Synthesis of Selenium-containing *para*-Phenylenediamines: Novel Antidegradants for Natural Rubber

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The synthesis of novel *N,N'*-substituted *para*-phenylenediamines bearing side-chains containing one or two monoselenide linkages is described. Reductive alkylation of *para*-phenylenediamines with oxoselenides using sodium cyanoborohydride in methanol gives good to high yields of these compounds. Compounds containing one selenide linkage react with 3 mol equivalents of ozone, and those containing two selenide linkages react with 4 mol equivalents of ozone, compared to only 2 mol equivalents of ozone in the case of *N*-isopropyl-*N'*-phenyl-*p*-phenylenediamine. Synthetic routes to the oxoselenides required as precursors are described.

THE only class of compound known to function as effective chemical antiozonants in unsaturated rubber vulcanizates is *N,N'*-disubstituted *para*-phenylenediamines.[1] Such compounds are also amongst the best thermal antioxidants available. Phenylenediamines (PDA's) have been shown [2] to react 50—100 times faster with ozone than hex-1-ene, and to effect complete protection until 2 mol equivalents of ozone have been passed.[2] Few classes of compound share this ability to undergo more rapid reaction with ozone than do olefinic bonds, but dialkyl selenides have been reported [3] to react with ozone 80 times more rapidly than 2-methylpent-2-ene, 1 mol equivalent of ozone being absorbed and selenoxide formation resulting. Unfortunately, dialkyl selenides do not function as antiozonants when mixed in rubber vulvanizates.[3] This failure may be attributed to an inability to form a protective film of ozonized material at the rubber surface, the mechanism by which PDA's are believed to act.[4]

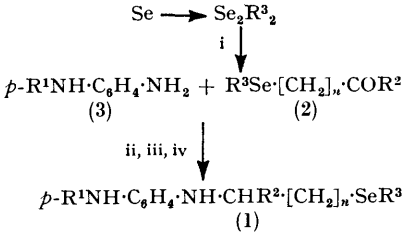
In this paper the synthesis of novel PDA's, bearing side-chains which contain selenide linkages, is reported. These compounds act as superior chemical antiozonants for unsaturated rubber vulcanizates;[5,6] the intrinsic ozone reactivities are enhanced to 3 or 4 mol equivalents of ozone, whilst the protective film forming properties of conventional PDA's are retained.

Because PDA's are of such commercial importance, the majority of data relevant to their preparation is in the patent literature. Their synthesis commonly involves the reductive alkylation of primary amino-groups with carbonyl compounds, a process usually accomplished *via* catalytic hydrogenation.[7] Since selenium compounds often act as catalyst poisons, an alternative method of reductive alkylation was sought. Utilizing sodium borohydride and a buffered aqueous acetic acid medium, Schellenberg [8] reported the reductive alkylation of aniline with acetone to proceed in high yield and suggested a mechanism involving reduction of an intermediate iminium ion.

Initial experiments with this system revealed that the commercial PDA, *N*-isopropyl-*N'*-phenyl-p-phenylenediamine (IPPD), could be obtained from acetone and *N*-phenyl-*p*-phenylenediamine in almost quantitative yield. This suggested that selenium containing PDA's (SEPDA's) of the general formula (1) could be prepared by sodium borohydride-mediated reductive alkylation of oxoselenides using the overall sequence shown in Scheme 1, which can be seen to be well suited to structural variation by choice of oxoselenide, (2) and of starting PDA (3).

The most convenient route to the diselenides required proved to be that of Gladysz *et al.*[9] based upon *in situ* formation of lithium diselenide and reaction with alkyl halides. Yields of 55—70% were commonly achieved. Alternative methods, such as reaction of alkyl selenocyanate with sodium methoxide,[10] gave higher yields (75—80%) of diselenide in some cases but proved more tedious and objectionable to perform.

The oxoselenides (2) required by Scheme 1 were largely unknown prior to this work, although Bergson *et al.*[11] had investigated various methods for the preparation of $EtSeCH_2Ac$. For oxoselenides wherein $n > 1$ the treatment of the sodium salts of selenols, R^3SeNa (prepared *in situ* by reduction of diselenide with sodium in liquid ammonia [12]), with appropriate chloroketones, $Cl[CH_2]_nCOR^2$, in ethanol solution (Method A), gave reasonable yields. Distillation of the resulting reaction products gave oxoselenides which were contaminated with 5—15% diselenide.



SCHEME 1 *Reagents:* i, $Cl[CH_2]_n·COR^2$; ii, $NaBH_4$; iii, $HOAc–H_2O–EtOH$; iv, NaOAc

Isolation of pure oxoselenides was better achieved by careful column chromatography on silica gel in ether–light petroleum mixtures; however, the presence of diselenide did not greatly affect the reductive alkylation procedure and in some cases it was more convenient to remove diselenide during purification of the SEPDA's.

