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APPENDICES

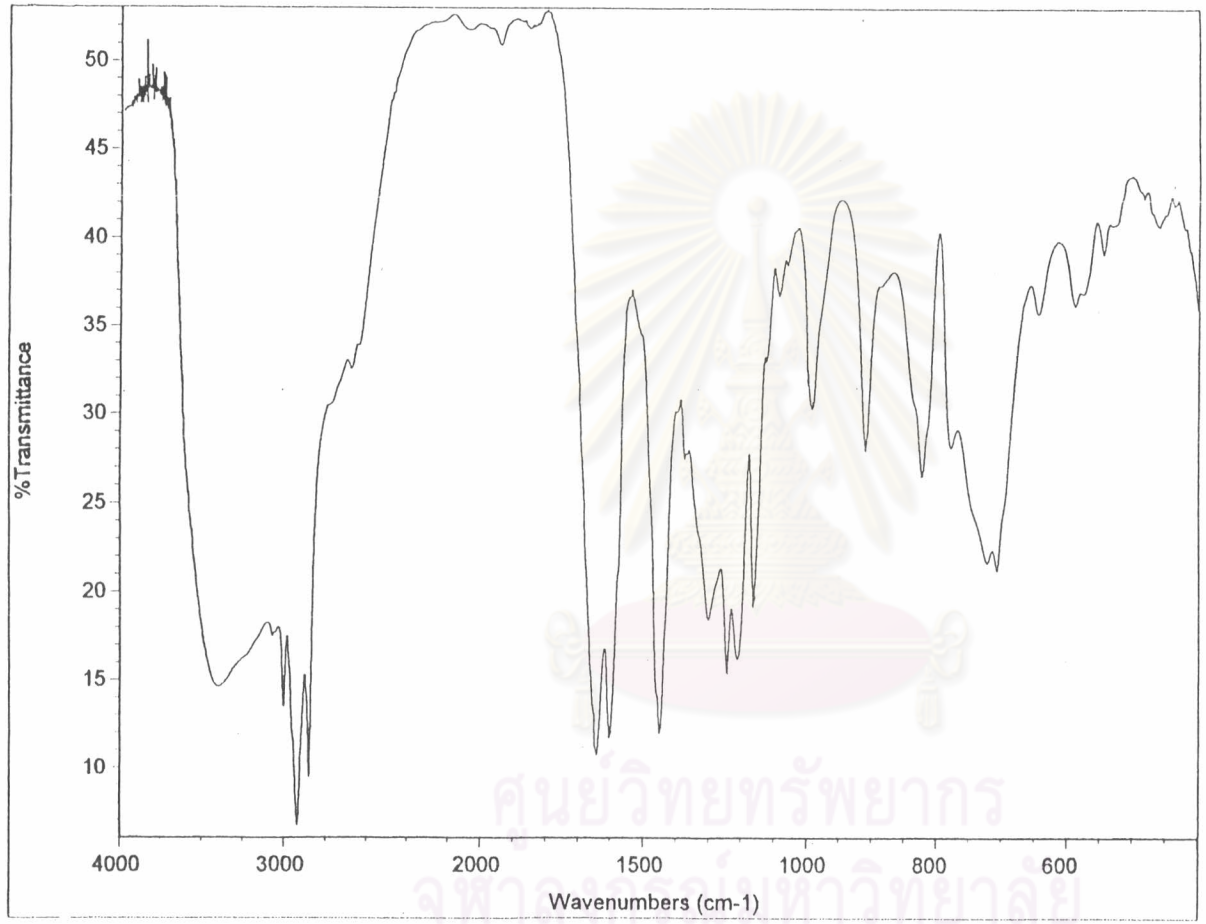


Figure A.1 IR spectrum of natural CNSL.

APPENDIX A

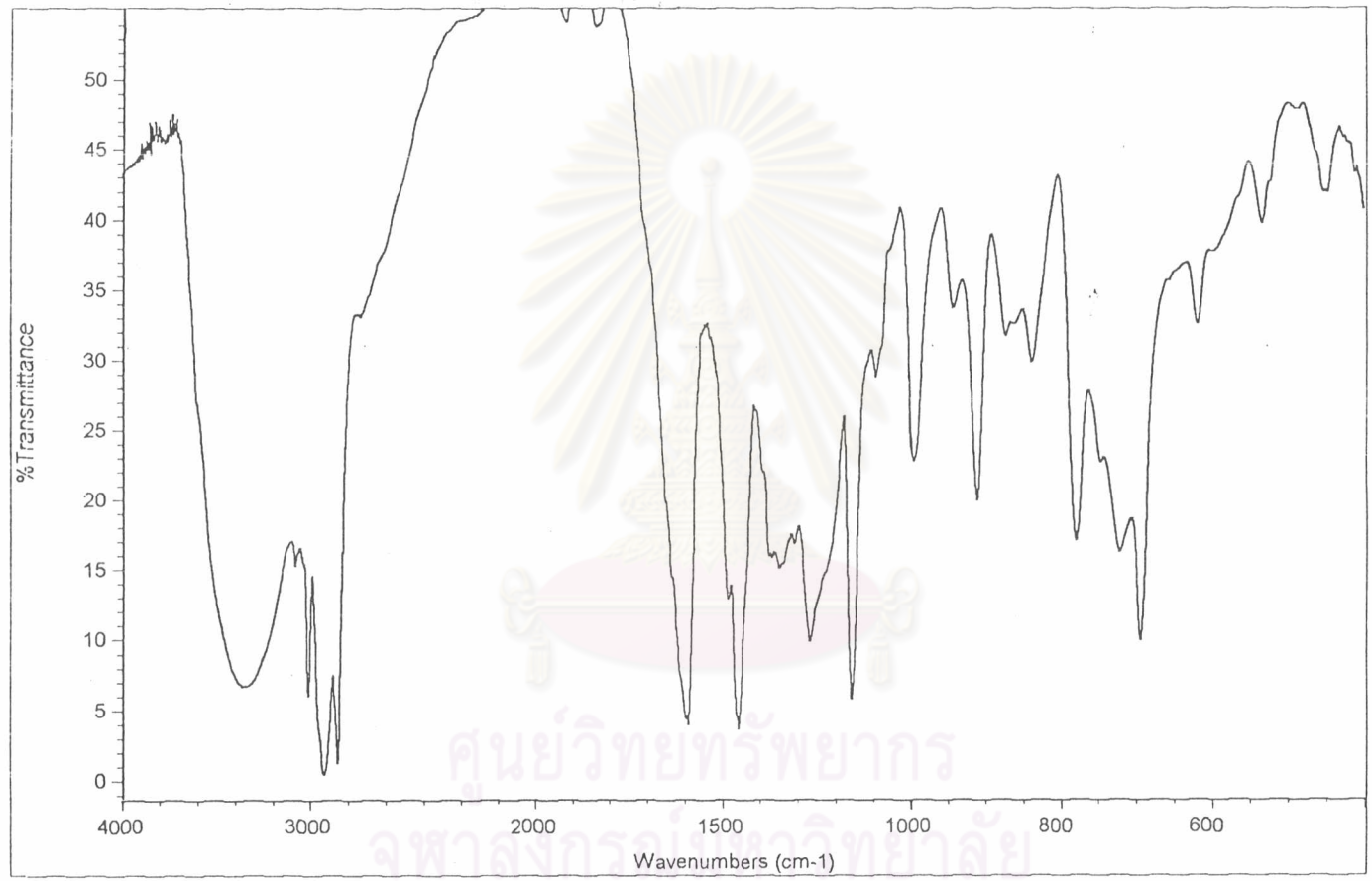


Figure A.2 IR spectrum of decarboxylated CNSL.

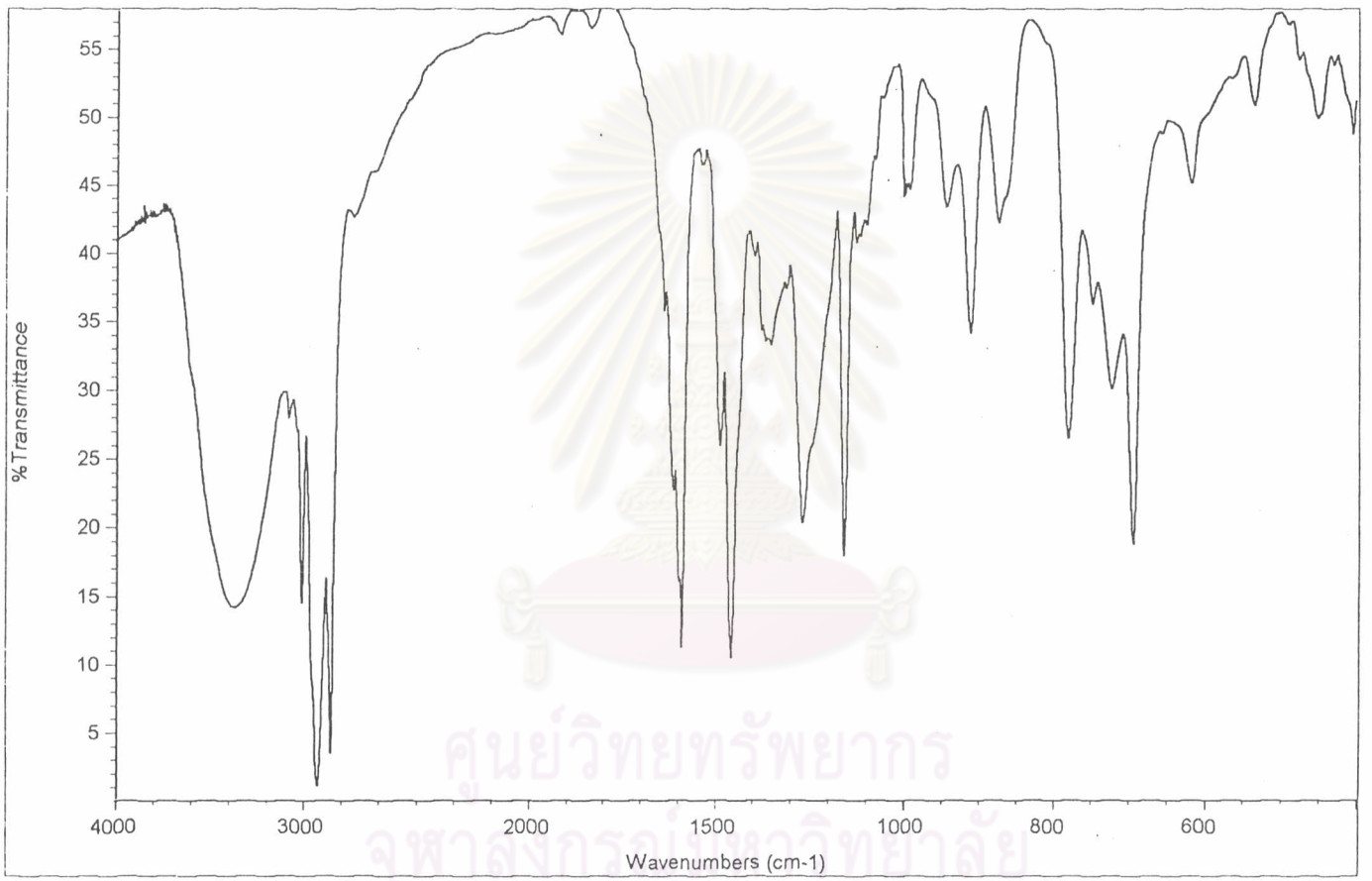


Figure A.3 IR spectrum of cardanol.

