COOH), 7.97, 7.71 (1 H, d, CH=CHCOOH, J = 16 Hz), 7.51–7.10 (3 H, m, aromatic H), 6.59, 6.34 (1 H, d, CH=CHCOOH, J = 16 Hz), 3.08–2.64 (4 H, m, benzylic H), 2.15–1.45 (6 H, m). Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.46. Found: C, 77.48; H, 7.49.

Acknowledgment. Financial support from the National Research Council of Canada and the President's Research Fund, Carleton University is gratefully acknowledged. The assistance of E. Isabelle, T. Ceska, and D. Taylor on some aspects of the characterizations is greatly appreciated.

Registry No.—**1a,** 65898-31-9; **1b,** 65898-32-0; **1c,** 65898-33-1; **1d,** 51932-70-8; **1d** DNP, 65898-34-2; **1e,** 4044-54-6; **1f,** 65898-35-3; **2a,** 18775-42-3; **2b,** 65898-36-4; **2c,** 51632-06-5; **2d,** 30084-91-4; **2d** DNP, 65898-37-5; **2e,** 65898-38-6; **2f,** 56635-88-2; **3a,** 17450-62-3; **3b,** 65898-39-7; **3c,** 41790-30-1; **3d,** 41828-13-1; **3d** DNP, 65898-40-0; **3e,** 4242-18-6; **3f,** 65898-41-1; **4a,** 17450-63-4; **4b,** 65898-42-2; **4c,** 6883-81-4; **4d,** 51529-97-6; **4d** DNP, 65898-43-3; **4e,** 1131-63-1; **4f,** 7498-69-3; **5a,** 65898-44-4; **5b,** 65898-45-5; **5c,** 65898-46-6; **5d,** 65898-47-7; **5d** DNP, 65898-48-8; **5e,** 4087-43-8; **5f,** 65898-49-9; **6a,** 41635-37-4; **6b,** 55037-99-5; **6c,** 65898-50-2; **6d,** 65898-51-3; **6d** DNP, 65898-27-3; **6e,** 41068-24-0; **6f,** 65898-28-4; indan, 496-11-7; tetralin, 119-64-2; benzosuberane, 1075-16-7; *o*-xylene, 95-47-6; 3-(chloromethyl)-*o*-xylene, 13651-55-3; 4-(chloromethyl)-*o*-xylene, 102-46-5.

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(29) The following examples represent typical systematic names for the types of compounds described in this paper: **1f**, 3-(4-indanyl)propenoic acid; **4d**, 5,6,7,8-tetrahydronaphthalene-2-carboxaldehyde; **5e**, benzcycloheptene-2-carboxylic acid.

Metalation of Ethylbenzene with *n*-Pentylsodium in the Presence of *N,N,N′,N′*-Tetramethylethylenediamine

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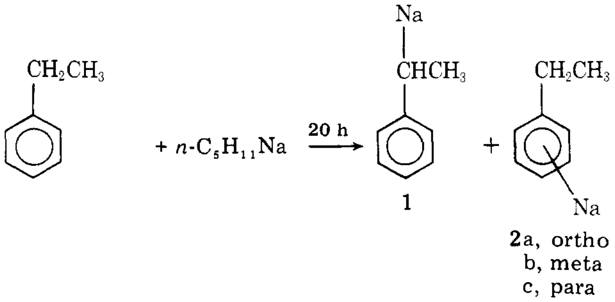
Ethylbenzene was metalated with *n*-pentylsodium activated by *N,N,N′,N′*-tetramethylethylenediamine (TMEDA) to give exclusively α-methylbenzylsodium (**1**) after 1 h in yields in excess of 95%. An examination of the reaction at shorter reaction times (5, 15, and 30 min) revealed that metalation occurred initially in a kinetically controlled process giving, in addition to **1**, *o*-, *m*-, and *p*-ethylphenylsodium (**2a, 2b,** and **2c**) and a disodio compound identified as α,α-disodioethylbenzene (**3**). With time, the ring and disodio compounds isomerized to the α isomer **1** in a thermodynamically controlled sequence.

