Summary

1. The results of the reaction of 4 N alkali at a temperature of 140° on five aldonic acids are recorded.

2. The results with three other acids from a previous paper have been included for comparison.

3. Lactic acid is the chief product formed from all aldonic acids studied except glycolic acid.

4. The "double bond rule" of Schmidt seems to offer an adequate explanation of the results.

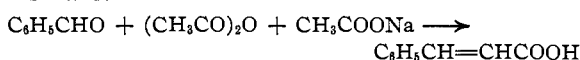[CONTRIBUTION FROM THE CHEMISTRY DEPARTMENT OF DUKE UNIVERSITY]

Condensations Brought about by Bases. V. The Condensation of the Anhydride with the Aldehyde in the Perkin Synthesis[1]

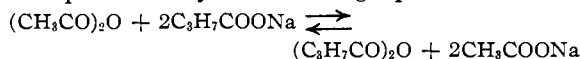BY DAVID S. BRESLOW AND CHARLES R. HAUSER

Perkin[2] assumed that in the reaction that bears his name

$$C_6H_5CHO + (CH_3CO)_2O + CH_3COONa \longrightarrow$$
$$C_6H_5CH\!\!=\!\!CHCOOH$$

the anhydride condenses with the aldehyde, the sodium acetate serving merely as a catalyst. As support for this view he showed that cinnamic acid is formed also when benzaldehyde is heated with acetic anhydride at 180° in the presence of other salts, for example, sodium butyrate.

Fittig[3] soon contested this view; he considered that the salt, and not the anhydride, condenses. In support of his view, Fittig[4] showed that when benzaldehyde is heated with acetic anhydride and sodium butyrate at 100°, instead of 180°, ethylcinnamic acid is the main product. He showed further that, as the temperature is raised, relatively less ethylcinnamic acid is formed and relatively more cinnamic acid; at 150°, he obtained half as much ethylcinnamic acid as cinnamic acid, while at 180°, he obtained only one-tenth as much ethylcinnamic acid, the reaction yielding almost entirely cinnamic acid as Perkin had reported.

Fittig explained these results on the assumption that at the higher temperatures (but not at 100°) acetic anhydride and sodium butyrate are converted by double decomposition into butyric anhydride and sodium acetate, the latter then condensing with the aldehyde to give cinnamic acid. The anhydride–salt exchange may be represented by the following equation

$$(CH_3CO)_2O + 2C_3H_7COONa \rightleftarrows$$
$$(C_3H_7CO)_2O + 2CH_3COONa$$

Michael[5] and others showed that this anhydride–salt exchange does actually occur, but that it takes place even at 100°; in fact, at this temperature the exchange proceeds to a greater extent[6] (*i. e.*, the equilibrium of the exchange is further on the side of butyric anhydride and sodium acetate) than at 180°. Michael[5] showed also that, like the experiment with acetic anhydride and sodium butyrate at 100°, benzaldehyde with butyric anhydride and sodium acetate at this temperature gives mainly ethylcinnamic acid.

A consideration of the products formed and of the equilibrium of the anhydride–salt exchange at various temperatures led Michael to support Perkin's view that the anhydride condenses. Fittig's view, however, received apparent confirmation from the work of Stuart,[7] who reported that a mixture of benzaldehyde, acetic anhydride and sodium malonate at room temperature evolves carbon dioxide and gives cinnamic acid. Since malonic acid is incapable of forming an anhydride, it would appear that the salt (sodium malonate) condenses.

(1) This work was supported in part by a grant from the Duke University Research Council.

(2) See especially, Perkin, *J. Chem. Soc.*, **31**, 389 (1877).

(3) See especially, Fittig, *Ber.*, **14**, 1824 (1881); *Ann.*, **227**, 48 (1885).

(4) See Fittig and Slocum, *ibid.*, **227**, 53 (1885).

(5) Michael, *J. prakt. Chem.*, **60**, 364 (1899); *Ber.*, **34**, 918 (1901). See also Tiemann and Kraaz, *ibid.*, **15**, 2061 (1882).

(6) It has been shown[5] that at 100° the equilibrium is far on the side of the salt of the stronger acid, *i. e.*, on the side of sodium acetate and butyric anhydride; in fact, Michael obtained butyric anhydride in good yield from acetic anhydride and sodium butyrate at 100°. At 180°, however, because of the greater volatility of acetic anhydride, the equilibrium is shifted somewhat toward acetic anhydride and sodium butyrate. Michael assumed that at this temperature the equilibrium was mostly on the side of acetic anhydride and sodium butyrate, and he showed that when sodium acetate and butyric anhydride were heated at 180°, acetic anhydride distilled off. We have observed that, on heating sodium acetate with butyric anhydride at 180°, acetic anhydride soon refluxes in the mixture. Although the position of equilibrium is not known, there is no doubt that it is further on the side of butyric anhydride and sodium acetate at 100° than at 180°.

