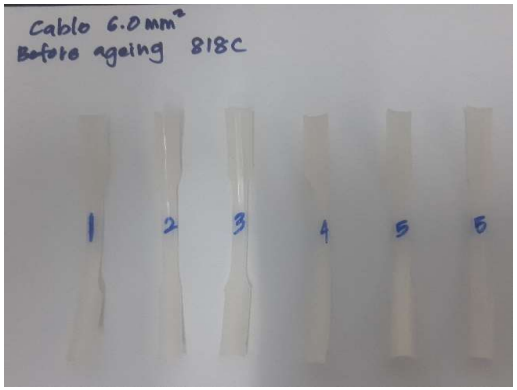
Shrinkage (< 4 %)	0	0	0
Hot set (Under Load < 175 %)	85	70	90
Permanent Set (Cooling < 15 %)	5	0	0

5. Bending Test After Ageing(150°C, 240 hours)

No of turns (6)	No Crack	No Crack	No Crack

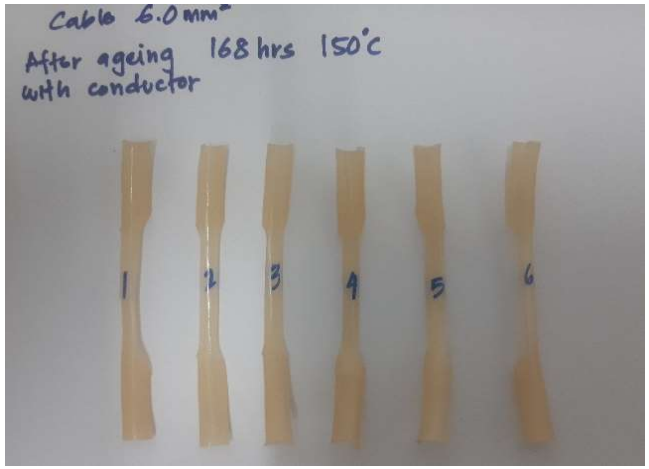
6.Oxidative Induction Time (OIT) minutes

Before Ageing	264	315	315
After ageing with conductor (150°C, 168 hours)	246	257	259



Before Ageing

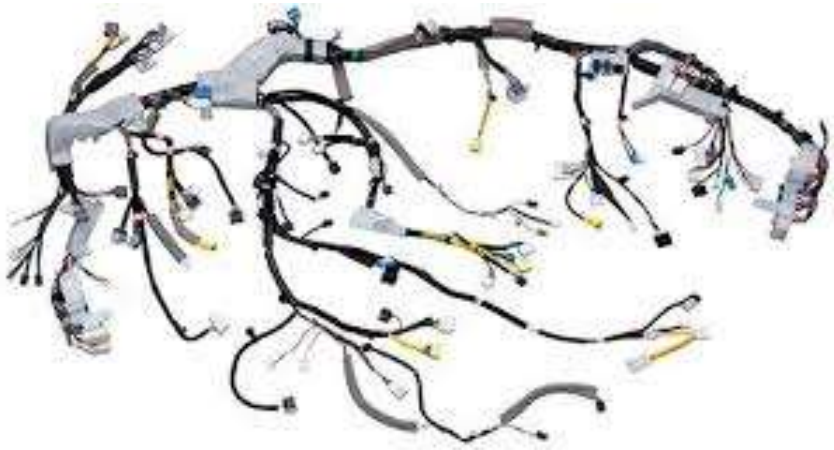
After Ageing 135°C, 168 hours without conductor