Relatively few reports appear in the literature regarding the activation of organosodium reagents such as *n*-pentylsodium with *N,N,N′,N′*-tetramethylethylenediamine (TMEDA) even though this effect is well documented for the corresponding organolithium reagents.[2] Trimitsis and coworkers[3] found that *n*-pentylsodium in the presence of TMEDA promoted the quantitative dimetalation of 1,3-dimethylnaphthalene and *m*-xylene on the benzylic carbons. In the absence of TMEDA, monometalation occurred in low yield. Recently, this laboratory[4] reported that cumene was metalated with *n*-pentylsodium activated with TMEDA to give α-cumylsodium in good yields and high isomeric purity. When TMEDA was omitted from the reaction, metalation occurred on the ring giving *m*- and *p*-isopropylphenylsodium.

In view of the rather profound effect which TMEDA had on the above reactions, we were prompted to investigate the metalation of ethylbenzene by *n*-pentylsodium in the presence of TMEDA. Previously, Benkeser and co-workers[5] reported that ethylbenzene was metalated by *n*-pentylsodium (no TMEDA) giving 68% α-methylbenzylsodium (**1**) along with 19% *m*- and 13% *p*-ethylphenylsodium (**2b** and **2c**) in an



1

2a, ortho
b, meta
c, para

Table I. Metalation of Ethylbenzene with *n*-Pentylsodium in the Presence of TMEDA as a Function of Time[a]

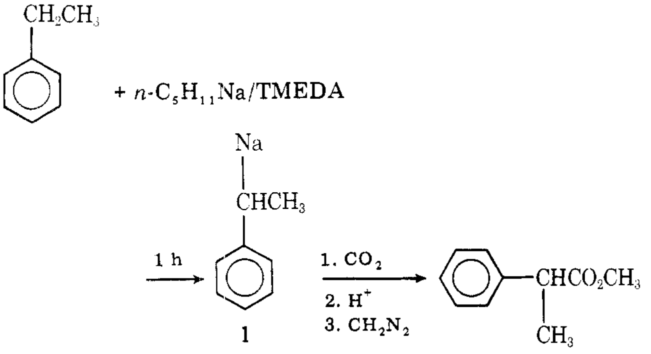
Time,	Product distribution, %[b]				
min	α	Ortho	Meta	Para	Di
5	12 (13)[c]	2 (2)	55 (57)	28 (25)	3 (3)
15	27 (31)	2 (2)	41 (38)	24 (21)	6 (8)
30	77 (87)	0 (0)	14 (7)	9 (6)	0 (0)
60	100 (100)	0 (0)	0 (0)	0 (0)	0 (0)

[a] The values reported in this table were obtained by removing and carbonating aliquots at 5-, 15-, and 30-min increments and carbonating the reaction after 60 min. [b] The yield of the combined crude esters was in excess of 95% for both sets of data. [c] Values in parentheses represent the results of a duplicate experiment.

overall yield of 46% after 20 h. At shorter reaction times, metalation occurred in a kinetically controlled process preferentially on the ring followed by a slow ring to side-chain isomerization.

Results and Discussion

The metalation of ethylbenzene with *n*-pentylsodium in the presence of TMEDA for 1 h gave *exclusively α-methylbenzylsodium* (**1**) *in a near quantitative yield*[6] based on the isolation of methyl 2-phenylpropanoate (**3**) upon carbonation and esterification of the reaction. The identity of **3** was established by comparing its IR and NMR spectra and VPC retention time with an authentic sample of this compound. Practically all of the *n*-pentylsodium was consumed as adjudged by the trace quantity of methyl hexanoate observed in the gas chromatogram.[7] In the absence of TMEDA, metalation of ethylbenzene gave in our hands 41% of the meta isomer **2b,** 33% of the para isomer **2c,** and 26% of the α isomer **1** in an overall yield of 55% after 24 h.