In agreement with the results of Bergson *et al.*[11] Method A was found to give little or none of the required

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$$R^3{}_2Se_2 \longrightarrow 2R^3SeNa \xrightarrow{2Cl[CH_2]_nCOR^2} 2R^3Se[CH_2]_nCOR^2 \quad \text{(Method A)}$$

$$R^3MgBr + R^3{}_2Se_2 \longrightarrow [R_2{}^3Se] + R^3SeMgBr \xrightarrow{ClCH_2COR^2} R^3SeCH_2COR^2 \quad \text{(Method B)}$$

$$Ph_2Se_2 \xrightarrow{SO_2Cl_2} PhSeCl \xrightarrow{Me_2CO} PhSeCH_2Ac \quad \text{(Method C)}$$

product when $n = 1$, instead the major product in a variety of solvents was the diselenide. Oxoselenides with $n = 1$ can be prepared in reasonable yield by Method B involving reaction of diselenide with a Grignard reagent and subsequent treatment of the R^3Se-MgBr intermediate with chloroacetone. Again mono- and di-selenide contaminants were removable by column chromatography. In the special case where R^3 = Ph, $n = 1$, the oxoselenide can be obtained by Method C. This method failed for R^3 = alkyl derivatives because of the instability of alkylselenenyl chlorides at ambient temperatures, diselenide being regenerated. The selenol ester, BuSeAc was obtained in good yield by a modification of the literature method,[13] which avoided the necessity of isolating free selenol (see Experimental section). Attempts to use this compound in place of (2) in Scheme 1 failed to give a SEPDA with $n = 0$.

The yield of oxoselenide obtained by Method A appears to be dependent upon the structure of the group bonded to selenium, decreasing in the order primary > secondary > benzyl.

The sodium borohydride based method of Schellenberg [8] was next applied to the preparation of *N*-phenyl-*N'*-(1-methyl-4-butylselenobutyl)-*p*-phenylenediamine (4). Using a 1 : 1 : 2 : 5.6 mole ratio of *N*-phenyl-*p*-phenylenediamine : 5-butylselenopentan-2-one : sodium acetate : sodium borohydride, the reductive alkylation procedure [8] afforded, after work-up, brown oils which h.p.l.c. analysis indicated to contain 50—55% of the SEPDA (4), 20% unchanged oxoselenide and 25% unchanged amine. An increase in the quantity of reducing agent (1 : 1 : 2 : 11 ratio) was beneficial in reducing the levels of unchanged material, and in increasing the product content of the oils to 65—70% (4) (overall yields around 60%). At the same time, however, reduction of oxoselenide to hydroxyselenide was observed. Further increases in the quantity of $NaBH_4$ employed resulted in a decrease of the SEPDA yield and increased hydroxyselenide formation.

p-PhNH·C_6H_4·NH·CH(Me)·$[CH_2]_3$·SeBu
(4)

The presence of oxoselenide and/or hydroxyselenide rendered chromatographic isolation of the required SEPDA more difficult, and the heterogeneous nature of the reduction was not found to be conducive to reproducibility. Therefore the use of the somewhat milder reducing agent, sodium cyanoborohydride was investigated. This agent, stable in methanol solution, has been reported [14] to effect the reductive alkylation of amines, but had not been used previously to synthesize PDA's. At pH > 5 reduction of ketones does not occur.[14]

The addition of a methanolic solution of $NaBH_3CN$ (6 mmol) to a solution of *N*-phenyl-*p*-phenylenediamine (20 mmol) and acetone (10 mmol) in methanol, acidified by the addition of hydrochloric acid (2 ml), resulted in a mildly exothermic reaction. Work-up after 16 h at room temperature gave an oil consisting of IPPD and starting amine, and the overall yield of IPPD was 87%. When applied to the synthesis of a SEPDA, an overall yield of 84% for compound (4) was achieved, without any significant formation of hydroxyselenide. The use of a 10—100% excess of starting amine was beneficial and was easily removed during column chromatographic isolation of the SEPDA (being retained on silica gel unless the ether–light petroleum eluants used contained >75% ether). Substitution of conc. hydrochloric acid for the methanolic HCl used in the original work [14] seemed not to introduce any significant problems, at least for PDA synthesis.

The synthesis of a variety of SEPDA's of general formula (1), (R^1 = Ph, Pr^i) was accomplished in high yield using the above procedure; results are contained in the Table and, in our opinion, reductive alkylation with sodium cyanoborohydride represents the method of choice for the laboratory preparation of a variety of *para*-phenylenediamines. All the compounds contained in the Table were obtained as red-brown viscous oils after chromatography on silica gel. Elution with 10% ether in redistilled light petroleum (b.p. 30—40 °C) removed any residual diselenide, whilst subsequent elution with 20 to 40% ether in light petroleum gave fractions containing pure SEPDA.