(7) Stuart, *J. Chem. Soc.*, **43**, 403 (1883); see also Fittig, *Ber.*, **16**, 1436 (1883).

Fittig's view that the salt condenses became generally accepted until 1928, when Kalnin[8] showed that acetic anhydride condenses with benzaldehyde in the absence of sodium acetate or other organic salt, if the reaction is carried out in the presence of certain amines or inorganic salts, for example, potassium carbonate. Kalnin showed further that the condensation was dependent upon the strength of base used and from this concluded, correctly we believe, that in the presence of the base (sodium acetate in the classic Perkin) the anhydride is first converted into its enolate, which condenses with the aldehyde. Kalnin then proposed an unlikely (and unnecessary) mechanism for the condensation of the anhydride enolate with the aldehyde. Kalnin's particular mechanism was soon disproved,[9] and perhaps partly for this reason his strong experimental evidence supporting the view that the anhydride condenses in the Perkin reaction has not received as wide acceptance as it deserves. Although a few recent workers[10] consider that the anhydride condenses,[11] most current texts of organic chemistry[12] represent the reaction as involving the condensation of the salt with the aldehyde, and regard the anhydride merely as a dehydrating agent.

In this paper we show that, contrary to Stuart's result, sodium malonate in the presence of acetic anhydride does not condense with benzaldehyde to any appreciable extent; hence one of the strongest arguments supporting Fittig's view that the salt condenses is no longer valid. Furthermore, we present experimental results which, considered with those of certain other workers, show that the Perkin reaction undoubtedly involves the condensation of the anhydride with the aldehyde.

In repeating Stuart's experiment we have used purified materials. A mixture of benzaldehyde, acetic anhydride and sodium malonate on standing at room temperature appeared to react, but

little if any carbon dioxide was evolved, and even after standing a week most of the benzaldehyde was recovered unchanged. No benzalmalonic acid and not more than a trace of cinnamic acid could be isolated from the reaction mixture. It should be pointed out that even in the absence of benzaldehyde a mixture of acetic anhydride and sodium malonate appears to react, the color of the mixture becoming brick-red on standing.

Stuart did not give a yield for cinnamic acid in his experiment with sodium malonate but, judging from the wording of his report, the yield was not large. A small yield of cinnamic acid might be explained on the basis that the acetic anhydride used by this early worker contained some acetic acid, since it has been shown by Stuart, and confirmed by us, that when glacial acetic acid, instead of acetic anhydride, is used in the reaction with benzaldehyde and sodium malonate (either at room temperature or 100°), benzalmalonic acid or cinnamic acid is formed. It should be pointed out that the formation of benzalmalonic acid when acetic acid is used has no direct bearing on the question of whether the anhydride or salt condenses in the Perkin synthesis, because in this experiment malonic acid (formed from sodium malonate and acetic acid), rather than the salt, very probably condenses with the aldehyde.[13]

The results obtained by Perkin and Fittig with mixtures of benzaldehyde, acetic anhydride and sodium butyrate (or other anhydride–salt mixtures) are difficult to interpret because of the probability that the anhydride–salt exchange occurs simultaneously with the condensation. In order to avoid the competing reaction of the anhydride–salt exchange we have carried out certain condensations in the following manner. A mixture of an anhydride and a salt was heated for several hours in order to establish equilibrium; benzaldehyde was then added and the heating continued for several hours longer at the same temperature. Under these conditions it seemed

(8) Kalnin, Helv. Chim. Acta, 11, 977 (1928).

(9) See Müller, Ann., 491, 257 (1931); Hurd and Thomas, This Journal, 55, 278 (1933).

(10) See, for example, Müller, Gawlick and Kreutzmann, Ann., 515, 97 (1934); Arndt and Eistert, Ber., 69, 2386 (1936).

(11) Bakunin and co-workers [Bakunin, Rend. accad. sci. (Napoli), [4] 2, 20 (1933); Bakunin and Peccerillo, Gazz. chim. ital., 65, 1145 (1935)] consider that a complex, formed from the anhydride and salt, condenses with the aldehyde.

