

THE ROSENMUND REDUCTION OF  
4-PHENYL-3-BUTENOYL CHLORIDE

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By

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Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1949

Submitted to the Faculty of the Graduate School of  
the Oklahoma Agricultural and Mechanical College  
in Partial Fulfillment of the Requirements  
for the Degree of  
MASTER OF SCIENCE

1951

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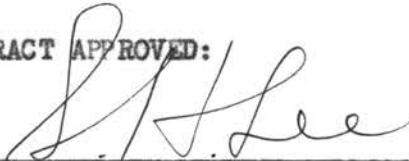
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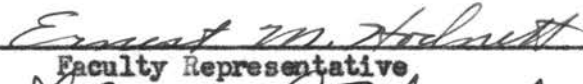
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THESIS AND ABSTRACT APPROVED:



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## ACKNOWLEDGEMENT

The author wishes to express his appreciation to Dr. Samuel H. Lee, under whose sponsorship and direction this investigation was done. He also wishes to acknowledge the assistance of Mr. John J. Hawkins in determining the experimental physical constants listed in Table I.

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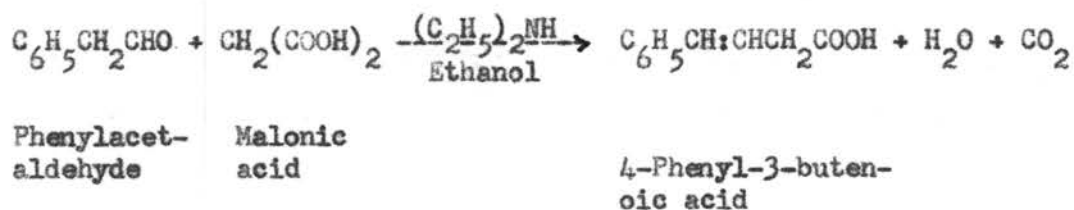
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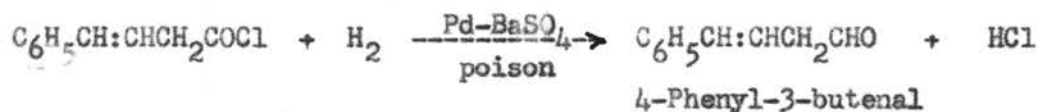
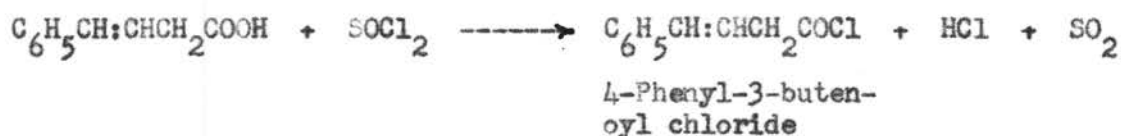
During the course of an investigation it is often either necessary or advantageous to make use of an aldehyde as a means of achieving a desired product. The very nature of aromatic aldehydes (i.e., sensitivity toward air oxidation and/or polymerization on standing) prohibits the commercial availability of all except those for which there is a considerable demand; therefore, in many instances the desired aldehyde must be obtained by synthesis.

The literature contains only one method for the preparation of 4-phenyl-3-butenal (22). This method requires the synthesis and purification of nine intermediate compounds in order to obtain this aldehyde from readily available starting materials. This, in conjunction with the required conditions for the final conversion - a pyrolysis at 280-300°, at which temperatures the aldehyde is unstable - suggested the improbability of obtaining the aldehyde on a preparative scale.

Of the various general methods for the preparation of aldehydes, the Rosenmund reduction of acid chlorides seemed to suggest the most interesting possibilities, and was therefore the reaction used.

The following scheme was decided upon in anticipation of obtaining the aldehyde, 4-phenyl-3-butenal:

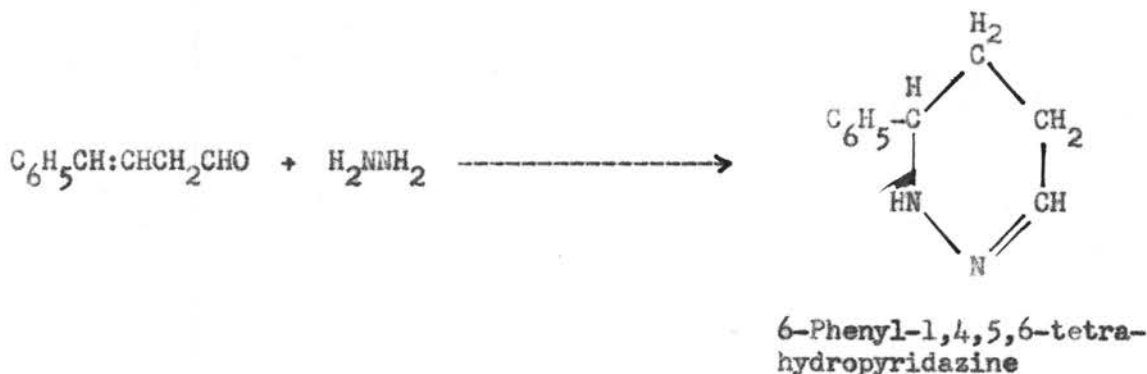




Of the various methods reported (38, 1, 6) for the preparation of 4-phenyl-3-butenic (styrylacetic) acid, that of Linstead and Williams (21) seemed the most promising in that it was simple and straight-forward and gave the most favorable yield. The phenylacetaldehyde-malonic acid condensation is the method suggested by Linstead and Williams.

$\alpha$ ,  $\beta$ -Unsaturated aldehydes generally undergo a condensation-cyclization reaction with hydrazine to yield the corresponding pyrazolines. By analogy, might not  $\beta$ ,  $\gamma$ -unsaturated aldehydes also undergo the same type reaction to give derivatives containing the pyridazine nucleus even though the conjugation between the carbonyl and the double bond is no longer present?

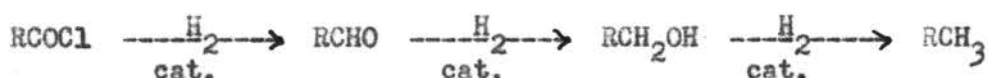
The purpose of this investigation was to prepare 4-phenyl-3-butenal, react it with hydrazine, and try to determine whether or not cyclization had occurred. The desired reaction is presented as follows:



## H I S T O R I C A L

The selective catalytic reduction of an acid chloride to the corresponding aldehyde is known as the Rosenmund reduction (30). This is often the easiest means of obtaining an aldehyde when the corresponding acid is readily available.