From Scheme 1 it can be seen that by employing 2 mol equiv. of oxoselenide (2) and *p*-phenylenediamine (3; R^1 = H) as the amine, the potential exists to prepare a SEPDA bearing two selenide-containing sidechains. Although moderate yields could be obtained in this fashion, much better results were achieved using the two stage procedure shown in Scheme 2.

$$p\text{-}NH_2\cdot C_6H_4\cdot NH_2 + R^1Se\cdot[CH_2]_n\cdot COMe \longrightarrow p\text{-}NH_2\cdot C_6H_4\cdot NH\cdot CHMe\cdot[CH_2]_n\cdot SeR^1 \quad (5)$$

$$(5) + R^2Se[CH_2]_n\cdot COMe \longrightarrow R^2Se\cdot[CH_2]_{n'}\cdot CHMe\cdot NH\cdot C_6H_4\cdot NH\cdot CHMe\cdot[CH_2]_n\cdot SeR^1 \quad (6)$$

a; $R^1 = R^2$ = Bu, $n = n' = 3$
b; R^1 = Bu, R^2 = Ph, $n = 3$, $n' = 1$
i = $NaBH_3CN$

SCHEME 2

Thus reaction of 5-butylselenopentan-2-one with a 50% excess of *p*-phenylenediamine led to the formation of compound (5a) in 70% yield. After work-up, treatment of a 20% excess of (5a) with a second quantity of the oxoselenide (and of reducing agent) led to an 85% yield of compound (6a), which was isolated as a red oil after column chromatography. Unchanged compound

TABLE 1

Yield (%) and proton n.m.r. spectral data (CCl_4, chemical shifts in p.p.m. from $SiMe_4$) for SEPDA's of general formula (1) prepared by $NaBH_3CN$ reductive alkylation

					Chemical shifts						
R^1	R^2	R^3	n	Yield (%)	R^1	R^2	R^3	CHR^2	$[CH_2]_n$	Aromatics	NH
Pr^i	Me	Bu	3	79	3.35 1.16	1.16	2.53 1.8—1.3 0.90	3.35	2.53 1.8—2.3	6.5	obscured
Ph	Me	Bu	3	84	7.3—6.13	1.14	2.5 1.9—1.4 0.92	3.41	2.5 1.4—1.95	7.3—6.13	5.2, 3.0
Ph	Me	Bu	2	85	7.2—6.3	1.17	2.48 2.0—1.2 0.90	3.5	2.56 2.0—1.2	7.2—6.3	5.2, 3.5
Ph	Me	Bu	1	80	7.2—6.5	1.28	2.56 1.7—1.3 0.90	3.6	2.75	7.2—6.5	5.3, 3.6
Ph	Me	Ph	1	66	7.5—6.5	1.16	7.5—6.5	3.5	3.05	7.5—6.5	5.35, 3.5
Ph	Et	Bu	2	77	7.2—6.5	1.8—1.3 0.95	2.55 1.8—1.3 0.95	3.4	2.62 1.8—1.3	7.2—6.5	5.4, 3.5
Ph	Me	cyclo-C_6H_{11}	3	49	7.2—6.3	1.17	2.85 2.0—1.2 2.46	3.5	2.56 2.0—1.2 2.46	7.2—6.3	5.2, obscured
Ph	Me	$C_{12}H_{25}$	3	69	7.3—6.3	1.17	2.0—1.4 1.0—0.8	3.38	2.0—1.4 1.3 1.0—0.8	7.3—6.3	5.2, 3.0
Ph	Me	Pr^i	3	68	7.3—6.5	1.18	3.08 1.40	3.35	2.60 1.8—1.3	7.3—6.5	obscured
Ph	Me	$PhCH_2$	3	31	7.2—6.5	1.15	7.28 3.75	3.35	2.51 1.6	7.2—6.5	5.4, 3.5

(5a) could be recovered for recycling by flushing the column with ether after elution of the SEPDA, (6a). A similar but unsymmetrical SEPDA (6b) was prepared by using 5-butylselenopentan-2-one in the first stage and 1-phenylselenopropan-2-one in step two. However, isolation of compound (6b) was complicated by the presence of 10—15% of (6a), formed during the first stage.

To prepare an SEPDA which incorporated an amidic function, a reaction similar to that used to prepare the oxoselenides (Method A) was utilized. The resulting compound, (7), was obtained after column chromatography as a light yellow solid (m.p. 75—76 °C).

$$p\text{-PhNH}\cdot C_6H_4\cdot\text{NH}\cdot\text{CO}\cdot CH_2Cl + \text{BuSeNa} \longrightarrow p\text{-PhNH}\cdot C_6H_4\cdot\text{NH}\cdot\text{CO}\cdot CH_2\cdot\text{SeBu}$$

(7)