After Ageing 150°C, 168 hours with conductor

Bending Test After Ageing 150°C, 240 hours

Cross-linked Halogen Free compounds



PLEXLINK 2235X-UV

Complying EI 109 & EM 104 EN 50264-1

Grade	Plexlink 2235X-UV			
Description	Crosslinkable, halogen free, low smoke flame retardant.			
Application	Insulation and sheathing compound for cables.			
Material Designation	EN 50264-1 type EI 109 & EM 104			
Properties	Test Method	Unit	Specification	Typical Value
Density	ASTM D 792	g/cm3	-------	Approx. 1.5
Tensile Strength	IEC 811-1-1	MPa	> 10	14.0
Elongation at Break	IEC 811-1-1	%	> 150	190
HOT set test after UV curing	IEC 811-2-1			
Elongation under load %	(200'C , 15 min	%	< 100	55
Permanent Elongation after cooling	20 N/cm2)	%	< 25	5
After Ageing at 135°C, 168 hrs				
Tensile Strength	IEC 811-1-2	MPa	> 10	14.0
Max. Variation		%	+/- 30	+ 11
Elongation at Break	IEC 811-1-2	%	> 150	170
Max. variation		%	+/- 30	- 6
After Ageing at 120°C, 240 hrs				
Tensile Strength	IEC 811-1-2	MPa	> 10	14.5
Max. Variation		%	+/- 30	+ 16.5
Elongation at Break	IEC 811-1-2	%	> 125	165
Max. variation		%	+/- 30	- 8
Ozone resistance test Method A 250-300 x10-4 , 25'C , 24 h Method B 20+/-50 x10-6 , 40'C , 72 h	EN 50305	----------	No crack No crack	All PASS
Water Absorption Test, after 70°C, 168 hrs	IEC 60811-1-3			
Max. Weight increase mg/cm2		Mg/cm2	15	6
Mineral Oil resistance with IRM 902	IEC 60811-2-1			
Tensile Strength , Max variation		%	+/- 30	15
Elongation at break , Max variation	100'C , 72h	%	+/- 40	20
Fuel resistance with IRM 903	IEC 60811-2-1			
Tensile Strength , Max variation		%	+/- 30	12
Elongation at break , Max variation	70'C , 168h	%	+/- 40	26

Bending test at low temperature	IEC 60811-1-4	—	No cracks	PASSED
Elongation at low temperature , Min	-40 'C	%	30%	>100 %
Pressure test at high temperature (100°C , 4 h)	IEC 811-3-1	%	< 50	23
Flame Retardant (Vertical Burning)	IEC 60332-1			
Distance between:				
Lower edge of top clamp & onset of charred portion		mm	> 50	200
Bunched Cable test	IEC 60332-3-24	mm	≥ 2.5 m	PASS
Oxygen Index	ASTM D 2863	%	> 30	32
Smoke Density	ASTM D2843	Dm	< 40	20
ACID and Alkaline resistance , 23'C , 168 h	EN 60811-2-1		+/-30	12
Tensile strength max variation		%	+/-100	27
Elongation at break variation , max		%		
Toxicity Index (ICT) max	EN 50305	-------	3	1
Acid Gas Emission	IEC 60754-2			
- pH	EN 50267-2-2	---	> 4.3	5.1
- conductivity		µS/mm	< 10	1.0
Amount of Halogen gas ; HCL , HBr	EN 50267-2-1		<0.5	0.2
HF	EN 60684-2		<0.1	0.08

XL-HFFR as PVC substitute for internal Wiring

BS EN 50363-5

BRITISH STANDARD

BS EN
50363-5:2005

Insulating, sheathing and covering materials for low voltage energy cables

Part 5: Halogen-free, cross-linked insulating compounds

BS EN 50525-2-3

BS EN 50525-2-31:2011

BSI Standards Publication

Electric cables — Low voltage energy cables of rated voltages up to and including 450/750 V (U_0/U)

Part 2-31: Cables for general applications — Single core non-sheathed cables with thermoplastic PVC insulation

BS EN 50525-3-41

BS EN 50525-3-41:2011

BSI Standards Publication

Electric cables — Low voltage energy cables of rated voltages up to and including 450/750 V (U_0/U)

Part 3-41: Cables with special fire performance — Single core non-sheathed cables with halogen-free crosslinked insulation, and low emission of smoke

Test results – EI5 grade

Ref No	Test	Unit	Test method described in IEC 60811		Requirement	Results
			Section	Clause	**EI5**	
1	**Mechanical Properties**					
1.1	Properties before aging		1-1	9.1		
1.1.1	Values to be obtained for the **tensile strength**					
	median value , min	N/mm2			10	**20**
1.1.2	Values to be obtained for the **Elongation at break**					
	median value , min	%			125	**256**
1.2	Properties after aging in air oven		1-2	8.1.3.1		
1.2.1	**Aging condition**					
	Temperature	C			135+/-2	
	duration of temerature	h			7x24	
1.2.2	Values to be obtained for the tensile strength					
	median value , min	N/mm2			---	
	variation , max	%			+/- 30	**4.3**
1.2.3	Values to be obtained for the Elongation at break					
	median value , min	%			+/- 30	**11.6**
	variation , max	%				
2	**Hot Set Test**					
2.1	Condition of treatment		2-1	9		
	Temperature	C			200 +/- 3	
	Time under load	min			15	
	mechanical stress	N/cm2			20	
2.2	Test requirements					
	max elongationunder load	%			100	**65**
	max elongationunder after loading	%			25	**4**
3	**Pressure test at high temperature**					
3.1	Test condition		3-1	8.1		
	Forced exerted by the blade	N	3-1	8.1.4		
	duration of heating under load	h	3-1	8.1.5		
	Temperature	C			100 +/- 2	
3.2	Results to be obtained					
	median of the depth of indentation	%			50	**22**