The conditions that permit the formation of the aldehyde from the acid chloride are also conducive to further reduction according to the following sequence of reactions:



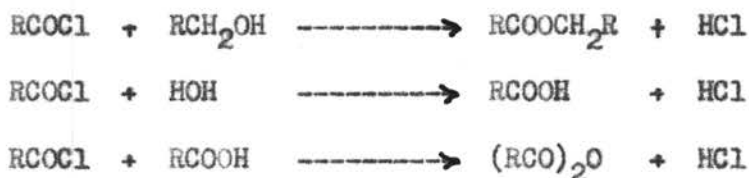
Therefore, it is apparent that a catalyst regulator is necessary which permits the reduction of the acid chloride to the aldehyde and simultaneously inactivates the catalyst toward further reduction.

The necessity for a catalyst poison or regulator was recognized by Rosenmund and Zetzsche (32) when they failed to get reproducible results from the reduction of benzoyl chloride to benzaldehyde using purified solvents. The earlier results (30) had been practically quantitative when technical grade solvents were used; and this success was doubtless due to impurities, in the solvent and/or the acid chloride, which regulated the reducing power of the catalyst.

In the event the aldehyde be reduced further to the alcohol and hydrocarbon, both the alcohol and water formed will react with the acid chloride to produce the acid and ester. The acid thus formed is capable of reacting with the acid chloride to yield the acid anhydride.



These reactions proceed according to the following scheme:



The anhydride formation becomes pronounced in the reduction of heterocyclic acid chlorides with improperly treated hydrogen, i.e., hydrogen that has not had the last traces of oxygen and moisture removed (28).

As other side reactions, the formation of the ether,  $\text{RCH}_2\text{OCH}_2\text{R}$ , and cleavage of the ester,  $\text{RCOOCH}_2\text{R}$ , to the acid,  $\text{RCOOH}$ , and the hydrocarbon,  $\text{RCH}_3$ , have been encountered (34).

Many heterocyclic acid chlorides (24) undergo reductive removal of the  $-\text{COCl}$  group as follows:



This cleavage has been observed as a side reaction in the aromatic series as well, e.g., in the preparation of *p*-anisaldehyde (34), 3,4,5-trimethoxybenzaldehyde (37), and 2-naphthaldehyde (17).

Palladium supported on barium sulfate is the catalyst most commonly used. The palladium content is usually 5 per cent, occasionally 2-3 per cent, and less commonly 10 per cent. Catalyst supports such as charcoal (30, 9), kieselguhr (32, 9, 33), asbestos (8), and calcium carbonate (39) have been reported. Other metals such as platinum (12, 36), nickel (30, 12, 31), and osmium (9) have been used but seemingly without any definite advantage over palladium. Generally, the catalyst-acid chloride ratio is from 1:5 to 1:10 (17, 24).

The catalyst regulator is usually an organic sulfur compound.

Thioquinanthrene and Quinoline-S, a crude preparation of thioquinanthrene, are the ones most commonly used. Thiourea has also been employed. Generally, 10 mg. of regulator per gram of catalyst is satisfactory (17). The absolute necessity for a catalyst poison in every case is questionable in view of the fact that fully two-thirds of the reported reductions were conducted without the use of a regulator (24). In two instances, the use of a regulator was definitely disadvantageous: from 1-phenyl-3-methyl-5-chloropyrazole-4-carboxylic acid chloride the acid anhydride was obtained as the main product (28), and 2-anthraquinonecarbonyl chloride gave a very poor yield of the aldehyde (23).

Xylene is the solvent most favored as the reduction medium. Benzene, toluene, tetralin and decalin are used to a lesser extent. For the sake of reproducible results, it is recommended that purified solvents be employed with a known amount of regulator added when deemed necessary (24).

The reaction temperature will vary with the solvent and the acid chloride; nevertheless, the optimum condition is the lowest possible temperature which permits a constant evolution of hydrogen chloride. rac.-Pilopic acid chloride is reduced at room temperature in good yield (25) whereas isovaleraldehyde is produced quantitatively in the vapor phase (8).

Commercial electrolytic hydrogen is satisfactory for the reduction of most acid chlorides. When the last traces of oxygen and moisture must be removed, as in the case of heterocyclic acid chlorides, the hydrogen is passed over a red-hot copper spiral (29) and dried over Drierite (17).

The yields obtained in the Rosemund reaction vary from zero to quantitative. Concerning the products obtained other than (and in some

cases in lieu of) the expected aldehyde, only a few examples will be cited. Triphenylacetyl chloride was converted quantitatively to triphenylmethane (3). Succinyl chloride yielded mainly butyrolactone with  $\beta$ -formylpropionic acid and succinic anhydride as by-products (9). 1-Phenylpyrazole-5-carboxylic acid chloride gave a considerable amount of 1-phenylpyrazole (29). 3-Methoxy-4-acetoxybenzoyl chloride was converted to vanillin in 82 per cent yield (35).

The extent to which reducible groups other than  $-\text{COCl}$  in a molecule may interfere with the Rosenmund reduction is not known and generalizations cannot be made as yet concerning them (24). Acid chlorides containing nitro or halogen groups have been successfully reduced without affecting the groups mentioned (32). Certain halogenated pyridinyl acid chlorides have given the corresponding halogenated aldehydes in the absence of a regulator (11, 10). Cinnamoyl chloride has given 50-60 per cent yields of cinnamaldehyde (35) whereas, undecylenoyl chloride resulted in both partial reduction and extensive migration of the double bond (5). However, this might be expected since isolated double bonds are generally more susceptible to catalytic hydrogenation than conjugated double bonds.

An excellent review of the Rosenmund reduction with a survey of the literature to November, 1947 has been made by Mosettig and Mozingo (24) and the accumulated data on all reported reactions are summarized in concise, tabulated form.

E X P E R I M E N T A LPurification of Xylene (17)

Approximately 600 ml. of technical-grade xylene was charged to a liter round-bottom flask, refluxed over 3 g. of sodium for 14 hours, decanted into a liter distillation flask containing a fresh 3-g. supply of sodium and distilled. The distillate was then stored over 3 g. of sodium.

Purification of Thionyl Chloride (7)

To a 200-ml. round-bottom flask were charged 50 ml. of technical grade thionyl chloride (Eastman Kodak Co.) and 10 ml. of quinoline. The contents of the flask were intimately mixed and distilled. The distillate was charged to a 200-ml. round-bottom flask, intimately mixed with 20 ml. of boiled linseed oil and distilled. The water-white thionyl chloride (b.p. 73-75°) was stored in a paraffin-sealed, glass-stoppered bottle. The yield of purified thionyl chloride was approximately 80 per cent of the original material.