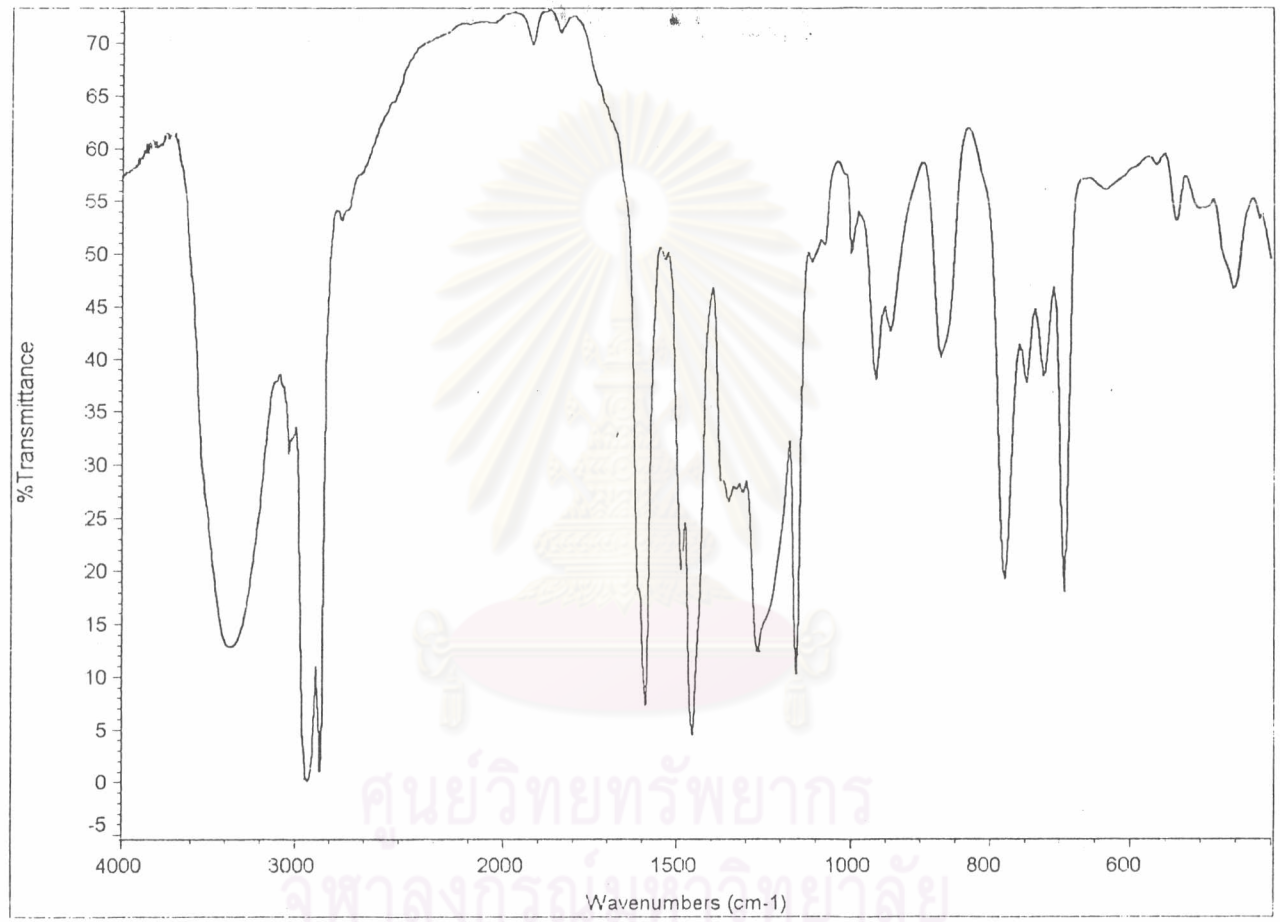


Figure A.4 IR spectrum of CPS.

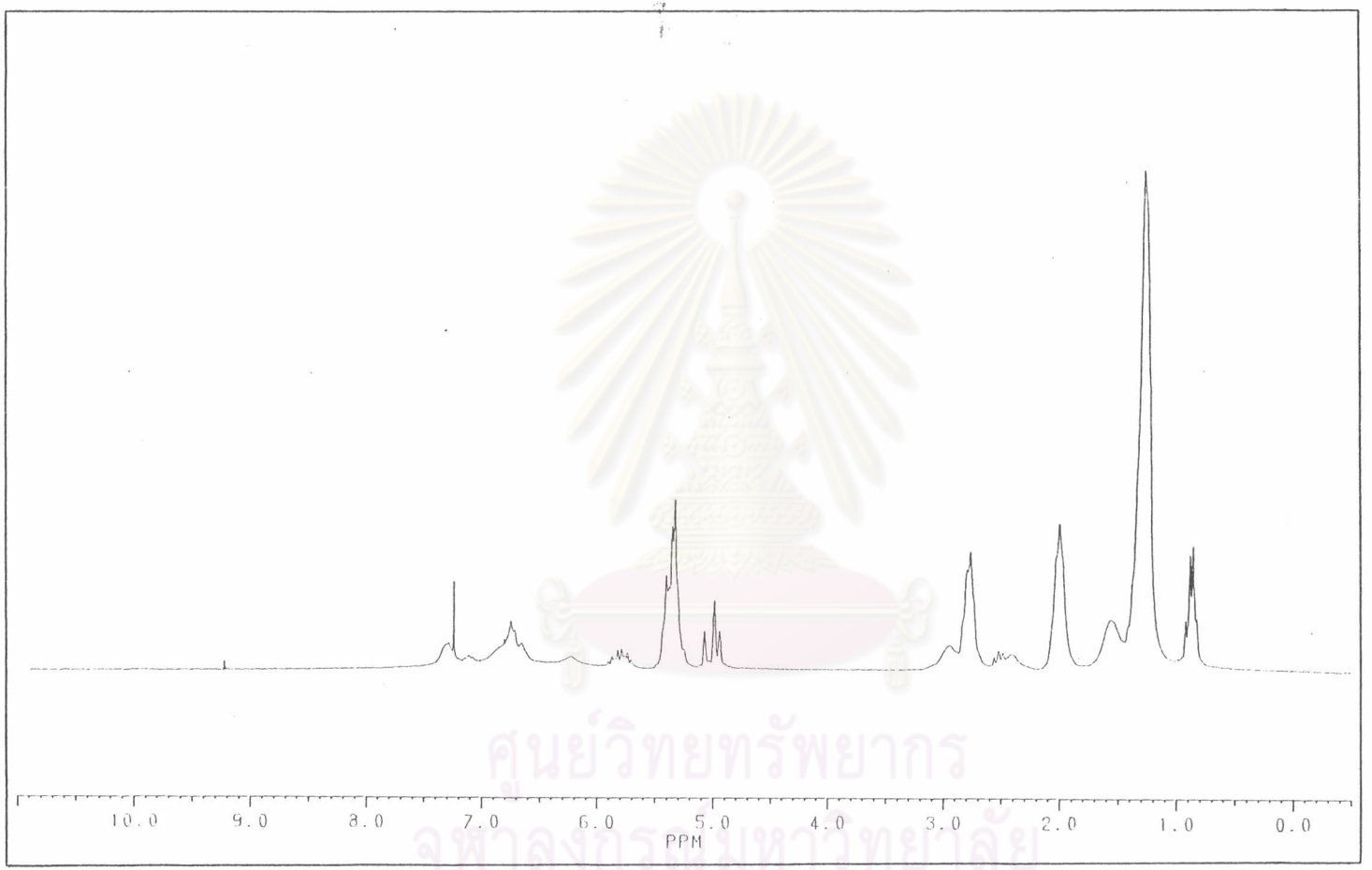


Figure A.5 ^{1}H NMR spectrum of natural CNSL.