The effectiveness of SEPDA's as antiozonants and antioxidants in rubber vulcanizates will be discussed elsewhere,[6] but the intrinsic ozone reactivities of these materials were measured at −20 °C in carbon tetrachloride solution by monitoring the ozone concentration in the exit stream of a reactor cell as a function of time. In this way results for compound (4), bearing a single selenide linkage, and for compound (6a), bearing two selenide side-chains were compared with those obtained for the conventional PDA, IPPD. It was clear that the presence of each selenide-containing side-chain led to the complete absorption of an additional 1 mol equivalent of ozone. Thus compound (6a) removed 4 mol equivalents of ozone, double that absorbed by IPPD. Compound (7) has been found to be an inferior antiozonant to IPPD, but functions as a superior antioxidant.[6]

EXPERIMENTAL

^1H N.m.r. spectra were run on a Perkin-Elmer R32 instrument in CCl_4 or $CDCl_3$ solution *vs.* tetramethylsilane. H.p.l.c. analysis was carried out on a Perkin-Elmer 601 instrument using Partisil (silica gel) or ODS-2 (reverse phase) columns and either r.i. or u.v. (220 nm) detection. All h.p.l.c. and column chromatography runs were performed using AnalaR light petroleum (b.p. 30—40 °C) which had been redistilled to remove involatile residues. Throughout ether refers to diethyl ether. Ozone uptake measurements were performed in AnalaR carbon tetrachloride which had been dried by distillation from phosphorus pentoxide, and used an apparatus of our own design connected to a Wallace-Tiernan Model BA-023 ozone generator, calibrated to pass 6 mmol/h of ozone (in oxygen). Diphenyl diselenide, 5-chloropentan-2-one, 5-chloropentan-3-one, and ' Super-Hydride ' were from Aldrich. Selenium powder, *p*-phenylenediamine, and chloroacetone were from B.D.H. Literature methods were used to prepare *N*-phenyl-*N'*-(chloroacetyl)-*p*-phenylenediamine [15] and 4-chlorobutan-2-one.[16]

*N-Isopropyl-*p*-phenylenediamine.* *p*-Nitroaniline (55.2 g, 0.4 mol) and methanol (1 l) were stirred and HCl (40 ml) was added, followed by acetone (21.2 g, 0.4 mol) in methanol (25 ml). A solution of sodium cyanoborohydride (25.2 g, 0.4 mol) in methanol (100 ml) was introduced dropwise, causing an exothermic reaction. The reaction mixture was stirred overnight, poured into water, and rendered alkaline by addition of 10% NaOH solution. The mixture was extracted with ether and the extract washed with water and dried ($MgSO_4$). Solvent removal left a yellow solid (48 g) which n.m.r. analysis revealed to consist of 2 : 1 mixture of *N*-isopropyl-*p*-nitroaniline and *p*-nitroaniline. Recrystallisation (EtOH) gave *N*-isopropyl-*p*-nitroaniline (18.2 g, 23.6%) as yellow crystals, m.p. 82—84 °C, δ, 8.13/8.03

6.54/6.44 (4 H, aromatic AA'BB'), 4.4 (1 H, broad s, NH), 3.71 (1 H, septet, C*H*Me$_2$), 1.22 (6 H, d, *Me*$_2$CH) (Found: C, 60.0; H, 6.6; N, 15.3. $C_9H_{12}N_2O_2$ requires C, 60.0; H, 6.7; N, 15.6%).

The above compound (18 g, 0.1 mol) and granulated tin (' AnalaR ') (23.7 g, 0.2 g-atom) were stirred mechanically and hydrochloric acid (10 ml) was added. An exothermic reaction occurred and a brown solution formed. When the reaction had subsided a further quantity of acid (10 ml) was added; a total of 50 ml of acid were added in this way after which the temperature was maintained at 90 °C for 1 h. The reaction mixture was cooled and stirred for several minutes with a solution of NaOH (37.5 g) in iced water (100 ml). The pale pink oil which separated was extracted into ether. The ethereal extracts were washed with water, dried ($MgSO_4$), and the solvent removed to leave a pale red oil (10.3 g, 69%) whose n.m.r. spectrum was consistent with that of *N*-isopropyl-*p*-phenylenediamine; δ 6.45 (4 H, s, aromatic), 3.42 (1 H, m, C*H*Me$_2$), 2.95 (3 H, broad s, amino H's), and 1.10 (6 H, d, *J* 7 Hz, CH*Me*$_2$).

Synthesis of Diselenides.—These compounds were mostly prepared by the literature method.[9] Thus obtained were *dibutyl diselenide*, (53%), b.p. 60—65 °C/0.05 mmHg, δ, 2.85 (4 H, t, CH_2SeSe), 1.9—1.3 (8 H, m, CH_2), 0.93 (6 H, t, C*H*$_3$ CH_2); dicyclohexyl diselenide [9] (55%), b.p. 100—104 °C/0.01 mmHg, δ 3.0 (2 H, m, SeC*H*) and 2.0—1.0 (20 H, m, cyclohexyl CH_2's); di-isopropyl diselenide (76%), δ 3.20 (2 H, septet, C*H*SeSe) and 1.43 (12 H, d, *Me*$_2$CH); dibenzyl diselenide,[9] (59%), m.p. 90—93 °C (from hexane), δ 7.22 (10 H, s, aromatics) and 3.76 (4 H, *CH*$_2$SeSe). An alternative literature procedure [10] was used to obtained didodecyl diselenide (75%), m.p. 28—30 °C (from acetone), δ 2.82 (4 H, t, CH_2SeSe), 1.8—1.0 (40 H, m, CH_2), and 0.85 (6 H, t, CH_3).