Preparation of Palladium Catalyst (40)

Palladium chloride was prepared from metallic palladium in the following manner: to 1.002 g. of palladium in a small, porcelain casserole was added 5 ml. of concentrated hydrochloric acid to dissolve any impurities present. The palladium was filtered and then taken up in two 10-ml. portions of aqua regia and the solution was evaporated almost to dryness on the steam bath after each digestion. The garnet-colored crystals were taken up in

three 7-ml. portions of concentrated hydrochloric acid and evaporated to dryness as before. The yield of palladium chloride was 1.626 g. and represents a 97.4 per cent conversion of palladium to the chloride. The palladium chloride was dissolved in about 30 ml. of hot distilled water containing a drop of concentrated hydrochloric acid.

Barium sulfate was precipitated in the cold by adding an aqueous solution of sodium sulfate (6.084 g. in 300 ml. of distilled water) to an aqueous solution of barium chloride dihydrate (10.44 g. in 300 ml. of distilled water). The barium sulfate was suspended in the supernatant liquid by a high speed, power stirrer. The previously prepared palladium chloride solution was added to the stirred solution. Next, the palladium was precipitated as the hydroxide on the suspended barium sulfate by the slow addition of a slight excess of approximately 2 N, aqueous sodium carbonate.

After the material had settled, the supernatant liquid was decanted and the chocolate-brown residue washed repeatedly with distilled water until the washings no longer gave a test for alkalinity with Hydrion indicator paper. The catalyst was then filtered with gentle suction and dried over potassium hydroxide pellets for 8 days. The yield was 11.96 g.

#### Preparation of Quinoline-S (17)

To an 8-inch test tube arranged for reflux were charged 1 g. of sulfur and 6 g. of freshly distilled C. P. grade quinoline (Eastman Kodak Co.) and the mixture was refluxed for 5 hours. The resulting dark brown crystals (Hershberg and Cason (12) reported a dark brown liquid) were dissolved in sufficient purified xylene to make 70 ml. of solution.

The above procedure was repeated using twice-distilled quinoline but again a mass of dark brown crystals was obtained in lieu of the dark brown liquid. Closer examination indicated the presence of three different crystalline modifications: colorless needles, light brown shiny platelets, and a dark brown powder. Separation by selective solvent extraction was tried without success. Ethanol-water, methanol-water, acetone-water, 1,4-dioxan-water, ether, petroleum ether and benzene were the solvents used.

#### Preparation of 4-Phenyl-3-butenoic Acid

The following procedure is essentially the one suggested by Linstead and Williams (21).

Technical-grade phenylacetaldehyde (50 per cent in ethanol, Matheson) was freshly distilled at a pressure of approximately 40 mm. of mercury before each run. Since the material distilled without apparent separation of alcohol and aldehyde, it was assumed that half of the distillate was phenylacetaldehyde. Diethylamine was used as a catalyst.

To a liter round-bottom flask arranged for reflux were charged 146 g. of freshly distilled aldehyde-alcohol mixture, 61 g. of malonic acid (Eimer and Amend), an additional 160 ml. of absolute ethanol, and 12 drops of diethylamine. The mixture was refluxed for 6 hours, cooled, and poured into an excess of 2 N sodium carbonate. The reaction mixture was extracted with ether and the aqueous layer was neutralized with dilute sulfuric acid. The oil that first formed crystallized readily when the wall of the container was scratched with a glass rod. The crude white crystals melted at  $78 - 83^{\circ}$  and then at  $83.5 - 85^{\circ}$  after one recrystallization from ethanol. Linstead and Williams reported a melting point of  $87^{\circ}$ .

The average yield for five runs was 20 per cent with variations in yield from 7 to 37 per cent. The yield of acid decreased with increasing age of the original aldehyde-alcohol solution. Linstead and Williams (21) reported a yield of 60 per cent but noted that the lower yields sometimes obtained were due to extensive esterification.

The ether extract from the first run was investigated after removal of the ether by distillation on the steam bath. A 10-ml. sample was refluxed with an excess of 60 per cent aqueous potassium hydroxide for 3 1/2 hours. The mixture was cooled and extracted with ether, and the aqueous layer was neutralized with dilute sulfuric acid producing a cloudy solution, but no acid settled out.

Since the original ether extract still gave positive aldehyde tests with both Schiff reagent and methone, a recovery of phenylacetaldehyde was attempted. Unless otherwise noted, all qualitative tests used for characterization and identification are those suggested by Cheronis and Entrikin (2).

After removing the solvent from the remaining ether extract, on the steam bath, the material was charged to a Claisen flask and distilled at 40 mm. of mercury pressure. Two cuts were taken: Cut I (approximately 60 ml.) distilling at 105 - 135° and Cut II (approximately 30 ml.) distilling at 137-165°. Both cuts were treated as previously described. No acid was obtained from Cut I; however, Cut II yielded approximately 0.2 g. of acid when the neutralized aqueous layer had stood for 2 days at room temperature.

One of the five runs gave such a poor yield of acid (7 per cent) and smelled so strongly of ester that extensive esterification was assumed to have occurred. Therefore, the oily layer from the ether extract was charged to a 500-ml. round-bottom flask containing an excess of 5 N aqueous sodium hydroxide

and refluxed for 5 1/2 hours. The reaction mixture was cooled, extracted with ether, and the aqueous layer was neutralized with dilute sulfuric acid, whereupon considerable cloudiness was observed. No acid was obtained, however, even when the solution was concentrated to half its original volume by evaporation and the residue was chilled in an ice bath.

#### Preparation of 4-Phenyl-3-butenoyl Chloride

Of the three common methods for the preparation of acid chlorides, the thionyl chloride method is the cleanest reaction in that both of the by-products are gases. Moreover, the phosphorus trichloride and phosphorus pentachloride methods are not desirable when the acid chloride is to be subjected to a Rosenmund reduction, because even traces of phosphorous compounds either seriously retard or completely prevent the reduction (41).

Considerable difficulty was encountered in the preparation of the acid chloride. Tarry products resulted when thionyl chloride was added directly to the acid, regardless of purity or dryness of the sample or the rate of addition of thionyl chloride. These results suggested the necessity of a solvent despite the fact that Linstead and Williams (21) have prepared the acid chloride by the thionyl chloride method with no mention of a solvent being used. The application of heat either during the reaction or during solvent removal resulted in resinous products. Failure to exclude moisture rigorously from the system also proved detrimental.

The effect of moisture on the acid chloride was an interesting phenomenon of itself. Instead of a recovery of the acid, as might normally be expected, a white powder was obtained which on repeated reprecipitation from petroleum ether began to decompose at 108°. This material might possibly be



the acid anhydride; however, the fact that it seemed to possess neither a definite crystalline structure nor a sharp melting point would seem to preclude its being the anhydride.