1

3

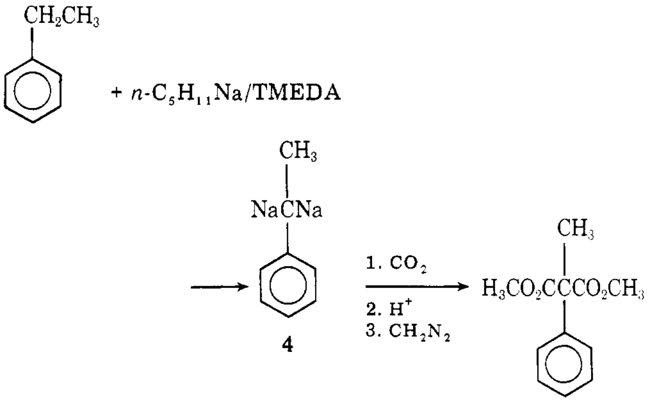
The metalation of ethylbenzene was also studied as a function of time by removing aliquots from the reaction. Table I shows that ethylbenzene was metalated with the *n*-pentylsodium/TMEDA reagent at short reaction times in a kinetically controlled fashion giving rise to ring and side-chain compounds (**1** and **2**) and a disodio compound. With time the ring compounds and the disodio compound rapidly equilibrated to α-methylbenzylsodium (**1**) in a thermodynamically controlled process. Presumably, the driving force for the equilibration was the stability derived from benzylic resonance. Previous work[5] has demonstrated that this equilibration is a transmetalation sequence occurring in the presence of excess ethylbenzene. It is important to note that the α isomer did not arise by the metalation of ethylbenzene with *n*-pentylsodium over the 1 h reaction period since the *n*-pentylsodium was practically all consumed in the first 5 min of reaction. This observation is based on the small quantity of methyl hexanoate found in the gas chromatogram of the 5-min sample using our usual method of analysis.

The disodio compound which formed at short reaction times was shown to be α,α-disodioethylbenzene (**4**) based on the isolation of dimethyl methylphenylmalonate (**5**) after carbonation, esterification, and vacuum distillation of the reaction. The identity of **5** was established by comparing its IR and NMR spectra and VPC retention time with an authentic sample synthesized from dimethyl phenylmalonate via a malonic ester synthesis. Admittedly, we were surprised to find that dimetalation yielded a product in which both sodiums were on the benzylic carbon. One would have predicted that such a compound would be so reactive that it would isomerize to a monosodio compound before its isolation as the dimethyl ester. Presumably, the short term stability of **4** could be due to its insolubility in the reaction mixture, thus slowing its conversion to the isomer **1**. It is of interest to point out that compounds in which two metal atoms are on the same carbon are not without precedence in the literature. West and Jones[8] reported that lithiation of toluene employing *n*-butyllithium in the presence of TMEDA gave α,α,p-trilithiotoluene in addition to the mono- and dilithiotoluenes.

Table II. Isomerization of *p*-Ethylphenylsodium[a] in the Presence of TMEDA[b]

Time,	Product distribution, %[c]				
min	α	Ortho	Meta	Para	Di
0[d]	0	0	0	100	0
5	4.5	trace	24.5	71	trace
15	21	2	39	38	0
30	61	2	20	13	4
60	100	0	0	0	0

[a] Prepared from *p*-bromoethylbenzene and sodium. [b] The values reported in this table were obtained by removing and carbonating aliquots at 0-, 5-, 15-, and 30-min increments and carbonating the reaction after 60 min. [c] The yield of the combined crude esters was 70% based on the starting *p*-bromoethylbenzene. [d] The data obtained at 0 min represent the isomer distribution prior to the addition of ethylbenzene and TMEDA.



4

5

In a related experiment, a sample of pure *p*-ethylphenylsodium prepared from *p*-bromoethylbenzene and sodium was permitted to equilibrate in the presence of ethylbenzene and TMEDA. Table II shows that initially the *p*-ethylphenylsodium reverted to the α, ortho, and meta isomers in addition to the di compound. After 1 h these compounds equilibrated to the more thermodynamically stable α isomer **1**. These findings corroborate the data presented in Table I and attest once again to the rapid formation of the α isomer in the presence of TMEDA. In sharp contrast, Benkeser and coworkers[5] reported that the isomerization of either *o*-, *m*-, or *p*-ethylphenylsodium in the presence of ethylbenzene (no TMEDA) gave only a 62% to 88% conversion to the α isomer even after 20 h.