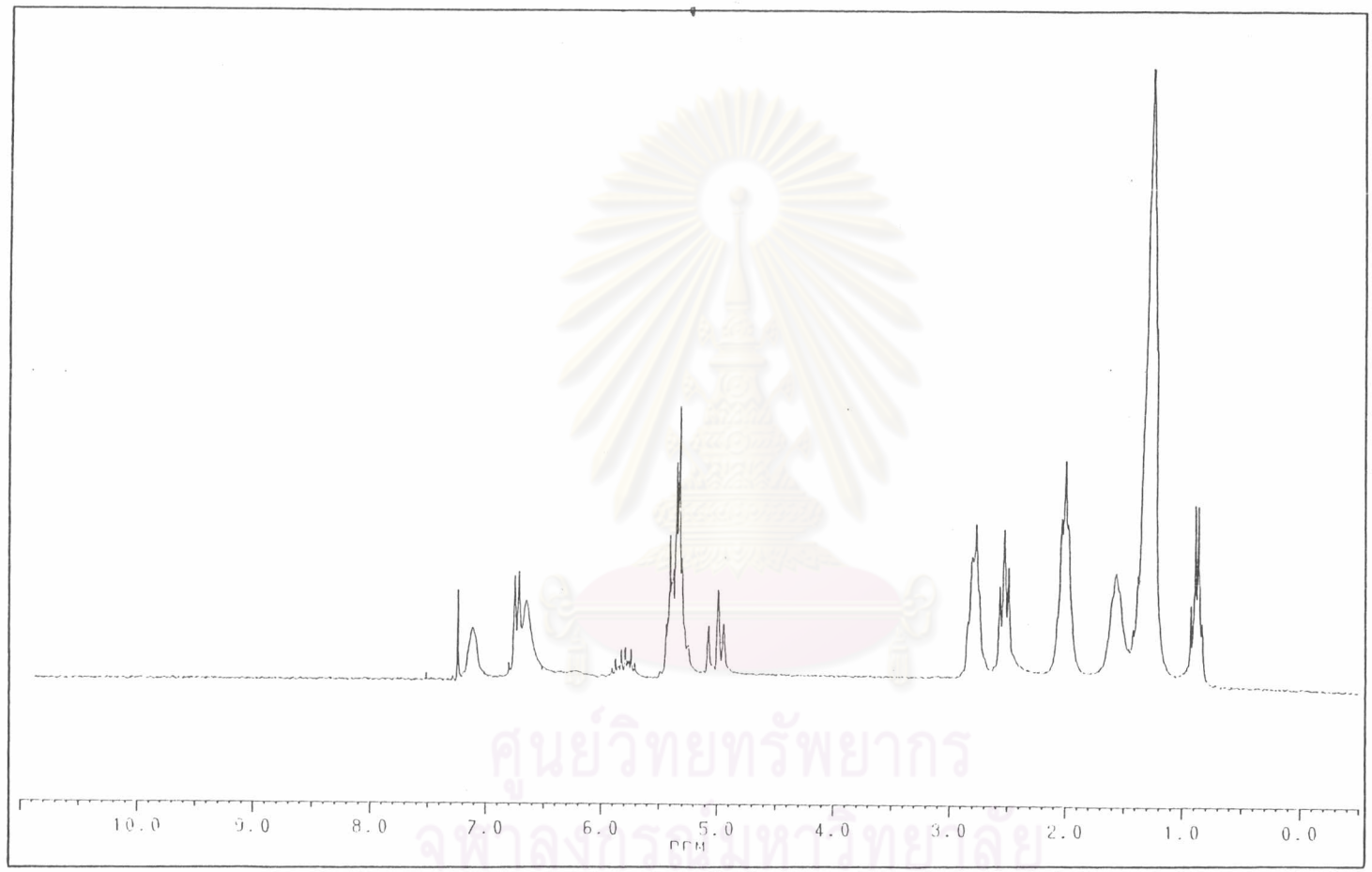


Figure A.6 ^{1}H NMR spectrum of decarboxylated CNSL.

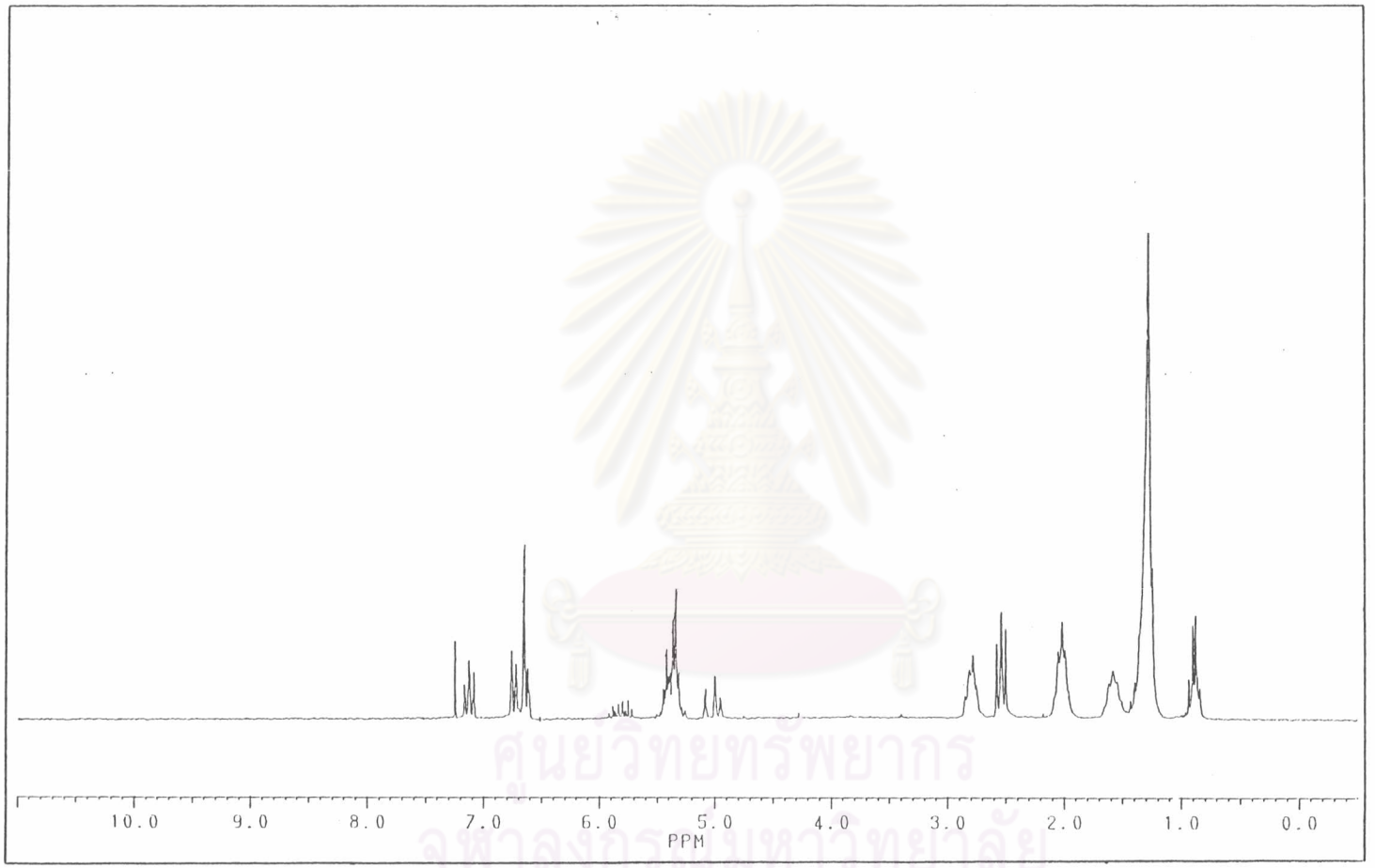


Figure A.7 ^{1}H NMR spectrum of cardanol.

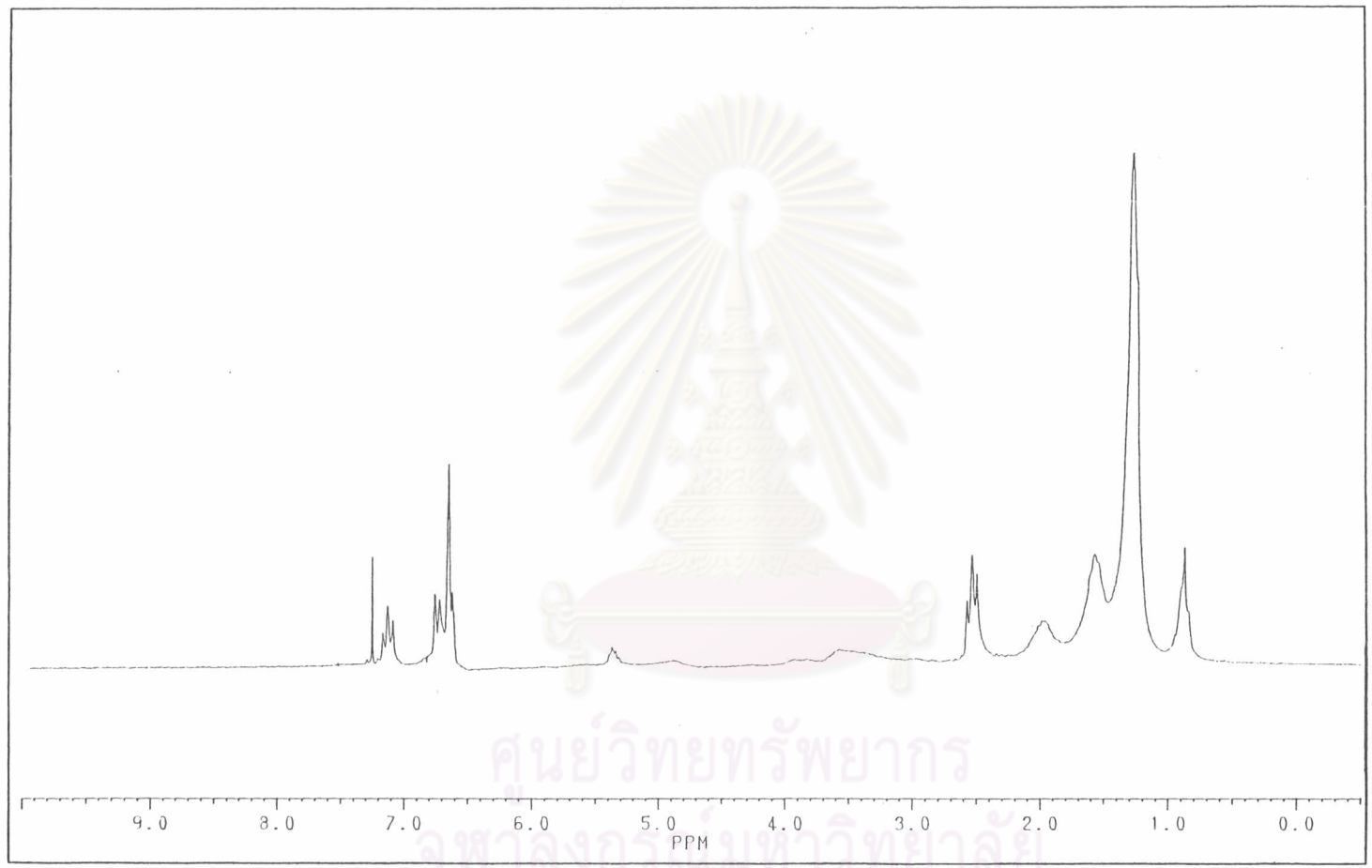


Figure A.8 ^{1}H NMR spectrum of CPS.