Petroleum ether dried over anhydrous calcium chloride was found to function excellently as a solvent. Benzene (thiophene-free) worked quite satisfactorily also.

The apparatus for the acid chloride preparation was as nearly all glass as possible. Two 500-ml. standard-taper flasks (A and B) were connected by means of an elbow and a modified adapter which extended into flask B. Small-diameter suction tubing connected the adapter and a 2-liter aspirator bottle via two drying towers -- the one nearer the aspirator bottle contained 4-mesh anhydrous calcium chloride whereas the one nearer the adapter contained a mixture of Drierite and activated alumina. The aspirator bottle was fitted with a three-way stopcock and an additional piece of glass tubing through which the aspirator bottle was connected with the rest of the system. One prong of the stopcock was joined to the water pump, the other was connected to a calcium chloride drying tower which in turn was opened to the atmosphere by means of a thick-walled capillary tube. The following is the procedure for a typical run:

To flask A were charged 20 g. of recrystallized and desiccator-dried acid, 125 ml. of petroleum ether, and 20 ml. of purified thionyl chloride. Flask A was then connected to the system and the stopcock was opened to the atmosphere. The reaction, which was endothermic, was allowed to proceed at room temperature (29 - 33°) with an occasional shaking, or rather swirling, of the contents of the flask. The end of the reaction was evidenced by the disappearance of solid acid, cessation of gas evolution, and thermal

equilibration between the flask and its surroundings. The reaction usually required about 3 days for completion but this time could be reduced to 36 hours with very frequent shaking of the reaction flask.

The stopcock was then turned to connect the water pump with the system and the solvent was removed at diminished pressure (about 40 mm. of mercury) at room temperature. After removing the solvent, the stopcock was regulated so that the pressure of the system was slowly raised to that of the atmosphere.

The acid chloride was always slightly discolored; however, since earlier attempts at purification were abortive, the flask was weighed, a small sample was taken for melting point determination, and 30 ml. of purified xylene were added to the flask, which was stoppered and placed in the ice box until used.

The acid chloride melted at  $39.5 - 41^{\circ}$ . Linstead and Williams (21) reported a melting point of  $42^{\circ}$  for the recrystallized product. The yield of acid chloride seemed to be practically quantitative.

Preparation of 4-Phenyl-3-butenal

## Run I.

To a 500-ml., 3-neck, standard-taper flask fitted with hydrogen-inlet tube, reflux condenser, and Tygon-seal power stirrer were charged 100 ml. of purified xylene, 3.54 g. of palladium-barium sulfate catalyst, and 35 mg. of Quinoline-S. (A Tygon-seal stirrer was used in lieu of the customary mercury-seal because mercury is detrimental to the reaction and the high-speed stirring necessary for smooth operation almost precludes the complete elimination of mercury from the reaction vessel.) Electrolytic hydrogen, which was first passed through a Drierite column, was bubbled slowly through the reaction flask thereby reducing the catalyst and displacing any air in the system. The solvent was refluxed on an oil bath. After a few milliliters of solvent had distilled and codistilled any moisture in the system simultaneously, heating was interrupted and the hydrogen cock was turned off. A solution of 42.2 g. (0.234 mole) of 4-phenyl-3-butenoyl chloride in 100 ml. of xylene was added through the condenser opening and the condenser was washed down with an additional 50 ml. of purified solvent. The gas evolution tube was then assembled. This consisted of a 4-foot length of rubber tubing extending from the top of the condenser to an appropriate length of 3-mm.-bore glass tubing which extended to the bottom of a 500-ml. Erlenmeyer flask containing 400 ml. of distilled water and 5 drops of 1 per cent phenolphthalein solution.

The bath temperature was raised to 145° and the flow of hydrogen was regulated so that from 100 to 300 bubbles per minute emerged in the Erlenmeyer flask. The stirrer was then started. The solution darkened almost instantaneously upon bubbling hydrogen through it. (This was characteristic of all runs.) The bath temperature was raised to 160° and maintained at this

temperature for about 20 minutes, but was lowered to the initial 143 - 147° range since the evolution of hydrogen chloride was no more rapid at the higher temperature.

The cleaved hydrogen chloride was titrated with 5 N sodium hydroxide. During the first 15 minutes, 5.5 ml. of base was neutralized. The total hydrogenation time was 10 1/2 hours. Contrary to expectation (17), the end of the reaction was not evidenced by an abrupt cessation of hydrogen chloride. The reaction was interrupted when the last partial drop of base was not neutralized within 2 minutes. The required alkali was 41.7 ml. and was equivalent to 89 per cent of the theoretically cleaved hydrogen chloride.

After cooling the flask, 2 g. of decolorizing charcoal was added and the reaction mixture was filtered with gentle suction through a hardened filter paper. The darkened solution was not significantly altered by addition of the charcoal.

The solvent was stripped from the reaction mixture by flash distillation at diminished pressure (17). This was accomplished by arranging a 125-ml. Claisen flask for vacuum distillation (water pump) with the usual capillary tube replaced by a dropping funnel whose stem extended to the bottom of the flask. The reaction mixture was added at such a rate that an accumulation of xylene was prevented. This operation required approximately 5 hours. Heating was accomplished by means of an oil bath maintained at a temperature of 95 - 102°.

After removing the solvent, the bath temperature was slowly raised to 185° during which time only a small forerun (approximately 10 ml.) of material smelling strongly of xylene was collected. Heating was interrupted, the dropping funnel was replaced by a capillary tube, and a vacuum pump was

connected to the system. The flask was then heated by a direct flame. Approximately 15 ml. of light yellow, slightly viscous material was obtained before decomposition of the reduction products became manifest. Heating was interrupted at this point. The material which distilled with only slight discoloration darkened considerably as soon as the vacuum was released.

In attempting to identify the reduction products, the following qualitative aldehyde tests were run: Schiff reagent, negative; methone, positive; phenylhydrazone, negative; 2,4-dinitrophenylhydrazone, negative; semicarbazone, positive—a few crystals formed but attempts to rid them of the contaminating oil were unsuccessful. The following qualitative alcohol tests were run: acetyl chloride, negative; xanthate test, negative.

The reduction material was set aside, and on standing three weeks a few crystals were formed. After standing an additional week in the icebox, approximately 250 mg. of crystals separated from the mother liquor. The mother liquor was decanted and selective solvent extraction was tried on the crystals without success. Methanol-water, ethanol-water, acetone-water, and benzene were the solvents used. Finally, a few crystals were placed on a filter paper and carefully wiped until the contaminating oil was no longer absorbed. Then the crystals were taken up in 4 drops of methanol, a drop of water was added, and the test tube was chilled in an ice bath. The resulting crystals were placed on a porous plate, dried in the desiccator, and the melting point determined, m.p.  $84.6 - 86.2^{\circ}$ . This value compared favorably with that of 4-phenyl-3-butenic acid (21) and the crystals were suspected of being the acid. The melting point of the prepared amide,  $129.2 - 129.7^{\circ}$ , as compared with the value  $130^{\circ}$  listed in Heilbron (16), confirmed this belief.