4	**Bending at low temperature**					
4.1	Test Conditions:		1-4	8.1		
	Temperature	C			-15 +/-2	
	period of application of low temperature	h	1-4	8.1.4		
4.2	Results to be obtained					Passed
5	**Elongation test at low temperature**					
5.1	Test Conditions:		1-4	8.3		
	Temperature	C			-15 +/-2	
	period of application of low temperature	h	1-4	8.3.4		
5.2	Results to be obtained					
	Elongation without break , min	%			30	110
6	**Ozone resistance test**					
6.1	Method A		2-1	8		
	Test temperature	C			25 +-2	
	Test duration	h			24	
	Ozone concentration (by volume)	%			250 to 300 E-4	
6.2	Method B		EN 50396	8.1.3		
	Test temperature	C			40 +/- 2	
	Test duration	h			72	
	Ozone concentration (by volume)	%			200 +/- 50 E-6	
6.3	Results to be obtained					Passed
7	Assessment of halogens					
7.1	**PH , min**		EN 50267-2-2		4.3	6.2
7.2	**Conductivity, max**	microS/mm	EN 50267-2-2		10	less 0.5
7.3	Amound of halogen acid gas					
	HCl and HBr , max	%	EN 50267-2-1		0.5	Passed
	HF, max	%	EN 60684-2		0.1	Passed
8	**Oxygen Index**	%	Additional	test		29

An Alternative to PVC Insulation ?

PLEXCHEM Technologies

- An inexpensive crosslinkable compound
- Would be 90'C rated
- Halogen free
- Low smoke
- Low Acidity
- Colourable
- Speed up to 300m/min
- Not hazardous in manufacture & disposal
- No plasticisers