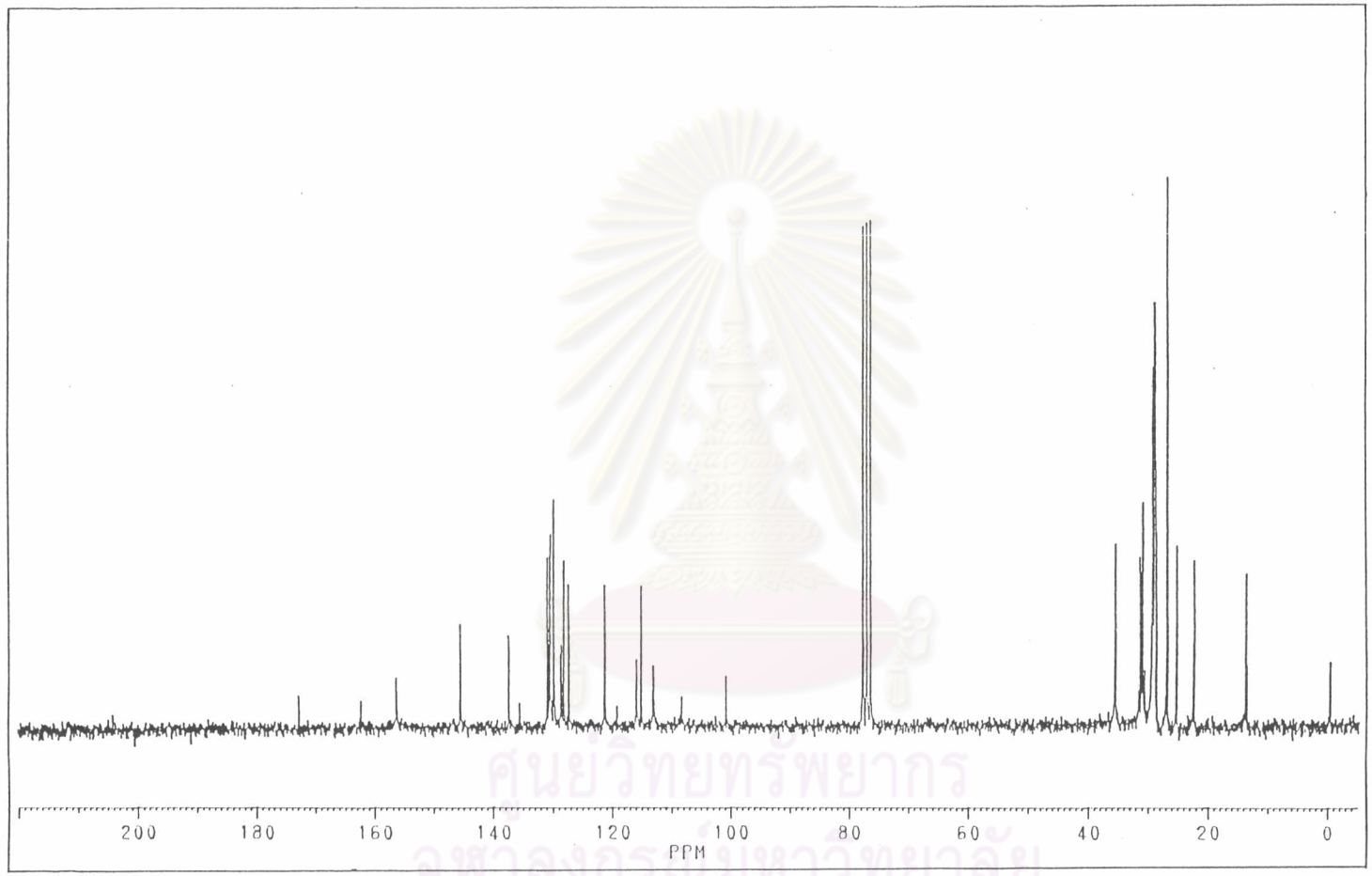


Figure A.9 ^{13}C NMR spectrum of natural CNSL.

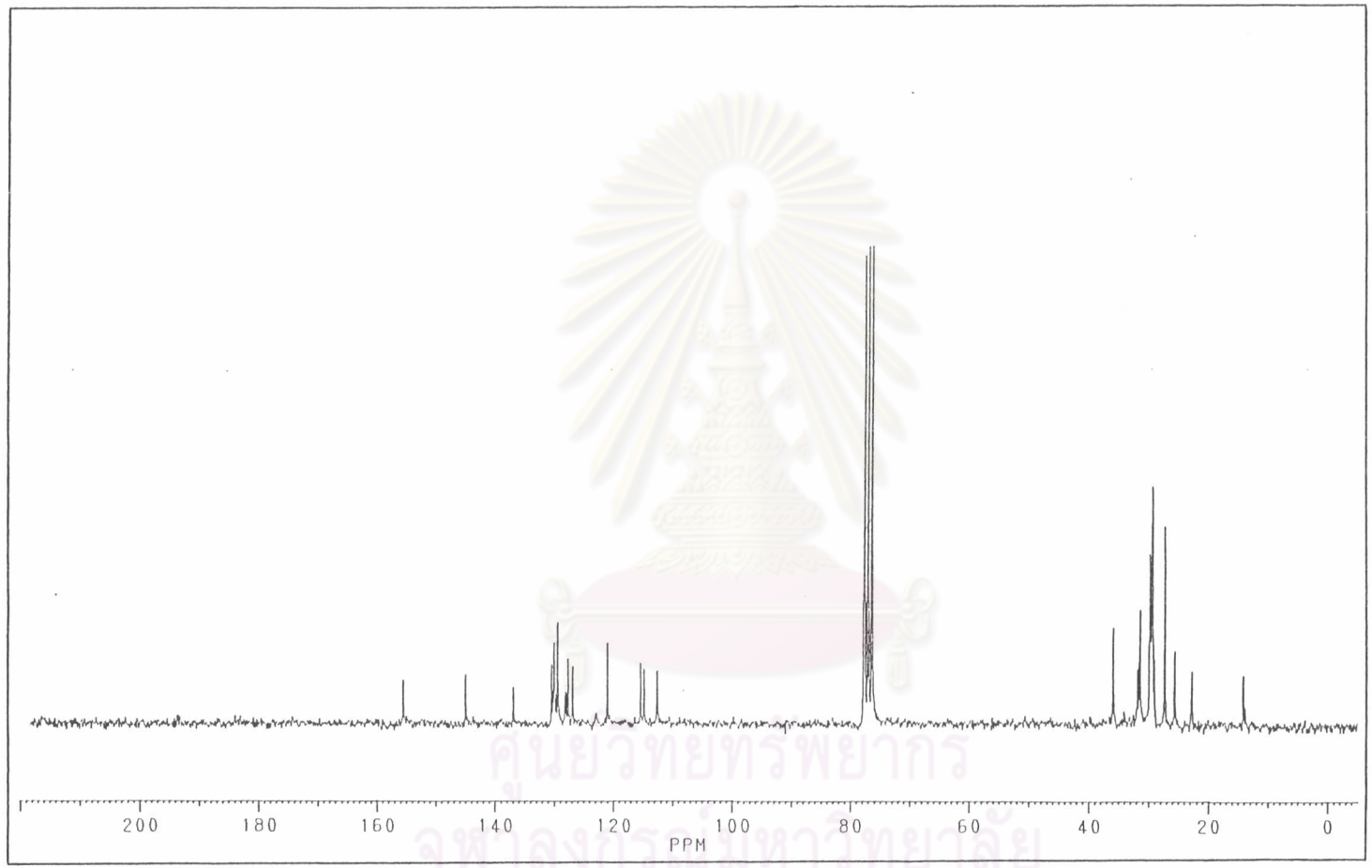


Figure A.10 ^{13}C NMR spectrum of decarboxylated CNSL.

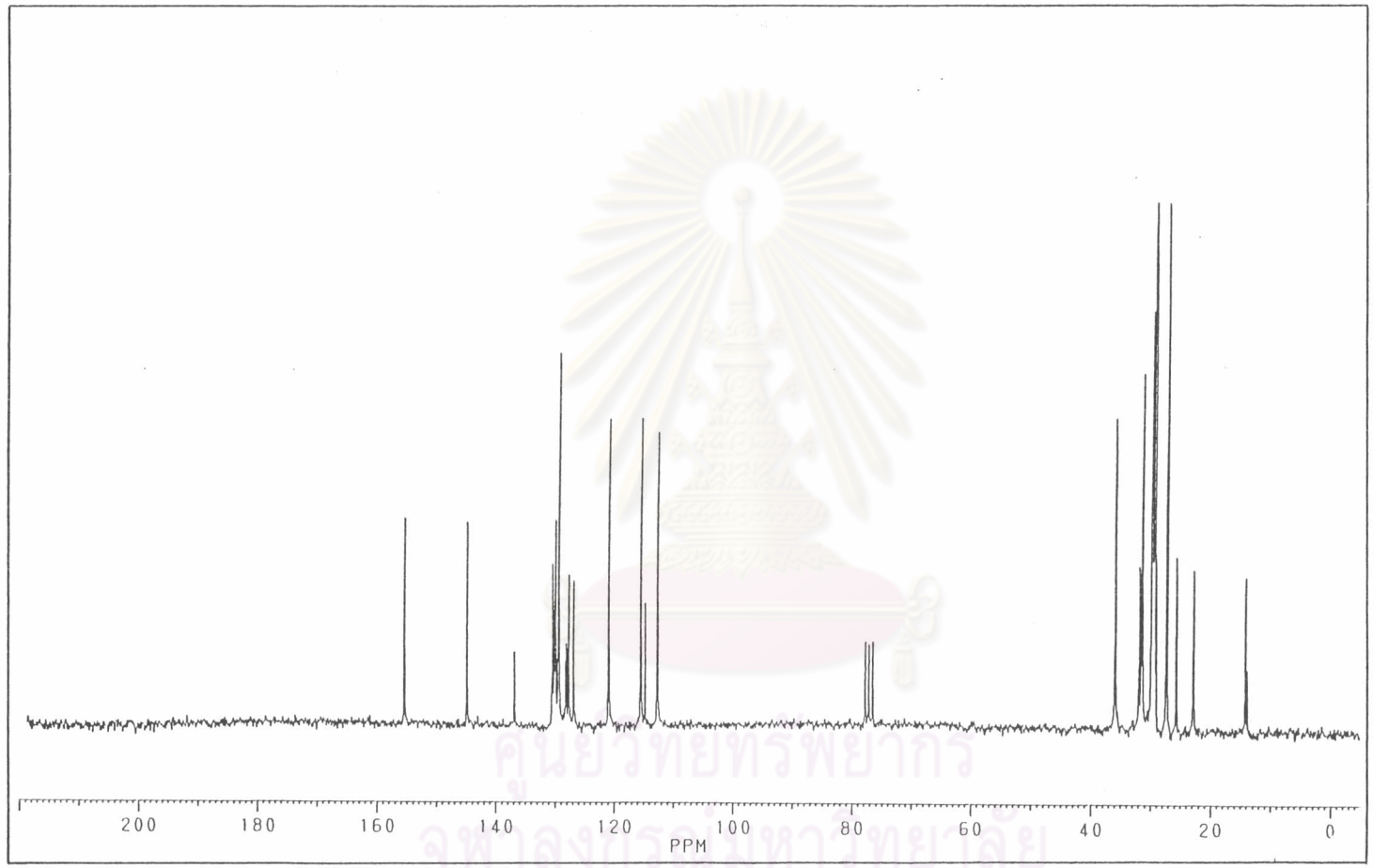


Figure A.11 ^{13}C NMR spectrum of cardanol.