## Run II.

To effect the reduction of small quantities of acid chloride, a different type hydrogenator was devised and employed in both Runs II and III. The reaction chamber consisted of a heavy-walled, pyrex test tube of approximately 100-ml. capacity. The open end was drawn out and to it a standard taper joint was sealed. A piece of glass tubing (4-mm. bore) was sealed into the bottom and curved to run parallel with the larger tube. Hydrogen, entering through the bottom of the reaction chamber, kept the catalyst well stirred. The apparatus was scrupulously cleaned and dried before using.

To the reaction flask were charged 1.62 g. of palladium-barium sulfate catalyst and 40 ml. of purified xylene. A standard taper condenser was fitted into the mouth of the vessel and the solvent was refluxed on an oil bath. Hydrogen, which was first passed through a calcium chloride-activated alumina drying tower, was bubbled through the solution until the catalyst had been reduced to metallic palladium and approximately 4 ml. of solvent had distilled. Heating was interrupted and the hydrogen cock was closed. A solution of 9.2 g. (0.051 mole) of 4-phenyl-3-butenoyl chloride in 12 ml. of xylene was added and the gas evolution tube was arranged as described in Run I. The oil-bath temperature was regulated to  $135 - 143^{\circ}$  and a stream of hydrogen was passed through the solution at such a rate that the catalyst remained suspended. The evolved hydrogen chloride was titrated with 1.02 N sodium hydroxide. The required alkali was 44.2 ml. and was equivalent to 88 per cent of the theoretically cleaved hydrogen chloride. The end of the reaction was evidenced by an abrupt cessation of evolved hydrogen chloride. The total reaction time was 190 minutes. No catalyst poison was used in this run.

The solvent was removed by flash distillation as described in the preceding run. The dark brown residue was quite viscous, became semi-solid when chilled in an ice bath, and was greasy to the touch. Crystals were observed in the mixture; therefore, selective solvent extraction was attempted on several small portions. Methanol-water, ethanol-water, acetone-water, benzene, ether, petroleum ether, and 5 per cent sodium hydroxide were tried to no avail. The remainder was divided into two portions.

Part 1 was subjected to a high-vacuum distillation at the mercury pump (0.65 - 0.35 mm. of mercury). The material refluxed from 150 - 165° but it would not distill. Continued increases of temperature only resulted in extensive charring of the material.

Part 2 was subjected to an extraction with boiling water. The supernatant layer was pipetted off and upon cooling yielded a white crystalline product which was slightly contaminated. After two additional recrystallizations from boiling water, approximately 0.5 g. of material was obtained which was identified as 4-phenyl-3-butenic acid, m.p. 86.2 - 86.6°; amide, m.p. 129.5 - 130°.

### Run III.

The hydrogenation apparatus described in the preceding run was employed. The preliminaries were essentially those described therein.

The quantities of materials used were as follows: 35 ml. of purified xylene, 3.0 g. of supported catalyst, 20 mg. of thiourea, and 9.2 g. of 4-phenyl-3-butenoyl chloride. The end of the reaction was evidenced by a rather abrupt cessation of evolved hydrogen chloride. The total hydrogen-

ation time was 215 minutes. Of the theoretically cleaved hydrogen chloride, 95 per cent was accounted for by titration with standard sodium hydroxide.

Solvent removal was accomplished by flash distillation at reduced pressure as previously described. The dark brown, slightly viscous residue showed no indication of crystallization even when chilled in an ice bath.

The material was washed twice with 10-ml. portions of 1 N sodium carbonate and then with three 10-ml. portions of distilled water. The carbonate washings were combined and carefully acidified with dilute sulfuric acid; however, no solid was obtained even when subjected to an ice-salt bath temperature for 6 hours which indicated that 4-phenyl-3-butenic acid was not formed in this run.

The following qualitative tests for aldehydes were run: methone, positive; semicarbazone, negative; benzidine, inconclusive; and sodium bisulfite, a few crystals separated only after 8 days standing. Both Fehling and Benedict solutions were reduced at room temperature which indicated the presence of a very easily oxidizable group. The acetyl chloride test for hydroxyl groups was negative.

The remainder of the reduction material was charged to a 25-ml. distilling flask arranged for vacuum distillation. The neck of the flask was packed loosely with glass wool. Heat was supplied by a Glas-Col mantle. At 165° and approximately 40 mm. of mercury pressure, two drops of water-white distillate were obtained which darkened and became quite viscous as soon as the pressure of the system was raised to that of the atmosphere. The preparation of a semicarbazone derivative was attempted on the distillate. On standing overnight in the cold, three needle-like crystals precipitated which were insufficient for a melting point determination.



The carbonaceous material left in the still pot had a sickening, jasmine odor which, to the author, is characteristic of partially decomposed aromatic aldehydes. The glass-wool plug was removed from the flask and subjected to an extraction with boiling water. A few droplets of reddish-brown oil were obtained which had a jasmine odor but failed to give a semicarbazone.

#### Investigation of the Solvent Fractions

The solvent fractions from the hydrogenation runs were investigated to determine whether or not a high boiling hydrocarbon had been formed during reduction. Unfortunately, the solvent fractions from Runs II and III had been combined previously and therefore could not be investigated separately.

The solvent was charged to a 100-ml. round-bottom flask equipped with a Snyder 3-ball fractionating column for a rough separation. Most of the material distilled at 135 - 138°. When distillation ceased in this temperature range, heating was interrupted. Approximately 8 ml. of dark material remained in the still pot. This was charged to a 10-ml. distilling flask and the neck packed with glass wool. Three cuts were taken before decomposition became apparent: Cut I, b.p. 137 - 142°; Cut II, b.p. 140 - 146°; and Cut III, b.p. 165°. The first two cuts were slightly discolored whereas the last cut was water white. A total of approximately 5 ml. of material was obtained.

The sodium D line refractive indices of the three cuts and the original solvent were read at 27° and compared. They were as follows: purified xylene, 1.4929; Cut I, 1.5097; Cut II, 1.5155; and Cut III, 1.5185. Since the trend appeared favorable, further purification was undertaken.

All three cuts were combined and charged to a small still pot. Approximately 10 ml. of n-butyl phthalate was added as a booster liquid. Fractions were taken on a Todd semimicro fractionating column with spiral column at 742 mm. mercury pressure. Four cuts were taken as follows: Cut I, b.p. 137 - 144°; Cut II, b.p. 142 - 145°; Cut III, b.p. 172 - 172.5°; and Cut IV, ca. 194°. Cuts I and II accounted for approximately 3 ml. of the original charge; Cut III, 1 ml.; and Cut IV, 0.2 ml.