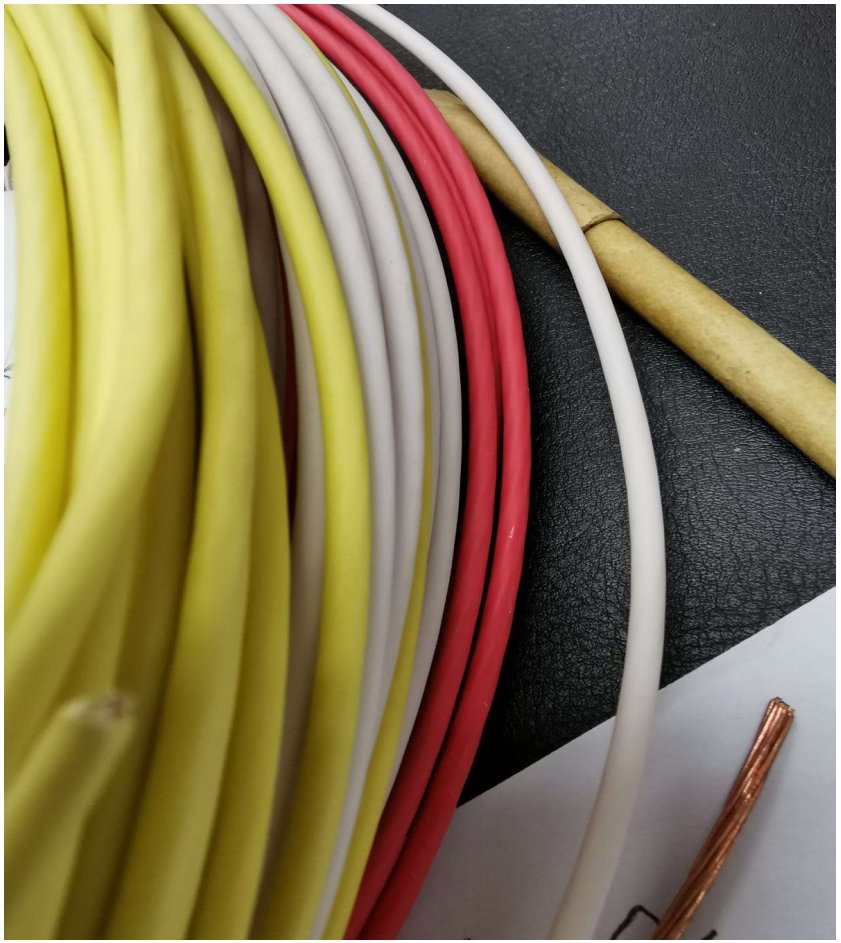
FR-XLPE

Material	USD /kg	Kg	USD
LLDPE	1.25	100	125
CaCO3	0.2	60	12
ATH	1	5	5
UV initiator	8	2.4	19.2
Silicon Oil	5	0.2	1
PE WAX	3	0.2	0.6
Anti Oxidant	8	0.1	0.8
MAH	4	4	16
Total material cost		171.9	179.6
			$ 1,044.79
Compounding			$ 200
Cost (per tone)			$ 1,244.79

Advantage of FR-XL in rating factor

Rating of 90'C insulation is 26% higher than 70'C insulation in different temperature

	Derating factor of current rating		
Ambient Temperature	Rated Temp 70'C	Rated Temp 90'C	Extra Rating
30	1.00	1.00	
35	0.94	0.96	2%
40	0.87	0.91	5%
45	0.79	0.87	10%
50	0.71	0.82	15%
55	0.61	0.76	25%
60	0.50	0.71	42%
65	0.35	0.65	86%



Cost Effectiveness

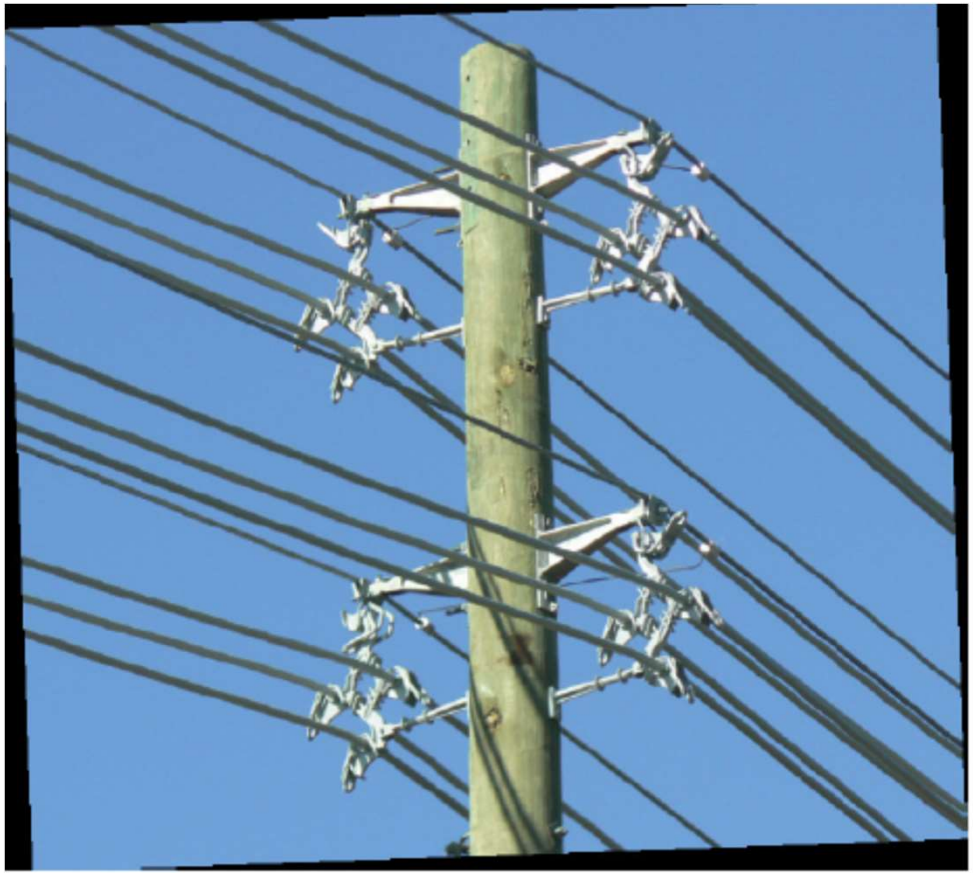
Wire Size	Conductor			NYA	NHX	PVC	FR-XL	NYA	NHX	Extra Rating
	No.	Wire Día	Diameter	Insulation Thickness		Price 1kM insulation USD		Current Rating Air (A)		
1.5	30	0.25	1.59	0.7	0.7	13.1	12.6	14.5	19	31%
2.5	50	0.25	2.05	0.8	0.8	18.7	17.9	19.5	26	33%
4	56	0.3	2.60	0.8	0.8	22.3	21.4	26	35	35%
6	84	0.3	3.19	0.8	0.8	26.2	25.1	34	45	32%
10	80	0.4	4.15	1.0	1.0	42.2	40.5	46	61	33%
16	126	0.4	5.21	1.0	1.0	50.9	48.8	61	81	33%
25	196	0.4	6.50	1.2	1.2	75.7	72.7	80	106	33%
35	276	0.4	7.71	1.2	1.2	87.6	84.1	99	131	32%
50	396	0.4	9.23	1.4	1.4	122.0	117.1	119	158	33%
70	360	0.5	11.00	1.4	1.4	142.3	136.6	151	200	32%
95	475	0.5	12.64	1.6	1.6	186.7	179.3	182	241	32%
NYA	EN 50525-2-31 (H07V-K)									33%
NHX	EN 50525-3-41 (H07Z-K)									