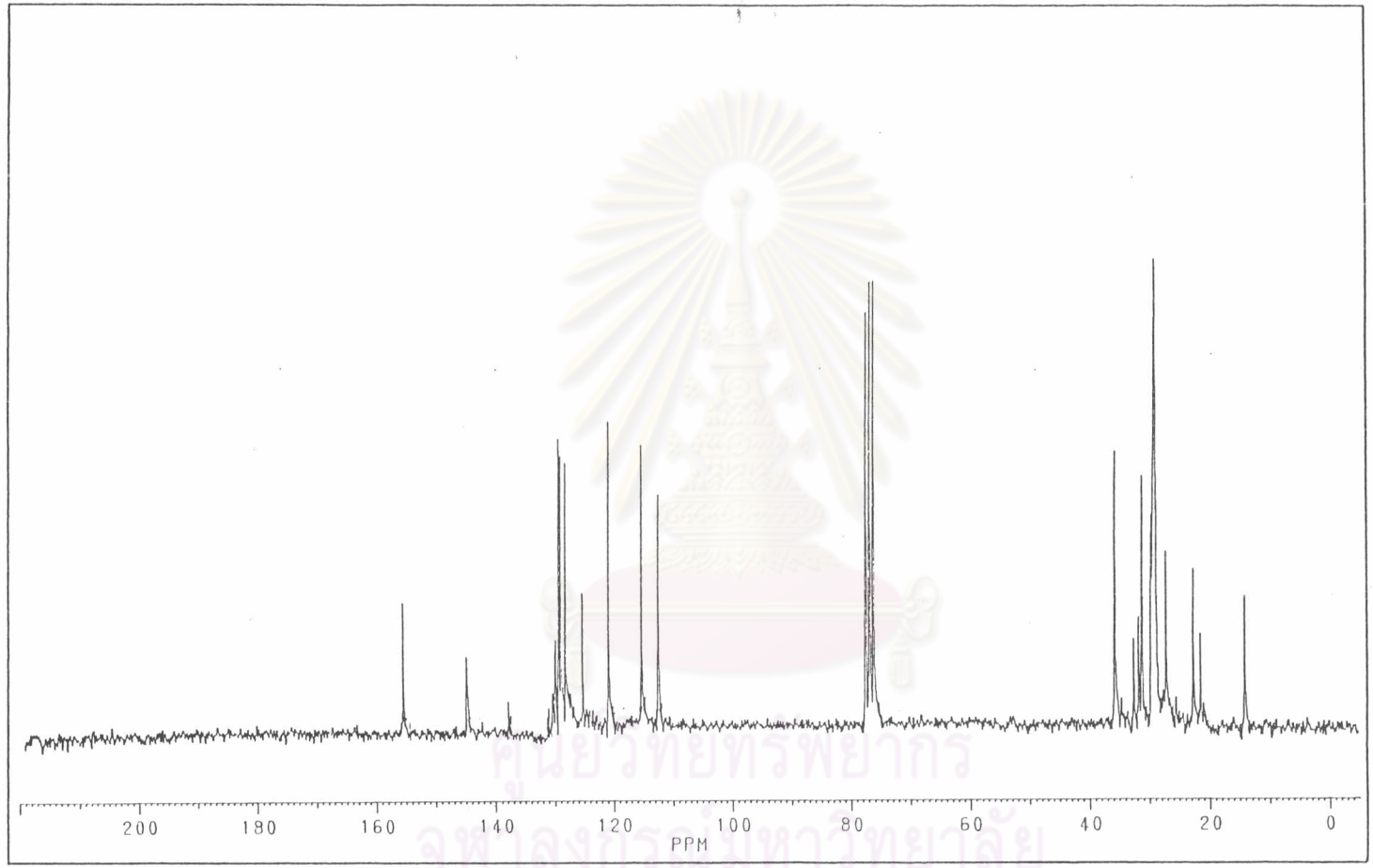


Figure A.12 ^{13}C NMR spectrum of CPS.

APPENDIX B

In this research the rheometer was used for determination of vulcanization characteristics and vulcanization curve, respectively.

Table B.1 Vulcanization characteristics of rubber compounds

		Compounds												
		A	B	B1	B2	B3	C	C1	D	D1	E	E1	E2	E3
Min τ	1st	1.26	1.26	1.26	1.15	1.11	1.39	1.05	1.24	1.13	0.98	0.98	0.93	0.96
	2nd	1.15	1.01	1.05	1.06	1.05	1.04	1.18	1.18	0.97	0.88	0.80	0.83	0.82
Max τ	1st	9.58	8.95	9.57	9.07	10.30	9.21	9.14	6.76	8.83	8.50	8.86	8.94	8.51
	2nd	9.42	8.79	9.31	10.14	10.33	8.42	9.18	6.82	8.78	8.30	8.57	8.62	9.30
Delta τ	1st	8.32	7.69	8.31	7.92	9.19	7.82	8.09	5.52	7.70	7.52	7.88	8.01	7.55
	2nd	8.27	7.78	8.26	9.08	9.28	7.38	8.00	5.64	7.81	7.42	7.77	7.79	8.48
T_{90}	1st	5.24	5.32	5.29	5.07	5.00	6.05	6.01	6.17	6.29	5.37	5.28	5.15	4.37
	2nd	6.05	6.09	5.56	5.45	5.37	6.35	6.13	6.37	6.35	7.43	6.35	5.98	5.99
Rate	1st	0.68	0.57	0.45	0.43	0.40	0.55	0.50	0.53	0.46	0.36	0.50	0.51	0.61
	2nd	0.68	0.59	0.47	0.40	0.42	0.51	0.51	0.49	0.45	0.37	0.51	0.49	0.60

APPENDIX C

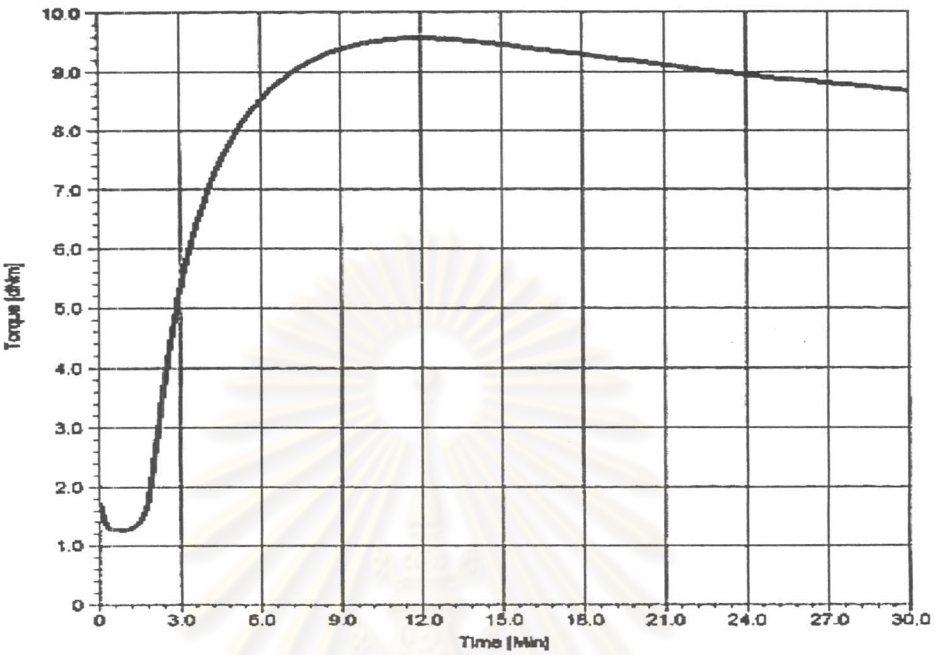


Figure C.1 A vulcanization curve of compound A.

Figure C.2 A vulcanization curve of compound B.

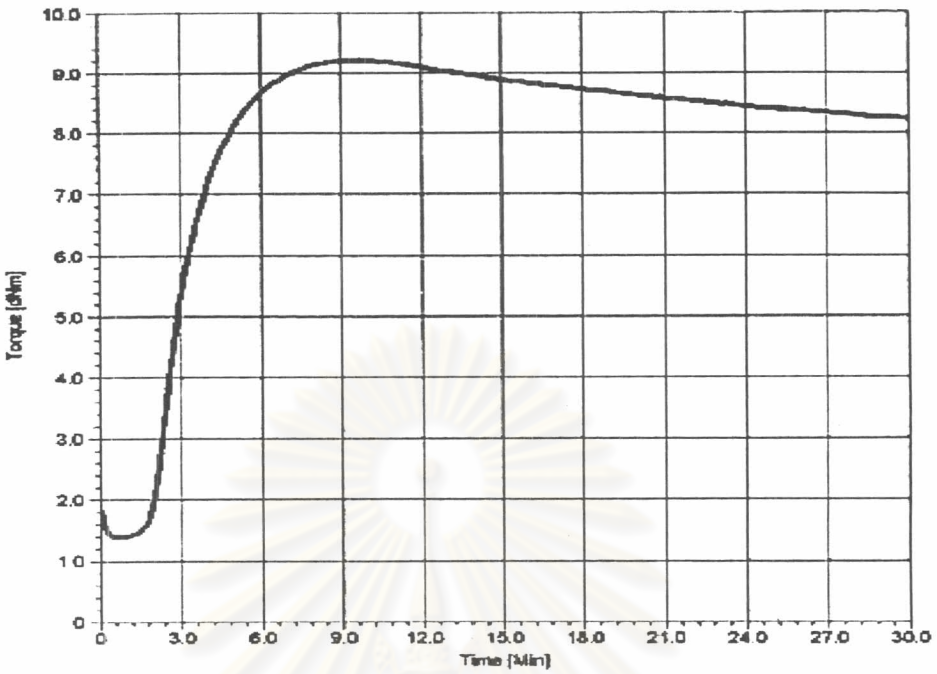


Figure C.3 A vulcanization curve of compound B1.