Synthesis of Oxoselenides.—1-*Phenylselenopropan*-2-*one* (Method C). Diphenyl diselenide (3.12 g, 0.01 mol) was stirred in CCl_4 (20 ml) under a nitrogen atmosphere and sulphuryl chloride (1.35 g, 0.01 mol) in CCl_4 (5 ml) was added dropwise. After 15 min this solution was added dropwise to acetone (5.8 g, 0.1 mol); each addition awaited the discharge of the red colouration associated with PhSeCl. Stirring was continued for 15 min following the addition after which the solvent was removed under reduced pressure to leave a yellow oil (3.6 g). This was distilled to give a further yellow oil, b.p. 72—74 °C/0.1 mmHg, containing >90% 1-phenylselenopropan-2-one (30% yield), δ 7.5—7.0 (5 H, m, aromatic H's), 3.41 (2 H, s, CH_2Se), and 2.14 (3 H, s, MeCO).

Se-*Butyl Ethaneselenoate*. This selenol ester was prepared by a modification of the literature method.[13] Dibutyl diselenide (13.6 g, 0.05 mol) and sodium (2.3 g, 0.1 g-atom) were added alternately in portions to liquid ammonia (100 ml) stirred under a nitrogen atmosphere. The mixture was then stirred 15 min after which the ammonia was evaporated. The residue was stirred vigorously with dry benzene (75 ml) and a solution of acetyl chloride (7.9 g, 0.1 mol) in benzene (10 ml) was added dropwise. An exothermic reaction occurred. The reaction mixture was refluxed for 1 h, cooled, and poured into water. The benzene layer was separated, dried ($MgSO_4$), and the solvent removed to leave a yellow oil (12.7 g) which contained 87% of the required product (62% yield), δ 2.86 (2 H, t, CH_2Se), 2.32 (3 H, s, MeCO), 1.8—1.2 (4 H, m, CH_2CH_2), and 0.92 (3 H, t, CH_3).

1-*Butylselenopropan*-2-*one* (Method B). A Grignard reagent was prepared in the usual way from 1-bromobutane (30 g, 0.22 mol) and magnesium (5.35 g, 0.22 g-atom) in sodium-dried ether (200 ml). This was stirred under a nitrogen atmosphere and a solution of dibutyl diselenide (54.4 g, 0.2 mol) in dry ether (50 ml) was added dropwise at a rate sufficient to cause the mixture to reflux; it was then stirred for 15 min after the addition. With vigorous stirring, a solution of chloroacetone (18.5 g, 0.2 mol) in dry ether (50 ml) was added dropwise at a rate sufficient to ensure continued refluxing of the mixture. After a period of 2 h under reflux, the mixture was cooled, poured into water, and extracted with ether. The ethereal extracts were dried ($MgSO_4$), and the solvent removed to leave a yellow oil (67 g) consisting of the required product, dibutyl diselenide, and dibutyl monoselenide. This oil was applied to a silica-gel column (1 m × 3.5 cm i.d.) and eluted with light petroleum (b.p. 30—40 °C) and then ether–light petroleum (5 : 95) which gave an oil (42 g) consisting of mono- and di-selenides. Elution with ether–light petroleum (25 : 75) gave the required product as a light yellow oil (22 g, 57%), δ 3.05 (2 H, s, $SeCH_2CO$), 2.55 (2 H, t, $SeCH_2CH_2$), 2.25 (3 H, s, COMe), 1.8—1.2 (4 H, m, CH_2CH_2), and 0.90 (3 H, t, CH_3CH_2).