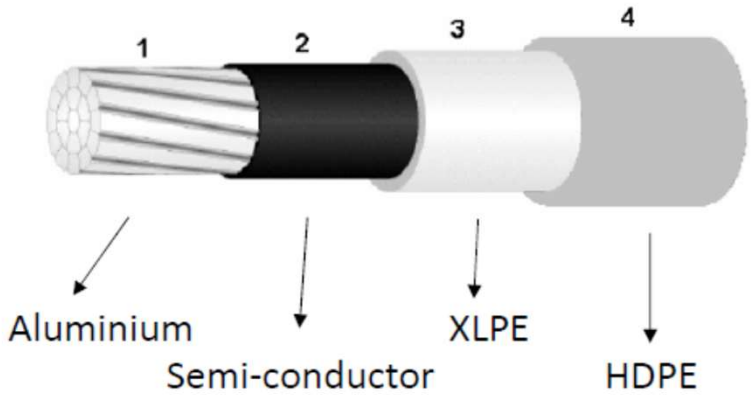
Cost of FR-XL is almost the same as PVC , including many safety advantages

In case copper price raise so much in the market , it preserves the higher current carrying capacity

Using FR-XL provides vantage point for manufacturers committed to quality against ones using rubbish PVC in the market.

MV Spaced Cables





Test results of Spaced cable production

PLEXCHEM Technologies

PRODUCT DESCRIPTION :

336.4 MCM 34.5KV ACSR COVERED CONDUCTOR TREEWIRE

REEL NO. 20160 - 10742 (693meters)	UV LED @ 70% power	Compound: PLEXLINK 271 MV compound		REFERENCE SPECIFICATIONS : MERALCO SPECS	
SUMMARY OF RESULTS					
Properties	**STANDARD**	**10 mpm**	**15 mpm**	**20 mpm**	**Remarks**
1. XLPE Insulation					
Wall Thickness, mm	2.858 min.	3.47 - 4.65	3.51 - 4.61	3.42 - 4.73	Complied
	3.175 min. ave.	4.06	4.06	4.08	Complied
Tensile Strength, MPa	12.5 min.	15.09 / 14.95	14.63 / 15.10	15.64 / 13.54	Complied
Elongation, %	250 min.	538.31% / 530.15%	552.85% / 524.44%	518.97% / 470.14%	Complied
Hot Creep Test, 150±2°C for 15mins.					
Maximum Elongation under Load	175% max.	100% (outer portion)	90% (outer portion)	100% (outer portion)	Complied
		100% (inner portion)	100% (inner portion)	110% (inner portion)	
Hot Set, 150±2°C for 5mins.	10% max.	0% (outer portion)	0% (outer portion)	0% (outer portion)	Complied
		0% (inner portion)	0% (inner portion)	0% (inner portion)	
2. Electrical Properties					
AC Voltage Test	Withstand 35 kv for 1 min.	Withstand 35 kv for 1 min.			Complied