An interesting comparison can be made between our findings and the corresponding lithium system. Broaddus[9] reported that ethylbenzene was metalated by *n*-butyllithium

Table III

Ester	Synthetic mixture, mol %	VPC analysis, %
α	31	31
Ortho	8	8
Meta	24	24
Para	29	28
Di	9	9

activated with TMEDA to give 38% α-methylbenzyllithium and 9% *o*-, 36% *m*-, and 17% *p*-ethylphenyllithium after 0.5 h. However, after 6.5 h, the isomer distribution remained unchanged demonstrating that no ring to side-chain conversions were occurring. Thus, in the sodium system the reaction is initially kinetically controlled followed by a rapid isomerization of the ring isomers **2** to the thermodynamically more stable α isomer **1**. In contrast, in the lithium system, metalation occurs either in a strictly kinetically controlled sequence on the ring or isomerization of the kinetic products to the thermodynamically favored α isomer is too slow to be observed in the 6.5 h reaction period.

In summary, the rapid ring to side-chain isomerization giving rise to α-methylbenzylsodium, the high yield of metalation products, and the formation of α,α-disodioethylbenzene once again attests to the profound activating influence which TMEDA has on these reactions. Presumably, the organosodium reagents complex with the TMEDA producing very reactive metalating agents. With *n*-pentylsodium, this effect accounts for the high yield of metalation products and, possibly, the formation of α,α-disodioethylbenzene. Similarly, under the influence of TMEDA, the ring sodio compounds are activated as metalating agents, thus promoting the rapid ring to side-chain transmetalation sequence. The exclusive formation of α-methylbenzylsodium can be explained by complex formation between the benzylic sodium and the TMEDA producing a resonance or peptizing effect as discussed in our previous paper.[4]

Experimental Section

Organosodium reactions were run in a Morton flask fitted with a Stir-O-Vac (La Pine Scientific Co.) high-speed stirring apparatus under a positive nitrogen pressure. All glassware employed in these reactions was dried in an oven at 110 °C and flushed with nitrogen before use. *n*-Octane, 1-chloropentane, and ethylbenzene were purified by standard techniques. TMEDA was distilled from CaH_2 immediately before use. NMR spectra were obtained on a Hitachi Perkin-Elmer R20A spectrometer and IR spectra on a Perkin-Elmer 457 spectrometer.

Reference Compounds. Methyl 2-phenylpropanoate and methyl *o*-, *m*-, and *p*-ethylbenzoate were prepared by esterifying the corresponding carboxylic acids with diazomethane. 2-Phenylpropanoic acid was purchased from Aldrich Chemical Co. and *o*- and *p*-ethylbenzoic acids were prepared by reacting *o*- and *p*-bromoethylbenzene (Aldrich Chemical Co.) with magnesium followed by carbonation. *m*-Ethylbenzoic acid was synthesized from *m*-ethylaniline (Aldrich Chemical Co.) by an adaptation of a standard literature method.[10]

Dimethyl methylphenylmalonate was prepared by treating phenylmalonic acid (Aldrich Chemical Co.) with excess diazomethane followed by the reaction of the resulting dimethyl ester with sodium methoxide prepared from 1.7 g (0.074 mol) of sodium in 40 mL of anhydrous methanol. To the resulting solution was added 10.65 g (0.075 mol) of methyl iodide using an adaptation of a literature procedure.[11] The dimethyl methylphenylmalonate boiled at 98 °C (0.6 mm) [lit.[12] 144–147 °C (9 mm)] and gave the expected IR and NMR spectra.

Analytical Method. Metalation reactions were analyzed by carbonating the reaction mixtures and esterifying the resulting carboxylic acids with diazomethane. The resulting methyl esters were analyzed on a Perkin-Elmer Model 3920 gas chromatograph equipped with a thermal conductivity detector using a 12 ft × 1/8 in. Apiezon L column (15% on Chromosorb W) at a column temperature of 200 °C with a helium flow of ca. 50 cm^3/min. Analysis of an authentic mixture of methyl esters demonstrated the validity of the analytical technique as listed in Table III.