5-*Butylselenopentan*-2-*one* (Method A). Liquid ammonia (500 ml) was stirred under a nitrogen atmosphere and sodium (16.1 g, 0.7 g-atom) and dibutyl diselenide (96 g, 0.35 mol) were added alternately in portions at −35 °C. The ammonia was then evaporated in a stream of nitrogen, and the residue taken up in absolute ethanol (500 ml). The solution was heated to reflux under a nitrogen atmosphere and 5-chloropentan-2-one (84 g, 0.7 mol) was rapidly added dropwise. Reflux was then maintained for 2 h. The mixture was cooled, poured into water (2 l), and extracted with ether. The combined extracts were dried ($MgSO_4$) and solvent removed to leave a dark brown oil (124 g). Distillation gave a yellow oil, b.p. 65—70 °C/0.02 mmHg consisting of the required oxoselenide and dibutyl diselenide (92 : 8 mixture). Pure oxoselenide could be obtained by column chromatography on silica gel; diselenide was eluted with a 5 : 95 mixture of ether–light petroleum (b.p. 30—40 °C) and oxoselenide with a 20 : 80 mixture: δ, 2.50 (6 H, t, CH_2CO + CH_2SeCH_2), 2.08 (3 H, s, COMe), 1.87 (2 H, m, $SeCH_2CH_2CO$) 1.8—1.2 (4 H, m, CH_2CH_2), and 0.93 (3 H, t, *Me*CH_2). Similarly prepared were 5-dodecylselenopentan-2-one, (66%), δ 2.45 (6 H, t, CH_2SeCH_2 + CH_2CO), 2.02 (3 H, s, COMe), 1.80 (2 H, m, $SeCH_2CH_2CH_2CO$), 2.0—1.0 (30 H, m, CH_2's), and 0.85 (3 H, t, CH_2CH_2); 5-cyclohexylselenopentan-2-one, (62%), δ 2.8 (1 H, broad m, CHSe), 2.50 (4 H, t, $SeCH_2$ + CH_2CO), 2.06 (3 H, s, COMe), 1.9 (2 H, m, $SeCH_2CH_2CH_2CO$), 1.7 (4 H, m, ring CH_2CHSe), and 1.4 (6 H, m, other ring CH_2's); 5-isopropylselenopentan-2-one, (40%), δ 3.04 (1 H, septet, CHSe), 2.6—2.5 (4 H, m, CH_2Se + CH_2CO), 2.08 (3 H, s, MeCO), 1.86 (2 H, m, $SeCH_2CH_2CH_2CO$), and 1.4 (6 H, d, *Me*$_2$CH); 5-benzylselenopentan-2-one, (23%), δ 7.32 (5 H, s, aromatic H's), 3.18 (2 H, s, PhC*H*$_2$Se), 2.40 (4 H, m, $SeCH_2$ + CH_2CO), 2.01 (3 H, s, MeCO), and 1.8 (2 H, m, $SeCH_2CH_2CH_2CO$); 4-butylselenobutan-2-one, (66%), δ 2.8—2.5 (6 H, m, CH_2SeCH_2 + CH_2CO), 2.10 (3 H, s, MeCO), 1.8—1.2 (4 H, m, CH_2CH_2), and 0.93 (3 H, t, CH_3CH_2); 5-butylselenopentan-3-one (65%), δ 2.68 (4 H, s, $SeCH_2CH_2CO$), 2.53 (2 H, t, CH_2Se), 2.38 (2 H, q, CH_3CH_2-Cl), 1.8—1.1 (4 H, m, CH_2CH_2), 1.04 (3 H, t, CH_3CH_2CO), and 0.94 (3 H, t, $CH_3CH_2CH_2$).

Reductive Alkylation.—The procedure using sodium cyanoborohydride is illustrated by the following examples. Yields and n.m.r data are contained in Table 1.

N-*Isopropyl*-N′-*phenyl*-p-*phenylenediamine* (IPPD). *N*-Phenyl-*p*-phenylenediamine (3.68 g, 0.02 mol) in methanol (15 ml) was stirred and concentrated HCl (2 ml) was added; this was followed by a solution of acetone (0.6 g, 0.01 mol) in methanol (5 ml). A solution of sodium cyanoborohydride (0.38 g, 0.006 mol) in methanol (10 ml) was then added dropwise during 10 min to produce a mild exothermic reaction. After the reaction mixture had been stirred for 16 h it was poured into water (150 ml) and rendered alkaline by the addition of 10% NaOH solution. The mixture was extracted with ether and the ethereal extracts washed with water and dried ($MgSO_4$). Solvent removal left a brown oil (3.5 g) h.p.l.c. analysis [ODS-2, 50 °C, EtOH–H_2O (70 : 30) at 1.5 ml/min, u.v. detection] showed this to contain 55.5% of the required product, representing a yield of 87%.