Figure C.4 A vulcanization curve of compound B2.

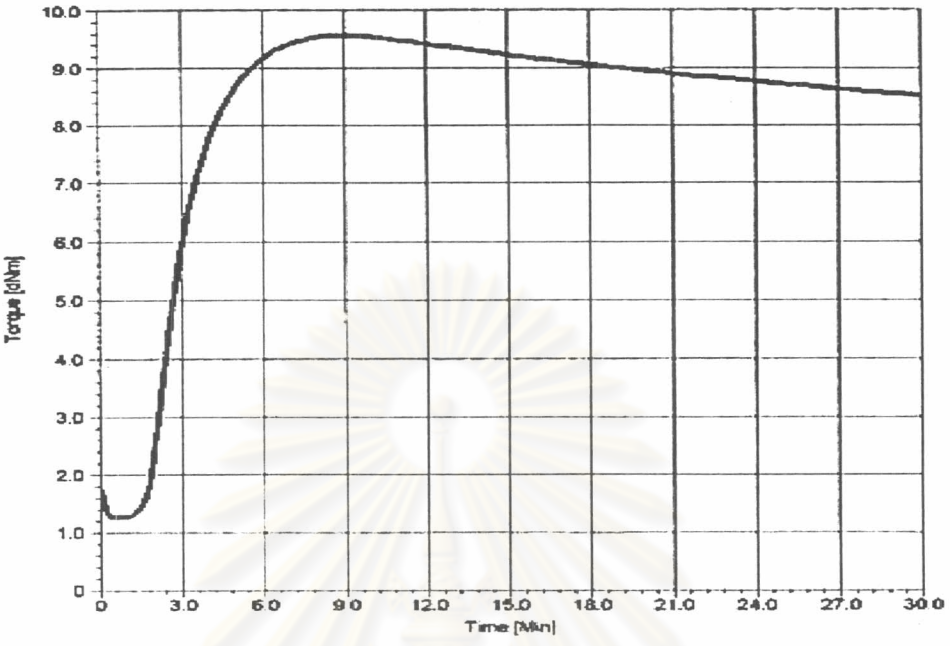


Figure C.5 A vulcanization curve of compound B3.

Figure C.6 A vulcanization curve of compound C.

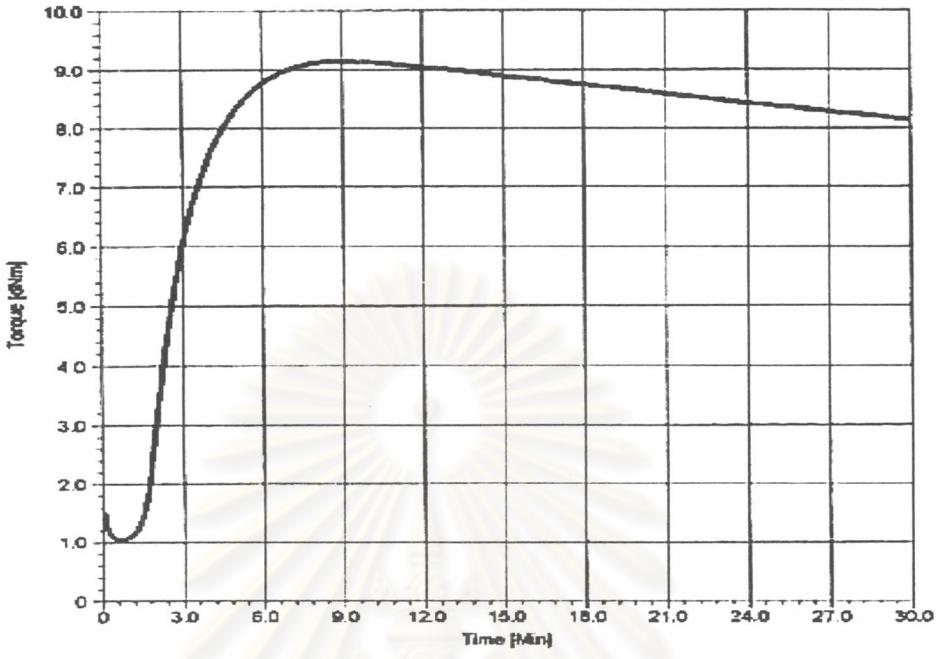


Figure C.7 A vulcanization curve of compound C1.

Figure C.8 A vulcanization curve of compound D.

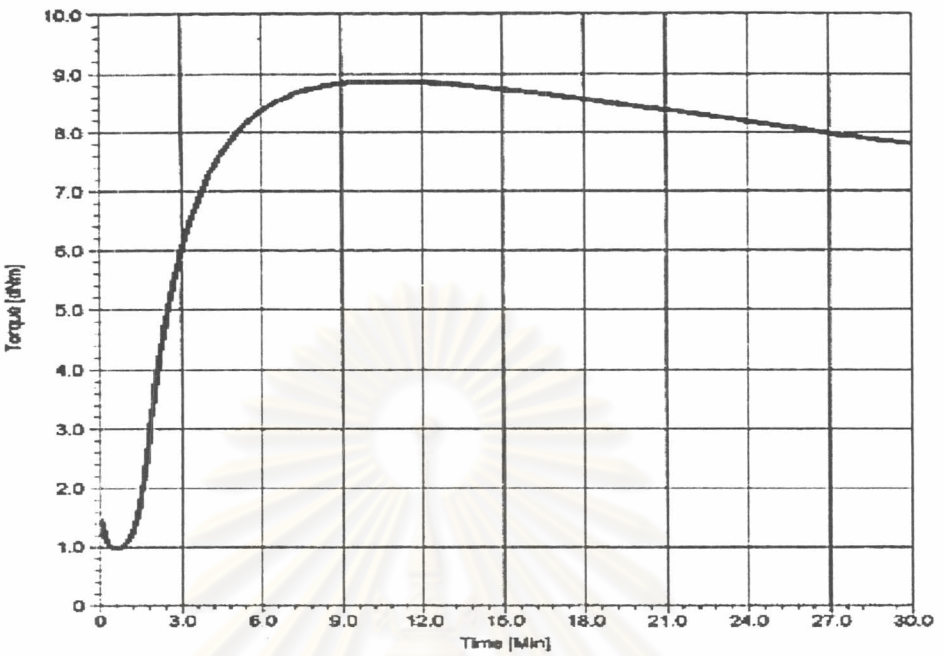


Figure C.9 A vulcanization curve of compound D1.

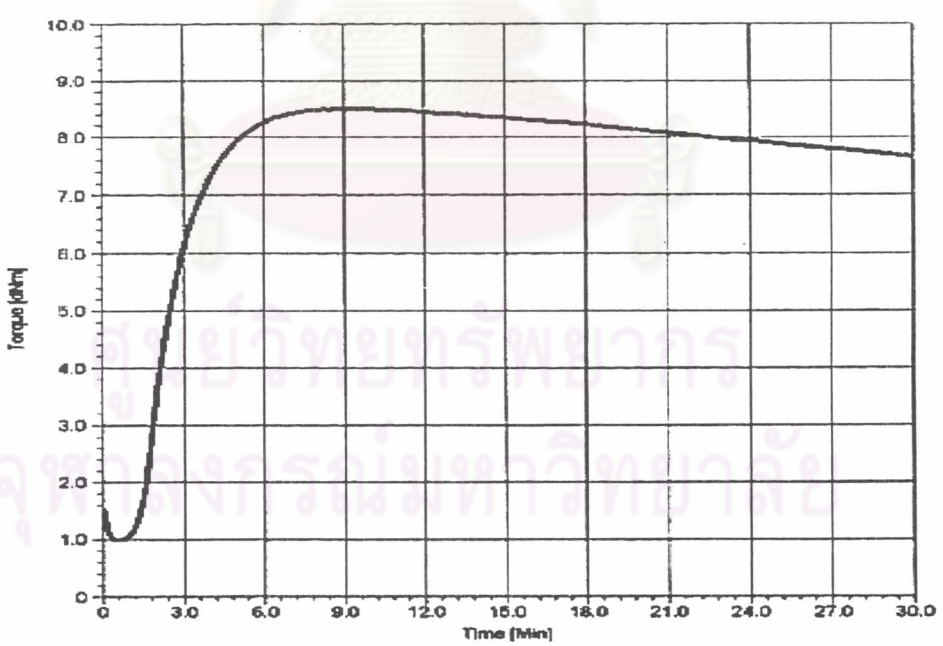


Figure C.10 A vulcanization curve of compound E.

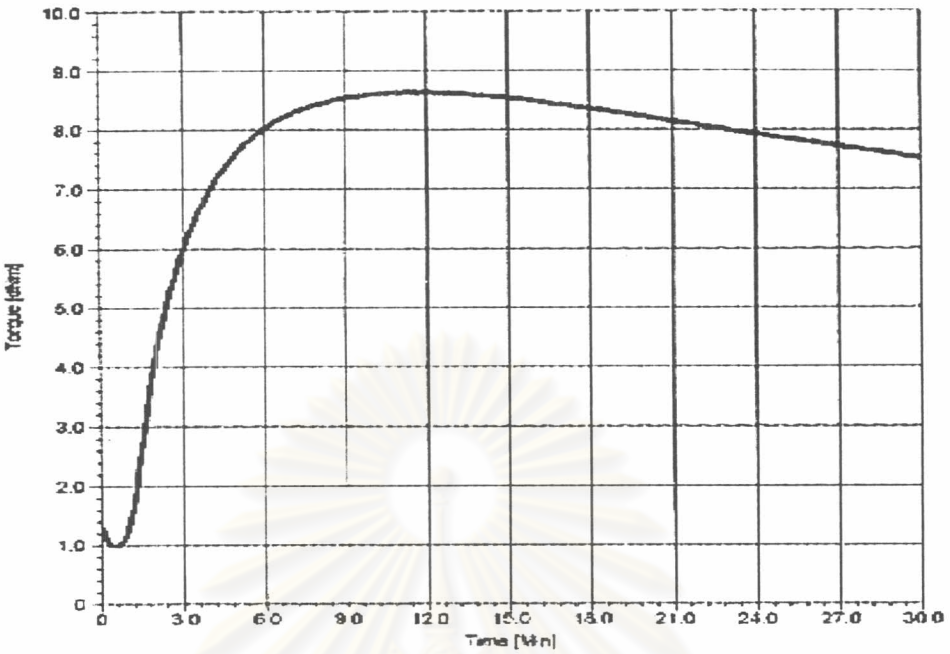


Figure C.11 A vulcanization curve of compound E1.