***n*-Pentylsodium.** To a vigorously stirred 9.2 g (0.4 mol) sodium dispersion in 125 mL of octane maintained at −10 to −20 °C was added 16.0 g (0.15 mol) of 1-chloropentane in 25 mL of octane over 1.5 h. The resulting *n*-pentylsodium was stirred for an additional 0.5 h at −10 to −20 °C to ensure complete reaction.

Metalation of Ethylbenzene with *n*-Pentylsodium in the Presence of TMEDA. To a *n*-pentylsodium sample in 150 mL of octane was added 31.8 g (0.3 mol) of ethylbenzene and 23.2 g (0.2 mol) of TMEDA. After the mixture stirred for 1 h at room temperature, carbonation was effected by pouring the reaction onto a dry ice–ether slurry. The resulting mixture was hydrolyzed followed by workup and esterification with diazomethane employing a previously described method.[4] VPC analysis of the crude product revealed that it was composed exclusively of methyl 2-phenylpropanoate. Distillation of this product gave 15.9 g (97% yield) of pure methyl 2-phenylpropanoate, bp 91 °C (6.5 mm) [lit.[13] 119 °C (22 (mm))], whose IR and NMR spectra were superimposable with a reference sample.

Metalation of Ethylbenzene with *n*-Pentylsodium in the Absence of TMEDA. Ethylbenzene was metalated with *n*-pentylsodium for 24 h in the absence of TMEDA at room temperature using the above procedure. A 55% yield of crude ethylbenzene methyl esters was realized consisting of 26% α, 41% meta, and 33% para isomers.

Metalation of Ethylbenzene with *n*-Pentylsodium in the Presence of TMEDA as a Function of Time. To a *n*-pentylsodium sample in 150 mL of octane was added 31.8 g (0.30 mol) of ethylbenzene and 23.2 g (0.2 mol) of TMEDA. Aliquots (20 mL) were removed and carbonated at 5-, 15-, and 30-min increments followed by carbonation of the reaction at 60 min. The results obtained upon workup, esterification, and VPC analysis of the samples appear in Table I. Additionally, the 5-min sample contained only trace quantities of *n*-pentylsodium based on the low concentration of methyl hexanoate in the gas chromatogram of this sample.

Isomerization of *p*-Ethylphenylsodium in the Presence of TMEDA. *p*-Ethylphenylsodium was prepared by the addition of 18.5 g (0.1 mol) of *p*-bromoethylbenzene to a 6.9 g (0.3 mol) sodium dispersion over 1.5 h. Initially the *p*-ethylbromobenzene solution was added to the sodium dispersion at room temperature until the reaction commenced as adjudged by the darkening of the mixture. At this point the flask was cooled to −10 to −20 °C. After the *p*-bromoethylbenzene was added, the mixture was stirred for an additional 0.5 h at −10 to −20 °C before a 20-mL aliquot was removed and carbonated prior to the addition of ethylbenzene and TMEDA to identify the isomer distribution at zero time. Ethylbenzene (26.6 g, 0.25 mol) and TMEDA (17.4 g, 0.15 mol) were then added to the flask. Aliquots (20 mL) were removed and carbonated at 5-, 15-, and 30-min increments followed by carbonation of the reaction at 60 min. The samples were worked up, esterified with diazomethane, and analyzed in the usual manner giving the results appearing in Table II.

Registry No.—**1**, 29706-16-9; **2a**, 65749-01-1; **2b**, 65749-02-2; **2c**, 65749-03-3; **3**, 31508-44-8; **4**, 65749-04-4; **5**, 65749-05-5; TMEDA, 110-18-9; ethylbenzene, 100-41-4; *n*-pentylsodium, 1822-71-5; *p*-bromoethylbenzene, 1585-07-5; methyl *o*-ethylbenzoate, 50604-01-8; methyl *m*-ethylbenzoate, 50604-00-7; methyl *p*-ethylbenzoate, 7364-20-7; 1-chloropentane, 543-59-9.

References and Notes

(1) T. F. C. wishes to express his appreciation to the Faculty Development Program of the University of Wisconsin—Oshkosh for financial assistance which made this research possible.

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(7) Carbonation and esterification of *n*-pentylsodium give methyl hexanoate.

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