N-*Phenyl*-N′-(1-*methyl*-4-*butylselenobutyl*)-p-*phenylenediamine* (4). This compound was similarly prepared from 5-butylselenopentan-2-one (2.21 g, 0.01 mol) and was worked up, to give a brown oil (4.6 g). H.p.l.c. analysis revealed this to contain 71% of the required compound (4), corresponding to a 84% yield based upon oxoselenide. The oil was applied to a 70 cm × 2.5 cm i.d. silica gel column which had been pre-wetted with light petroleum (b.p. 30—40 °C). Elution with 10% ether in light petroleum served to remove any residual diselenide present (marked by the passage of an exothermic front down the column). Elution with 20—40% ether in light petroleum (1.5 l) then afforded fractions containing essentially pure compound (4), as a red-brown *oil* (Found: C, 64.5; H, 7.6; N, 7.3; Se, 20.7. $C_{21}H_{30}N_2Se$ requires C, 64.8; H, 7.7; N, 7.2; Se, 20.3%). Similarly prepared were the following: N-*phenyl*-N′-(1-*methyl*-4-*cyclohexylselenobutyl*)-p-*phenylenediamine* (Found: C, 67.3; H, 7.65; N, 6.65; Se, 18.5. $C_{23}H_{32}N_2Se$ requires C, 66.5; H, 7.7; N, 6.7; Se, 19.0%); N-*phenyl*-N′-(1-*methyl*-4-*dodecylselenobutyl*)-p-*phenylenediamine*, h.p.l.c. analysis required a 80 : 20 isopropyl alcohol–water solvent at 1 ml/min (Found: C, 69.0; H, 9.6; N, 5.6; Se, 15.1. $C_{29}H_{46}N_2Se$ requires C, 69.5; H, 9.2; N, 5.6; Se, 15.7%); N-*phenyl*-N′-(1-*methyl*-4-*isopropylselenobutyl*)-p-*phenylenediamine* (Found: C, 63.7; H, 7.4; N, 7.6; Se, 20.6. $C_{20}H_{28}N_2Se$ requires C, 64.0; H, 7.5; N, 7.5; Se, 21.0%); N-*phenyl*-N′-(1-*methyl*-4-*benzylselenobutyl*)-p-*phenylenediamine*, h.p.l.c. analysis revealed the crude oil to contain 29% of the required product, a purer sample was isolated by preparative h.p.l.c. whose n.m.r. spectrum was consistent with the assigned structure; N-*phenyl*-N′-(1-*methyl*-3-*butylselenopropyl*)-p-*phenylenediamine* (Found: C, 64.9; H, 7.35; N, 7.55; Se, 19.8. $C_{20}H_{28}N_2Se$ requires C, 64.0; H, 7.5; N, 7.5; Se, 21.0%); N-*phenyl*-N′-(1-*ethyl*-3-*butylselenopropyl*)-p-*phenylenediamine* (Found: C, 64.7; H, 7.7; N, 7.3; Se, 19.8. $C_{21}H_{30}N_2Se$ requires C, 64.8; H, 7.7; N, 7.2; Se, 20.3%); N-*phenyl*-N′-(1-*methyl*-2-*butylselenoethyl*)-p-*phenylenediamine* (Found: C, 63.4; H, 7.4; N, 7.2; Se, 22.1. $C_{19}H_{26}N_2Se$ requires C, 63.2; H, 7.2; N, 7.7; Se, 21.9%); N-*phenyl*-N′-(1-*methyl*-2-*phenylselenoethyl*)-p-*phenylenediamine* (Found: C, 66.0; H, 5.6; N, 7.5; Se, 19.9. $C_{21}H_{22}N_2Se$ requires C, 66.1; H, 5.8; N, 7.4; Se, 20.7%).

N-*Isopropyl*-N′-(1-*methyl*-4-*butylselenobutyl*)-p-*phenylenediamine*. This compound was obtained as a red oil by the general method except that 1.65 g (0.011 mol) of *N*-isopropyl-*p*-phenylenediamine and 2.21 g (0.01 mol) of 5-butylselenopentan-2-one were used. H.p.l.c. analysis required the use of a 80 : 20 isopropyl alcohol–water solvent at 1.5 ml/min. Column chromatographic isolation involved the use of 40% ether in light petroleum to elute the product (Found: C, 61.0; H, 8.9; N, 7.5; Se, 22.1. $C_{18}H_{32}N_2Se$ requires C, 60.8; H, 9.1; N, 7.9; Se, 22.2%).

N-(1-*Methyl*-4-*butylselenobutyl*)-p-*phenylenediamine* (5). *p*-Phenylenediamine (3.24 g, 0.03 mol) was stirred in methanol (35 ml) and concentrated HCl added (2 ml). A solution of 5-butylselenopentan-2-one (4.42 g, 0.02 mol) in methanol (10 ml) was added. A solution of sodium cyanoborohydride (0.76 g, 0.012 mol) in methanol (10 ml) was added dropwise during 10 min. After 16 h the reaction mixture was worked up as detailed for compound (4) to give a brown oil (4.75 g). H.p.l.c. analysis (Partisil 10, 50 : 50 ether–light petroleum at 2 ml/min, u.v. detection) revealed this to contain 75% of the required product (5), together with 15% of compound (6a). A pure sample was obtained as a red oil by preparative h.p.l.c. and gave an n.m.r. spectrum identical with that of (6a) except for relative integral values.