Figure C.12 A vulcanization curve of compound E2.

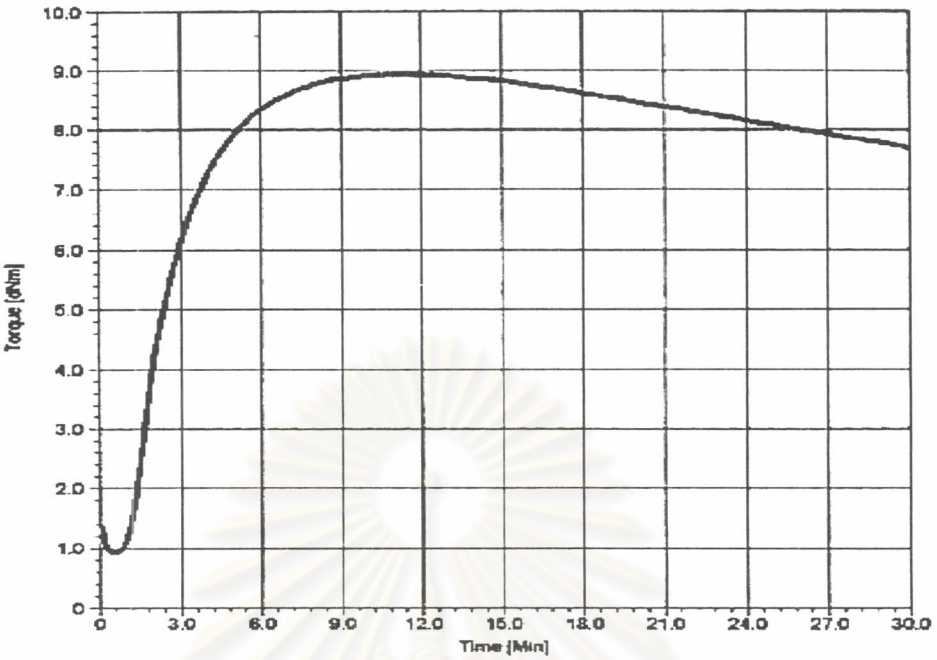


Figure C.13 A vulcanization curve of compound E3.

APPENDIX D

D.1 Mechanical Properties of Compounds A-E

Table D.1 Tensile strength of rubber compounds A-E

Examples	Tensile strength (Mpa)		Average
	1st Experiment	2nd Experiment	
A	22.78 ± 0.52	25.58 ± 0.98	24.18
B	22.67 ± 0.57	25.46 ± 0.98	24.07
B1	24.14 ± 0.75	27.94 ± 0.66	26.04
B2	23.12 ± 0.85	26.45 ± 1.56	24.79
B3	23.17 ± 0.88	24.79 ± 0.62	23.98
C	22.58 ± 0.37	24.66 ± 0.56	23.62
C1	23.28 ± 0.46	26.03 ± 1.22	24.66
D	20.88 ± 0.50	22.84 ± 1.30	21.86
D1	23.17 ± 0.69	24.20 ± 1.48	23.69
E	14.64 ± 0.48	14.98 ± 1.65	14.81
E1	14.11 ± 1.10	16.48 ± 0.80	15.30
E2	14.05 ± 0.48	18.64 ± 1.41	16.35
E3	16.15 ± 1.16	18.84 ± 1.49	17.50

Table D.2 Elongation of rubber compounds A-E

Examples	Elongation (%)		Average
	1st Experiment	2nd Experiment	
A	649.48 ± 10.37	576.87 ± 2.89	613.18
B	616.17 ± 12.89	623.37 ± 11.39	619.77
B1	651.47 ± 8.76	615.17 ± 12.51	633.32
B2	662.93 ± 10.52	624.90 ± 10.02	643.92
B3	660.23 ± 23.62	699.13 ± 12.96	679.68
C	637.17 ± 13.68	632.98 ± 16.56	635.08
C1	639.05 ± 10.91	651.08 ± 16.48	645.07
D	647.82 ± 14.54	639.17 ± 37.18	643.50
D1	644.75 ± 22.76	669.57 ± 17.91	657.16
E	654.77 ± 18.83	675.42 ± 17.62	665.10
E1	656.30 ± 11.18	688.33 ± 11.91	672.32
E2	657.77 ± 11.42	697.08 ± 6.42	677.43
E3	687.67 ± 12.43	689.92 ± 16.92	688.80

Table D.3 Modulus 500% of rubber compounds A-E

Examples	Modulus (500%)		Average
	1st Experiment	2nd Experiment	
A	16.26 ± 0.63	15.66 ± 0.86	15.96
B	13.16 ± 0.39	15.48 ± 0.90	14.32
B1	14.65 ± 0.67	13.00 ± 0.42	13.83
B2	12.01 ± 0.41	15.40 ± 0.81	13.71
B3	13.53 ± 0.53	13.18 ± 0.25	13.36
C	12.70 ± 0.62	15.61 ± 0.64	14.16
C1	11.95 ± 0.97	12.65 ± 0.42	12.30
D	11.98 ± 0.77	14.88 ± 0.82	13.43
D1	13.23 ± 0.50	10.94 ± 0.60	12.09
E	9.02 ± 0.36	10.00 ± 0.42	9.51
E1	9.46 ± 0.39	10.80 ± 0.42	10.13
E2	10.30 ± 0.96	12.33 ± 0.75	11.32
E3	11.52 ± 0.55	12.11 ± 0.76	11.82

Table D.4 Hardness (Shore-A) of rubber compounds A-E

Examples	Hardness (Shore-A)		Average
	1st Experiment	2nd Experiment	
A	47.7	45.1	46.40
B	45.4	44.2	44.80
B1	46.4	46.5	46.45
B2	46.7	47.0	46.85
B3	49.9	47.9	48.90
C	42.8	43.3	43.05
C1	46.6	44.9	45.75
D	37.6	36.4	37.00
D1	43.8	45.3	44.55
E	47.3	40.1	43.70
E1	45.9	44.6	45.25
E2	45.6	46.2	45.90
E3	46.3	47.0	46.65

Table D.5 Rebound resilience (%) of rubber compounds A-E

Examples	Resilience (%)			Average
	1st Experiment	2nd Experiment	3nd Experiment	
A	80.1	78.8	80.4	79.8
B	75.7	77.2	77.4	76.8
B1	81.0	80.0	79.2	80.1
B2	82.8	82.8	82.6	82.7
B3	82.6	83.4	83.2	83.1
C	76.5	74.0	72.8	74.4
C1	76.8	81.2	79.4	79.1
D	69.1	69.8	70.4	69.8
D1	80.4	78.2	77.4	78.7
E	68.9	70.7	68.9	69.5
E1	68.7	70.7	71.9	70.4
E2	75.1	78.2	76.3	76.5
E3	75.7	79.0	79.2	78.0

APPENDIX E

The accelerated aging test was investigated for studying the reversion of rubber compounds. The percentage of change in properties or % reversion was calculated as following :

$$\textbf{\% reversion} = \frac{X_a - X_o}{X_a} \times 100$$

$$= X_a - X_o \qquad \text{(for hardness)}$$

Where

X_o is the value of the property before aging

X_a is the value of the hardness after aging

E.1 Reversion of aged rubber compounds

E.1.1 Aged for 1 day

Table E.1 % reversion of tensile strength for 1 day aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average of % reversion
	Tensile Strength (MPa)	% reversion	Tensile Strength (MPa)	% reversion	
A	15.67 ± 0.13	-31.20	15.67 ± 0.52	-38.76	-34.98
B	16.35 ± 0.36	-27.90	17.59 ± 0.55	-30.91	-29.41
B1	18.93 ± 0.74	-21.60	21.49 ± 0.97	-23.08	-22.34
B2	19.28 ± 0.90	-16.61	23.20 ± 0.76	-12.29	-14.45
B3	20.45 ± 0.47	-11.76	22.22 ± 0.98	-10.37	-11.07
C	16.60 ± 0.88	-26.50	17.09 ± 0.77	-30.71	-28.61
C1	18.79 ± 0.49	-19.29	19.74 ± 1.02	-18.44	-18.87
D	16.78 ± 0.64	-19.66	17.76 ± 0.66	-22.24	-20.95
D1	18.69 ± 1.55	-19.34	19.09 ± 0.67	-21.10	-20.22
E	11.51 ± 0.94	-21.38	12.25 ± 0.91	-18.25	-19.82
E1	11.84 ± 0.76	-16.11	14.01 ± 1.98	-14.99	-15.55
E2	12.31 ± 0.82	-12.41	16.49 ± 0.92	-11.55	-11.98
E3	14.62 ± 0.68	-9.47	17.37 ± 0.82	-7.81	-8.64

Table E.2 % reversion of elongation for 1 day aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average of % reversion
	Elongation at break (%)	% reversion	Elongation at break (%)	% reversion	
A	447.95 ± 22.37	-31.03	406.08 ± 18.10	-29.61	-30.32
B	467.93 ± 16.58	-24.06	475.81 ± 15.18	-23.67	-23.87
B1	502.68 ± 15.23	-22.84	468.12 ± 16.21	-23.90	-23.37
B2	533.95 ± 25.00	-19.46	502.65 ± 4.47	-19.56	-19.51
B3	544.57 ± 21.52	-17.52	555.70 ± 24.68	-20.52	-19.02
C	526.48 ± 25.67	-17.37	531.52 ± 27.84	-16.03	-16.70
C1	540.00 ± 17.04	-15.44	546.07 ±17.83	-16.13	-15.79
D	549.42 ± 17.64	-15.19	548.65 ± 25.93	-14.16	-14.68
D1	558.35 ± 29.93	-13.40	562.98 ± 29.71	-15.92	-14.66
E	557.27 ± 16.18	-14.89	590.03 ± 19.10	-12.64	-13.77
E1	577.82 ± 10.70	-11.96	594.86 ± 16.02	-13.58	-12.77
E2	574.02 ± 29.45	-12.73	636.15 ± 12.01	-8.74	-10.74
E3	614.37 ± 20.86	-10.66	634.08 ± 16.09	-8.09	-9.38