Cut III seemed to indicate the presence of a high boiling hydrocarbon in that its odor was reminiscent of phenylcyclopropane and it had a similar boiling point (see Table I). The following physical constants were determined (See Table I for numerical values): refractive index ( $n_D$ ) on the Abbe refractometer, molecular weight by the vaporimetric mercury displacement method (14), density with the semimicro pycnometer, and ultraviolet absorption spectrum in isooctane on the Beckman DU Model spectrophotometer. The molar refraction was calculated from experimental data and the Lorenz-Lorentz equation.

Since the physical data obtained thus far did not confirm the material as being a pure compound, Cut III was assumed to be a mixture and treated accordingly. Previous qualitative tests indicated the absence of an active hydroxyl group by means of ceric nitrate reagent and the presence of an easily oxidizable group by means of neutral permanganate. An orange precipitate was given immediately with 2,4-dinitrophenylhydrazine (20) and when recrystallized from methanol melted at 237°(d.). Both methone and benzidine reagents gave positive tests which differentiated the carbonyl as being aldehydic in nature. The semicarbazone was prepared with some difficulty and separated from the alleged hydrocarbon layer only after

being chilled in an ice bath overnight. The shiny white platelets were dried on a porous plate for 4 hours and, without further purification, melted at  $213.6 - 214.2^{\circ}$  as compared with Meyer's value of  $212 - 214^{\circ}$  for 4-phenyl-3-butenal semicarbazone (1). Approximately 10 mg. of material was obtained and this was sufficient for three melting point determinations. Since the semicarbazone was the only known derivative of 4-phenyl-3-butenal, it was decided to attempt the preparation of other well known aldehyde derivatives and determine their melting points. The 2,4-dinitrophenylhydrazone was again prepared (20), recrystallized from methanol, and the melting point determined,  $237^{\circ}$  (d.), which corroborated the previous determination. The phenylhydrazone was an oil. This was not expected in view of the fact that the 2,4-dinitrophenylhydrazone had such a high melting point. The methone derivative melted at  $192.8 - 193.2^{\circ}$ . The xanthene derivative was prepared by cyclizing the methone derivative with a drop of concentrated hydrochloric acid (19). The crude material melted at  $202.8 - 203.2^{\circ}$  after one recrystallization from methanol.

Reactions with Hydrazine

## Run I.

To a 200-ml., 3-neck flask fitted with power stirrer, reflux condenser, and dropping funnel were charged 20 ml. of absolute ethanol and 8 ml. of hydrazine hydrate. The solution was raised to reflux temperature on an oil bath and a solution of 2.5 g. of 4-phenyl-3-butenic acid in 15 ml. of absolute ethanol was added dropwise over a period of 65 minutes. Refluxing was continued for an additional 3 hours.

The solvent and excess hydrazine were removed by flash distillation at diminished pressure as previously described. A small amount of dark red, viscous material resulted. On standing overnight, a small amount of white precipitate was observed which was insoluble in water and only slightly soluble in methanol and acetone. The reaction mixture was extracted with cold acetone and the residue was dissolved in hot methanol and reprecipitated by the addition of a few drops of water. Only a few milligrams of material was obtained; therefore, a qualitative nitrogen determination was run via sodium fusion. The test for nitrogen was negative.

After evaporation of the solvent from the acetone extract, the viscous material smelled strongly of quinoline. However, the quinoline odor vanished in approximately 4 hours. The material gave a negative test for hydroxyl group with acetyl chloride.

## Run II.

The apparatus described in the previous run was used here. The preliminaries were essentially those described therein. The quantities of materials used were as follows: 20 ml. of benzene (thiophene free), 3 g. of hydrazine dihydrochloride, and 4.4 g. of 4-phenyl-3-butenoyl chloride in 15 ml. of benzene.

The hydrazine dihydrochloride was suspended in the benzene, and the acid chloride solution was added dropwise over a period of 45 minutes. The total reflux time was 2 hours.

The reaction mixture was cooled and filtered. The precipitate was extracted with water to remove the unreacted hydrazine dihydrochloride and filtered. The resulting precipitate was washed with acetone, dried, and its melting point determined, m.p. 108 - 110° (d.). A sodium fusion was run on the solid material and then, qualitative nitrogen tests were run on the alkaline filtrate. These tests were negative.

The solvent was stripped from the reaction mixture by flash distillation at reduced pressure, and the darkened residue was distilled. Approximately 2 ml. of a colorless oil was obtained which darkened within 15 minutes.

In attempting to determine whether or not cyclization had occurred, the following qualitative tests for carbonyl group were run: phenylhydrazone, an oil resulted; 2,4-dinitrophenylhydrazone (20), an orange precipitate was obtained which melted at 218 - 221° (d.); semicarbazone, after standing in the cold for several days a small amount of white precipitate formed which was insufficient for a melting point determination after recrystalli-

zation from methanol. Both benzidine and methone reagents gave negative tests and indicated that the carbonyl group was not aldehydic in nature.

## D I S C U S S I O N

### I. The Rosenmund reduction of 4-Phenyl-3-butenoyl chloride

This investigation was, primarily, an extension of the Rosenmund reduction. The experimental results indicate that the Rosenmund reaction is not a satisfactory method for the preparation of 4-phenyl-3-butenal from the corresponding acid chloride, at least not under the conditions used. The aldehyde was obtained in very small quantity and was isolated as the 2,4-dinitrophenylhydrazone, semicarbazone, and methone derivatives.

#### A. Composition of Cut III (See Table I, page 28)

1. Two maxima of the ultraviolet absorption spectrum of the fraction containing the aldehyde (Cut III) compared rather favorably with known values for styrene (26). It is believed that the styryl group in 4-phenyl-3-butenal (styrylacetaldehyde) is a plausible explanation for these maxima, in view of the fact that a methylene group separates the styryl and carbonyl groups and therefore the latter should modify only slightly the absorption maxima of the styryl group or, more specifically, styrene. The similarity between the Cut III values and those of styrene is even more striking when one considers that experimental readings were taken neither between 280 and 284 nor at 291 millimicrons. However, both 1-phenyl-1-propene and 1-phenyl-1-butene would be expected to give very similar absorption spectra; moreover, it is possible to explain either or both of these hydrocarbons as products from the Rosenmund reduction of 4-phenyl-3-butenoyl chloride.