Test results of Spaced cable production

PLEXCHEM Technologies

PRODUCT DESCRIPTION : 3/0 AWG 34.5KV ACSR COVERED CONDUCTOR TREEWIRE			
REEL NO. 20160 - 10744	QTY 527	REFERENCE SPECIFICATIONS : MERALCO SPECS	
SUMMARY OF RESULTS			
Properties	**STANDARD**	**ACTUAL**	**Remarks**
2. XLPE Insulation			
Wall Thickness, mm	2.858 min.	3.45	Complied
	3.175 min. ave.	3.66	Complied
Tensile Strength, MPa	12.5 min.	12.69 / 13.94 / 14.02	Complied
Elongation, %	250 min.	426.35% / 418.43% / 466.58%	Complied
Hot Creep Test, 150±2°C for 15mins.			
Maximum Elongation under Load	175% max.	130	Complied
Hot Set, 150±2°C for 5mins.	10% max.	0	Complied
5. Electrical Properties			
Rated Voltage	34.5 kV	34.5 kV	Complied
AC Voltage Test	Withstand 35 kv for 1 min.	Withstand	Complied

Quality of surface - comparisons

Summary of Advantages

- **Low cost of equipment** (About USD60K)
- **Ease of processing** and cleaning
- Inexpensive cost of compound with **long shelf life**
- Low energy consumption. **Only 20KW**
- **No need** for extensive **modification** of production facility
- Extrusion of PE/HFFR thermoplastic with **no pre-crosslinking** issue
- High draw down = **reduced material consumption**
- **Post production** operations could be done **immediately**
- Processing **XL-HFFR** cables

Next Developments

- **UV protected cables (2.5% carbon black content).**

  High concentration of carbon black; blocks UV penetration and requires a special formulation.

Difficult for co-extrusion, if outer semi con is required. Must be extruded in tandem

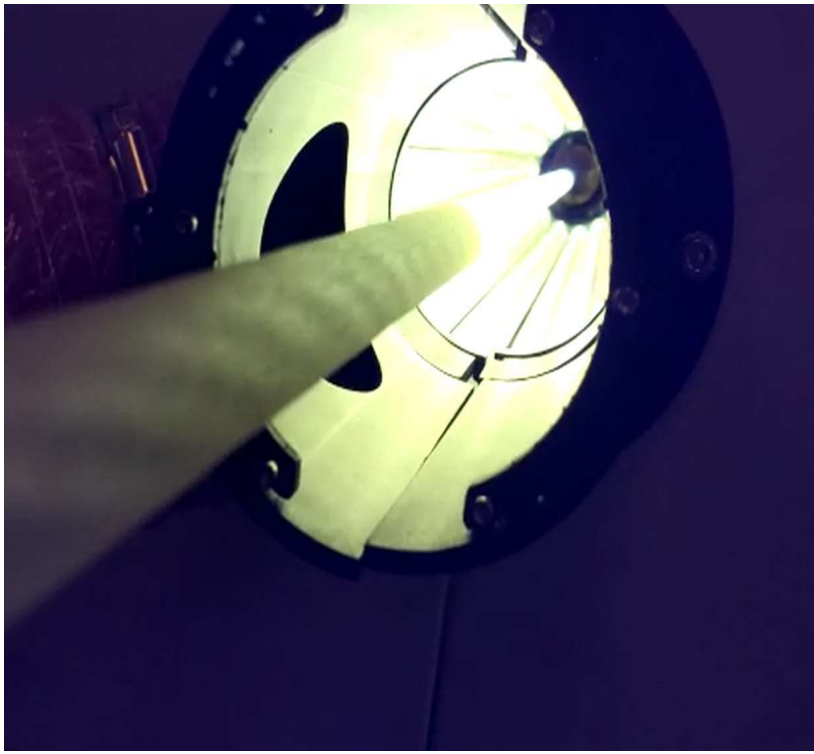
- **Speed adaptation of equipment especially for thin insulation. Our current systems allows for speeds up to 350m/min**
- **Limitation on high insulation thickness (more than 6 mm)**
- **Side reactions of photo initiators forms organic by products which are flammable. Reduces effectiveness in HFFR formulations.**
- **High degree of Crosslink (typical hot set is <40%) reduces elongation values.**
- **Special colours masterbatches have to be used.**

Safety Requirements

- **Irradiation**. Never look into the beam of a high power LED; the lights very high intensity damage your eyes.
- **Ozone generation**: Short wavelength (,240nm) light may generate ozone from oxygen (however our wavelength is between 350-400nm) and our unit comes with a well ventilated fume hood.
- **Lamps**: Most lamps operate at high temperature and at high vapour pressure. Never move or touch lamps during operation.

PLEXCHEM Technologies

Thank you for your attention



The good news under quantum rules, if you understood nothing you have understood everything

www.Plexchem.com.sg