N,N′-*Bis*-(1-*methyl*-4-*butylselenobutyl*)-p-*phenylenediamine* (6a). The crude oil obtained above [4.75 g; containing 3.56 g of (5) (0.0114 mol)] was stirred in methanol (35 ml) and concentrated HCl added (2 ml). A solution of 5-butylselenopentan-2-one (1.8 g, 0.008 mol) in methanol (5 ml) was added. A solution of sodium cyanoborohydride (0.33 g, 0.005 mol) in methanol (5 ml) was added dropwise during 5 min. The resulting mixture was stirred overnight and worked up in the way described for compound (4), to give a red oil (5.25 g). This was applied to a silica-gel column pre-wetted with light petroleum (b.p. 30—40 °C), and light petroleum (1 l) was passed through. This eluted a small amount of intensely red material. Elution with 10% ether in light petroleum served to remove any residual diselenide present. The solvent system was changed to 20% and then 40% ether in light petroleum; fractions eluted by the latter contained the required compound (6a) as a red oil. Flushing the column with ether at the end of the procedure removed unchanged compound (5) (Found: C, 55.8; H, 8.4; N, 5.4; Se, 31.1. $C_{24}H_{44}N_2Se_2$ requires C, 55.6; H, 8.5; N, 5.4; Se, 30.5%), δ 6.38 (4 H, s, aromatic H's), 3.32 (2 H, m, NHC*H*Me), 2.48 (10 H, broad m, CH_2SeCH_2 + N*H*, reduced to 8 H by addition of D_2O), 1.7—1.2 (16 H, m, CH_2's), 1.12 (6 H, d, NHCH*Me*), and 0.91 (6 H, t, CH_3).

N-(1-*Methyl*-4-*butylselenobutyl*)-N′-(1-*methyl*-2-*phenylselenoethyl*)-p-*phenylenediamine* (6b).—This compound was prepared from (5) and 1-phenylselenopropan-2-one (1.7 g, 0.008 mol) as described for compound (6a). Similar work-up gave a brown oil which h.p.l.c. analysis indicated as containing 33% of the required compound (6b), and 21% of compound (6a). Preparative h.p.l.c. gave a pure sample of (6b) (Found: C, 56.2; H, 7.4; N, 5.6; Se, 30.5. $C_{24}H_{36}N_2Se_2$ requires C, 56.4; H, 7.1; N, 5.5; Se, 30.9%), δ 7.45/7.2 (3 H/2 H, m, C_6H_5), 6.3 (4 H, s, C_6H_4), 3.5—2.7 (6 H, 2 × C*H*NH + 2 × N*H* + PhSeSeCH_2), 2.50 (4 H, m, CH_2SeCH_2), 1.7—1.3 (8 H, m, CH_2CH_2), 1.21/1.11 (3 H/3 H, 2 × d, 2 × *Me*CHNH), and 0.90 (3 H, t, CH_3CH_2).

N-*Phenyl*-N′-(*butylselenoacetyl*)-p-*phenylenediamine* (7). Liquid ammonia (50 ml) was stirred under a nitrogen atmosphere and dibutyl diselenide (1.36 g, 0.005 mol) and sodium (0.23 g, 0.01 g-atom) were added alternately in portions. After addition the ammonia was evaporated in a stream of nitrogen and the residue taken up in absolute ethanol (50 ml) and stirred at 70 °C under a nitrogen atmosphere. *N*-Phenyl-*N*′-(chloroacetyl)-*p*-phenylenediamine (2.6 g, 0.01 mol), as a suspension in ethanol (30 ml), was then added in portions. The reaction mixture was then refluxed for 1 h after which it was cooled and poured into water (250 ml).

The mixture was extracted with ether and the extract dried ($MgSO_4$). Removal of solvent gave a brown oil (4.8 g) which was shown by h.p.l.c. analysis (ODS-2, 60 : 40 EtOH : H_2O at 1.5 ml/min, u.v. detection) to contain 73% of the required product (7). The oil was applied to a silica-gel column and residual diselenide removed with 10% ether in light petroleum (b.p. 30—40 °C) as eluant. Elution with 40% ether in light petroleum gave essentially pure compound (7) as a yellow solid, m.p. 75—76 °C (Found: C, 59.4; H, 6.2; N, 7.4; Se, 21.4. $C_{18}H_{23}N_2OSe$ requires C, 59.8; H, 6.1; N, 7.7; Se, 21.9%), δ 7.5—6.8 (9 H, m, aromatic H's), 3.20 (2 H, s, $COCH_2Se$), 2.58 (2 H, t, $SeCH_2CH_2$), 1.8—1.2 (4 H, m, CH_2CH_2), and 0.92 (3 H, t, CH_3CH_2).

Larger-scale preparations gave crude products containing unchanged starting chloride. Chromatography on silica gel in ether–light petroleum separated compound (7) and starting chloride from other materials, but it was necessary to employ a second purification on silica gel, to separate pure (7). This used 10% acetone in light petroleum (b.p. 30—40 °C) as eluant. (NOTE: Most other SEPDA's undergo decomposition if chromatographed on silica gel with acetone-containing eluants.)

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