2. The boiling point and molecular weight determinations seem to agree about equally well with both 1-phenyl-1-propene and

phenylcyclopropane. The cut would not freeze, although cloudiness was observed, when subjected to an ice bath for about 1 hour. This would not eliminate 1-phenyl-1-propene as a possibility of itself, because the presence of the aldehyde would not only lower the freezing point of the solvent but also would make crystallization very difficult indeed.

3. The refractive index, when converted to  $20^{\circ}$ , gives closer agreement with that of phenylcyclopropane than 1-phenyl-1-propene. It also gives fair agreement with that of phenylcyclobutane.

4. The molar refraction agrees well with only that of phenylcyclobutane.

5. The density does not agree well with any of the compounds under consideration; however, the low value may be due to experimental error.

6. The experimental data seem to favor both 1-phenyl-1-propene and phenylcyclopropane as possibilities. The odor of the material would favor phenylcyclopropane; the absorption spectrum, 1-phenyl-1-propene. It cannot be said with certainty which, if either, of the hydrocarbons might be present.

7. Since all analyses were run on a 1-ml. constant-boiling fraction, it was deemed more advisable to attempt the identification of the aldehyde present rather than the alleged hydrocarbon.



TABLE I.

<u>Compound</u>	<u>B.P., °C</u> <u>@ 760 mm.</u>	<u>D<sub>4</sub><sup>20</sup></u>	<u>n<sub>D</sub><sup>20</sup></u>	<u>Molecular</u> <u>Weight</u>	<u>Molar</u> <u>Refraction</u>	<u>λ<sub>max.</sub> (μμ)</u>
Cut III (p.21)	172.5-173 @ 742 mm.	0.876 @ 30°	1.5273 @ 28°	121.5	42.8	248, 284, 292
1-Phenyl-1- butene	188.9	0.9106	1.5387	132.2	44.3	.....
1-Phenyl-1- propene	173.5 (m.p., 20°)	0.9105	1.5420	118.2	39.7	.....
Phenylcyclo- propane	170.5	0.9397	1.5285	118.2	38.0	255, 260, 267, 274
Phenylcyclo- butane	190-191 @ 755 mm.	0.9378	1.5277	132.2	42.6	.....
Styrene	145.3	0.90675	1.5465	104.1	35.1	274, 282, 291
4-Phenyl-3- butenal	130-132 @ 14 mm.	.....	.....	146.2	44.4	.....

## Notes:

1. The values for boiling point, density, and refractive index for each of the hydrocarbons are from Egloff, "Physical Constants of Hydrocarbons" (4).
2. The boiling point of 4-phenyl-3-butenal is that reported by Meyer (22).
3. The u.v. absorption spectra values for styrene and phenylcyclopropane are from Robertson, Music, and Matsen (26).
4. The molar refractions (except Cut III) were calculated from the Auwers-Eisenlohr values for atomic refractivities (9A).

## B. Recommendations

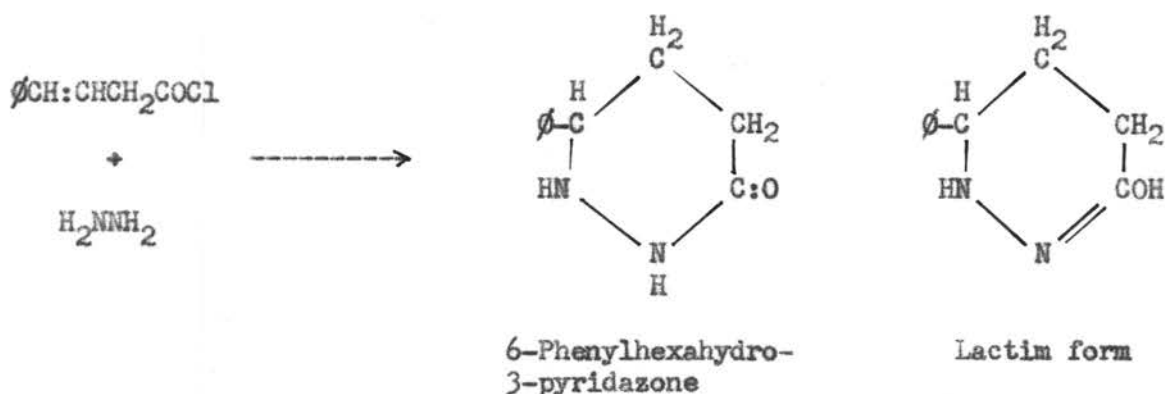
Future work on the Rosenmund reduction of 4-phenyl-3-butenoyl chloride might include:

1. working at room temperature since the acid chloride was found earlier to be unstable toward heat.
2. operating at slightly reduced pressure. Cinnamoyl chloride has been reduced satisfactorily at 540 mm. of mercury (18).
3. using solvents such as ether and petroleum ether which could be removed from the reaction mixture at room temperature and thereby would minimize the possibility of polymerization. Solvents more volatile than xylene would also enhance the ease and probability of a clean separation.

## II. Reactions with Hydrazine

Had 4-phenyl-3-butenal been obtained on a preparative scale, it was intended to investigate the products obtained from the reaction between the aldehyde and hydrazine.  $\alpha, \beta$ -Unsaturated aldehydes are well known to undergo a condensation-cyclization reaction with hydrazine to yield the corresponding pyrazoline derivatives. It would be interesting, indeed, to know whether or not  $\beta, \gamma$ -unsaturated aldehydes might undergo the same type of reaction to give the corresponding pyridazine derivatives. This would tend to explain the effect, if any exists, of conjugation on cyclization.

Carrying the analogy a step further, it was decided to react both 4-phenyl-3-buteonic acid and the corresponding acid chloride with hydrazine separately, and try to determine whether or not cyclization had occurred. In either case the cyclization product would be the same substituted pyridazine. The anticipated reaction is presented as follows:



#### A. Indications of cyclized reaction products

The products obtained from the reaction between 4-phenyl-3-butenoyl chloride and hydrazine dihydrochloride gave positive ketone tests which indicated that cyclization might have occurred to a small extent. The condensation-cyclization product would be 6-phenylhexahydro-3-pyridazone, a compound which has not yet been reported in the literature.

The sulfanilamido derivatives of several of the substituted 3-pyridazones have been prepared and found to possess enhanced bacteriostatic activity (18, 13); therefore, the sulfanilamido derivative of this postulated pyridazone might also be beneficial as a medicinal.

#### B. Recommendations

Further work on this reaction might include:

1. using pure hydrazine which is soluble in organic solvents and therefore would be likely to improve the yield.
2. varying the temperature to determine its effect on the yield.
3. employing the ester in lieu of the acid chloride to determine whether or not it would undergo the cyclization reaction.