Table E.3 % reversion of modulus 500% for 1 day aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average of % reversion
	Modulus 500% (MPa)	% reversion	Modulus 500% (MPa)	% reversion	
B2	13.77 ± 0.67	14.65	17.77 ± 0.98	15.39	15.02
B3	15.64 ± 0.73	15.59	15.45 ± 0.55	17.22	16.41
C	13.91 ± 0.56	9.53	17.49 ± 0.73	12.04	10.79
C1	13.63 ± 0.74	14.02	14.77 ± 0.97	16.76	15.39
D	13.61 ± 0.74	13.61	17.05 ± 0.56	14.58	14.10
D1	15.10 ± 0.69	14.13	12.95 ± 0.86	18.34	16.24
E	10.44 ± 0.83	15.74	12.05 ± 0.55	20.50	18.12
E1	11.03 ± 0.50	16.60	13.01 ± 0.44	20.46	18.53
E2	12.06 ± 0.95	17.09	14.94 ± 0.55	21.17	19.13
E3	13.54 ± 0.51	17.53	14.77 ± 0.65	21.97	19.75

Example A, B and B1 can not determine

Table E.4 % reversion of hardness for 1 day aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average
	Hardness (Shore-A)	% reversion	Hardness (Shore-A)	% reversion	
A	49.8	2.1	47.6	2.5	2.30
B	46.6	1.2	45.5	1.3	1.25
B1	47.7	1.3	47.8	1.3	1.30
B2	48.8	2.1	48.7	1.7	1.90
B3	52.1	2.2	50.5	2.6	2.40
C	44.2	1.4	44.8	1.5	1.45
C1	49.6	3.0	46.3	1.4	2.20
D	39.2	1.6	37.5	1.1	1.35
D1	46.0	2.2	48.2	2.9	2.55
E	52.0	4.7	40.5	0.4	2.55
E1	48.8	2.9	46.9	2.3	2.60
E2	48.6	3.3	48.2	2.0	2.50
E3	49.6	3.3	49.7	2.7	3.00

E.1.2 Aging for 3 days

Table E.5 % reversion of tensile strength for 3 days aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average of % reversion
	Tensile Strength (MPa)	% reversion	Tensile Strength (MPa)	% reversion	
A	8.74 ± 0.12	-61.64	9.12 ± 0.85	-64.34	-62.99
B	9.42 ± 0.18	-58.45	11.51 ± 1.56	-54.79	-56.62
B1	13.08 ± 0.62	-45.82	14.98 ± 0.77	-46.39	-46.11
B2	14.59 ± 0.60	-36.89	16.66 ± 0.84	-37.03	-36.96
B3	15.06 ± 0.16	-34.99	16.33 ± 1.08	-34.15	-34.57
C	14.20 ± 0.47	-37.10	13.88 ± 0.82	-43.71	-40.41
C1	16.93 ± 0.19	-27.28	18.23 ± 0.50	-29.98	-28.63
D	14.26 ± 0.44	-31.71	15.64 ± 0.36	-31.52	-31.62
D1	16.57 ± 0.64	-28.49	18.49 ± 0.86	-23.59	-26.04
E	10.91 ± 0.85	-25.48	11.49 ± 1.09	-23.30	-24.39
E1	10.85 ± 0.58	-23.14	14.32 ± 0.47	-13.12	-18.13
E2	11.46 ± 0.15	-18.47	15.74 ± 0.12	-15.57	-17.02
E3	13.28 ± 0.55	-17.76	15.58 ± 0.37	-17.32	-17.54

Table E.6 % reversion of elongation for 3 days aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average of % reversion
	Elongation at break (%)	% reversion	Elongation at break (%)	% reversion	
A	254.48 ± 28.62	-60.82	276.27 ± 19.02	-52.11	-56.47
B	303.53 ± 16.13	-50.74	297.60 ± 10.15	-52.26	-51.50
B1	317.13 ± 64.21	-51.32	306.08 ± 18.10	-50.24	-50.78
B2	389.37 ± 40.86	-41.27	370.37 ± 40.69	-40.73	-41.00
B3	397.80 ± 16.31	-39.75	413.22 ± 16.87	-40.90	-40.33
C	372.30 ± 9.38	-41.57	326.10 ± 36.24	-48.48	-45.03
C1	396.77 ± 37.37	-37.91	447.82 ± 25.39	-31.22	-34.57
D	389.53 ± 18.47	-39.87	364.58 ± 18.09	-42.96	-41.42
D1	501.70 ± 9.56	-22.19	516.82 ± 21.06	-22.81	-22.50
E	542.62 ± 21.35	-17.13	553.23 ± 20.42	-18.09	-17.61
E1	548.98 ± 16.90	-16.35	572.28 ± 11.57	-16.86	-16.61
E2	549.58 ± 18.63	-16.45	579.75 ± 18.01	-16.83	-16.64
E3	547.23 ± 30.80	-16.50	583.75 ± 45.07	-15.39	-15.95

Table E.7 % reversion of modulus 500% for 3 days aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average of % reversion
	Modulus 500% (MPa)	% reversion	Modulus 500% (MPa)	% reversion	
D1	15.81 ± 0.64	19.50	13.15 ± 0.77	20.20	19.85
E	11.06 ± 0.64	22.62	12.07 ± 0.89	20.70	21.66
E1	11.75 ± 0.59	24.21	13.28 ± 0.77	22.96	23.59
E2	13.20 ± 0.70	28.16	15.68 ± 0.75	27.17	27.67
E3	14.80 ± 0.64	28.47	15.62 ± 0.81	28.98	28.73

Example A, B, B1, B2, B3, C, C1 and D can not determine

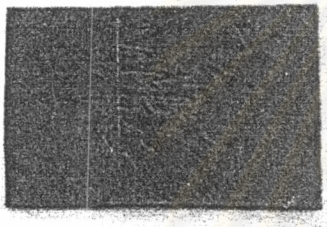
Table E.8 % reversion of hardness for 3 days aging of rubber compounds

Examples	1st Experiment		2nd Experiment		Average
	Hardness (Shore-A)	% reversion	Hardness (Shore-A)	% reversion	
A	50.1	2.4	47.7	2.6	2.50
B	47.6	2.2	46.6	2.4	2.30
B1	49.0	2.6	48.9	2.4	2.50
B2	49.8	3.1	49.9	2.9	3.00
B3	52.8	2.9	51.0	3.1	3.00
C	45.0	2.2	45.1	1.8	2.00
C1	48.8	2.2	47.3	2.4	2.30
D	39.5	1.9	38.7	2.3	2.10
D1	46.3	2.5	48.0	2.7	2.60
E	50.3	3.0	42.6	2.5	2.75
E1	48.6	2.7	47.5	2.9	2.80
E2	48.5	2.9	48.9	2.7	2.80
E3	49.8	3.5	49.9	2.9	3.20

APPENDIX F

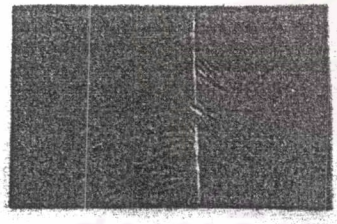
A

B



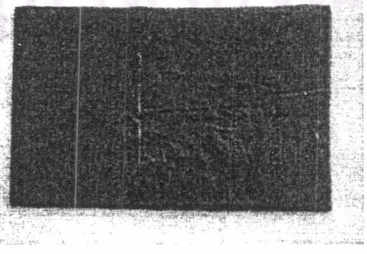
B1

B2

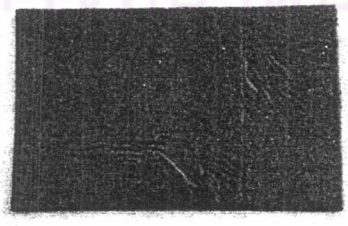


B3

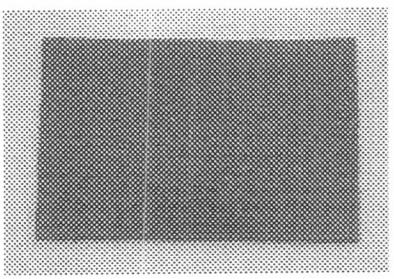
C



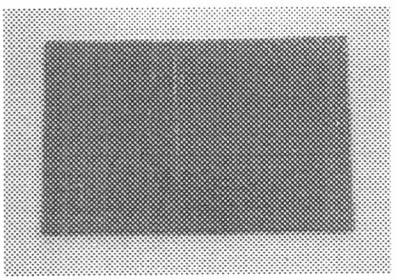
C1



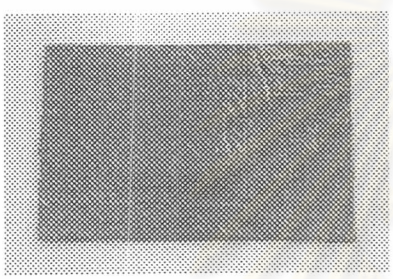
D



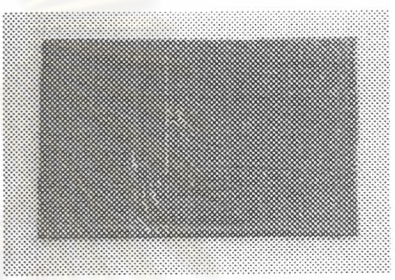
D1



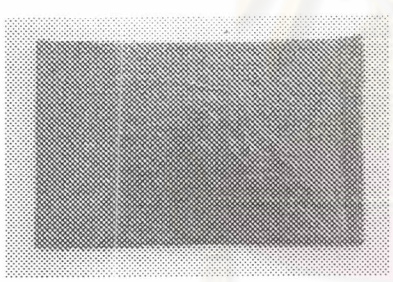
E



E1



E2



E3

Figure F.1 Pictures of rubber compounds.

VITA

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