S U M M A R Y

1. 4-Phenyl-3-butenic (Styrylacetic) acid was prepared by the phenylacetaldehyde-malonic acid condensation method suggested by Linstead and Williams (21). The average yield for five runs was 20 per cent as compared with the 60 per cent yield reported by them.

2. 4-Phenyl-3-butenoyl (Styrylacetyl) chloride was prepared in petroleum ether from the acid by the modified thionyl chloride method. It was found that only by operating at room temperature and in a solvent could the acid chloride be obtained. An anhydrous system was also necessary. The yield of acid chloride was almost quantitative under these conditions.

3. The acid chloride was reduced with electrolytic hydrogen using a palladium-barium sulfate catalyst. Reactions were run using Quinoline-S, thiourea, and no catalyst regulator.

4. 4-Phenyl-3-butenic acid was obtained when either Quinoline-S or no catalyst regulator was used. No acid was obtained when thiourea was employed.

5. A constant-boiling cut (about 1 ml.) was obtained from the stripped solvent fractions on the Todd semimicro column. This fraction was suspected of being a hydrocarbon. Its odor was reminiscent of phenylcyclopropane. The following physical constants were determined: density, refractive index ( $n_D$ ), molecular weight, molar refraction, and ultraviolet absorption spectrum. However, these values were insufficient to establish the identity of the alleged hydrocarbon present in this cut.

6. 4-Phenyl-3-butenal (Styrylacetaldehyde) was isolated as its derivatives and identified by the melting point of the semicarbazone,

213.6-214.2°.

7. The following characteristic derivatives of 4-phenyl-3-butenal, as yet unreported, were prepared and their melting points determined: 2,4-dinitrophenylhydrazone, 237° (d.); phenylhydrazone, an oil was obtained; methone, 192.8 - 193.2°; xanthene, 202.8 - 203.2°. The quantities of derivatives obtained indicated that the yield of aldehyde was extremely small.

8. 4-Phenyl-3-butenoyl chloride was reacted with hydrazine dihydrochloride and qualitative tests were run on the reaction mixture to determine whether or not cyclization had occurred. The 2,4-dinitrophenylhydrazone was prepared and melted at 218 - 221° (d.). The semicarbazone was prepared; however, an insufficient amount of material was obtained for a melting point determination after recrystallization. Both benzidine and methone reagents gave negative tests which indicated that the carbonyl group was not aldehydic in nature.

## B I B L I O G R A P H Y

1. Borsche, Niemann, and Hartman, Ber. 69, 1996 (1936).
2. Cheronis and Entrikin, "Semimicro Qualitative Organic Analysis," Thomas Y. Crowell Co., New York, 1947.
3. Daniloff and Venus-Danilova, Ber., 59, 377 (1926).
4. Egloff, "Physical Constants of Hydrocarbons," Reinhold Publishing Corporation, New York, 1946, Vol. III.
5. English and Velick, J. Am. Chem. Soc., 67, 1413 (1945).
6. Fichter and Pfister, Ber., 37, 2001 (1904).
7. Fieser, "Experiments in Organic Chemistry," D. C. Heath and Co., New York, 1935, p. 339.
8. Froeschl and Danoff, J. prakt. Chem., [2] 144, 217 (1936).
9. Froeschl, Maier, and Heuberger, Monatsh., 59, 256 (1932).
- 9A. Gilman, "Organic Chemistry," John Wiley and Sons, Inc., New York, 1943, 2nd Ed., Vol. II, p. 1751.
10. Graf and Laszlo, J. prakt. Chem., [2] 138, 231 (1933).
11. Graf and Weinberg, Ibid., 2 134, 177 (1932).
12. Grignard and Mingasson, Compt. rend. 185, 1173 (1927).
13. Grundmann, Chem. Ber., 81, 1 (1948).  
via C. A. 43, 176 (1949)
14. Hawkins, Master's Thesis, Okla. A. and M. College (1949).
15. Heer and Miescher, Helv. Chim. Acta, 30, 777 (1947).
16. Heilbron, "Dictionary of Organic Compounds," University of Oxford Press, New York, 1938, Vol. III., p. 644.  
cf. Stoermer and Stockman, Ber., 47, 1794 (1914).
17. Hershberg and Cason, "Organic Synthesis," John Wiley and Sons, Inc., New York, 1941, Vol. 21, p. 84.
18. Homer, Gregory and Wiggins, J. Chem. Soc. 2191 (1948). via  
C. A. 43, 3007<sup>b</sup> (1949)

19. Horning and Horning, *J. Org. Chem.*, 11, 95 (1946).
20. Iddles and Jackson, *Ind. Eng. Chem., Anal. Ed.*, 6, 454 (1934).
21. Linstead and Williams, *J. Chem. Soc.*, 2741 (1926).
22. Meyer, *Compt. rend.*, 204, 508 (1937).
23. Mitter and Banerjee, *J. Indian Chem. Soc.*, 9, 375, (1932).
24. Mosettig and Mazingo, "Organic Reactions," John Wiley and Sons, Inc., New York, 1948, Vol. IV, Ch. 7.
25. Preobrashenski, Poljakowa, and Preobrashenski, *Ber.*, 68, 844 (1935).
26. Robertson, Music and Matsen, *J. Am. Chem. Soc.*, in press, and private communication.
27. Rogers, *Ibid.*, 69, 2544 (1947).
28. Rojahn and Fahr, *Ann.*, 434, 252 (1923).
29. Rojahn and Seitz, *Ibid.*, 437, 297 (1924).
30. Rosenmund, *Ber.*, 51, 585 (1918).
31. Rosenmund, *Z. angew. Chem.*, 35, 483 (1922).
32. Rosenmund and Zetzsche, *Ber.*, 54, 425 (1921).
33. Rosenmund, Zetzsche and Fluetsch, *Ibid.*, 54, 2888 (1921).
34. Rosenmund, Zetzsche and Heise, *Ibid.*, 54, 638 & 2038 (1921).
35. Rosenmund, Zetzsche, and Weiler, *Ibid.*, 56, 1481 (1923).
36. Ruzicka and Marxer, *Helv. Chim. Acta*, 25, 1561 (1942).
37. Spaeth, *Monatsh.*, 40, 129 (1919).
38. Stoermer and Stockman, *Ber.*, 47, 1794 (1914).
39. Waser, *Helv. Chim. Acta*, 8, 117 (1925).
40. C. Weygand, "Organic Preparations," Interscience Publishers, Inc., New York, 1945, p. 16.
41. Zetzsche and Arnd, *Helv. Chim. Acta*, 8, 591 (1925).  
cf. Zetzsche and Arnd, *Ibid.*, 9, 173 (1926).



B I O G R A P H Y

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THESIS TITLE: A Rosenmund Reduction of 4-Phenyl-3-Butenoyl  
Chloride

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