(12) See, for example, Gilman, "Organic Chemistry," John Wiley and Sons, Inc., New York, N. Y., 1938, p. 562; Whitmore, "Organic Chemistry," D. Van Nostrand Co., Inc., New York, N. Y., 1937, p. 286; Lucas, "Organic Chemistry," American Book Co., New York, N. Y., 1935, p. 431; Hickinbottom, "Reactions of Organic Compounds," Longmans, Green and Company, New York, N. Y., 1936, p. 145.

(13) Since sodium malonate does not condense in the presence of acetic anhydride the acid would not be likely to do so. The condensation that takes place in the presence of acetic acid is to be explained, therefore, on the basis that the malonic acid, formed from the salt and acetic acid, condenses with the aldehyde. According to the modern theory of condensation which postulates the intermediate formation of enolates, malonic acid should condense more readily than sodium malonate, because malonic acid should form the enolate more easily; an enolization of the salt would amount to a secondary or tertiary ionization. The presence of salts should facilitate the enolization of malonic acid, while the presence of acetic acid is considered to "activate" the carbonyl group of the aldehyde, both facilitating the condensation. The complete mechanism will be discussed in a later paper.

probable that the same results would be obtained whether we started with acetic anhydride and sodium butyrate or with butyric anhydride and sodium acetate; this has been verified.

In Table I are given the relative yields of cinnamic and ethylcinnamic acids obtained at 100 and at 180° from benzaldehyde, acetic anhydride and sodium butyrate, and from benzaldehyde, butyric anhydride and sodium acetate. It can be seen that at the same temperature the ratio of cinnamic acid to ethylcinnamic acid is essentially the same (within limits of experimental error) in the two experiments. It can also be seen from Table I that although more ethylcinnamic is formed at both temperatures the ratio of cinnamic acid to ethylcinnamic acid is greater at 180° than at 100°; that is, relatively more cinnamic acid (and correspondingly less ethylcinnamic acid) is formed at the higher temperature.

TABLE I

THE CONDENSATION OF 0.25 MOLE OF BENZALDEHYDE WITH ANHYDRIDE–SALT MIXTURES

Temp., °C.	An-hydride	Sodium salt	Yield of acid, g. Cinnamic	α-Ethyl-cinnamic	Wt. ratio cinnamic/ ethyl-cinnamic
180	Acetic	n-Butyrate	7.31	10.27[a]	5:7
180	n-Butyric	Acetate	7.61	12.06	5:8
100	Acetic	n-Butyrate	2.46	9.73	2:8
100	n-Butyric	Acetate	2.26	10.14	2:9

[a] This yield is probably low because of an attempted alcohol–water recrystallization.

These results are intelligible only on the basis that the two anhydrides in the equilibrium mixture condense with the aldehyde. The relative rates of these two competing condensations depend upon the relative concentrations of the anhydrides and upon their reactivities.[14] As measured by the Zerevitinov method there appears to be not much difference in the activities of the hydrogens on the α-carbon atoms of butyric and acetic anhydrides.[15] Consequently, with this particular mixture the rates of condensation (and the products formed) appear to depend primarily upon the relative concentrations of the two anhydrides. Since at 100° the concentration of butyric anhydride in the equilibrium mixture is much higher than that of acetic anhydride, the fact that at this temperature much more ethylcinnamic acid than cinnamic acid is formed when the equilibrium

mixture is condensed with benzaldehyde is to be explained on the basis that the anhydrides condense. Even more conclusive evidence in support of this view is furnished by the fact that at 180° a higher yield of cinnamic acid (and a corresponding lower yield of ethylcinnamic acid) is obtained than at 100°. It has been shown that at the higher temperature there is relatively more acetic anhydride (and proportionately less butyric anhydride) than there is at 100°, hence, independent of the relative reactivities[16] of the two anhydrides, the yield of cinnamic acid should be greater at the higher temperature. In order to explain these results on the basis that the salts condense it would be necessary to assume, first, that sodium butyrate, which at 100° is present in the equilibrium mixture in very small amount, condenses with the aldehyde many times faster than sodium acetate; and, second, that the temperature coefficient of the condensation of sodium acetate with the aldehyde is much greater than that of the condensation of sodium butyrate with the aldehyde. Both of these assumptions are entirely unwarranted.

These results justify Michael's explanation of Fittig's result with a mixture of benzaldehyde, acetic anhydride and sodium butyrate at 100°. Michael assumed that before much condensation occurred, this anhydride and this salt were converted mostly into sodium acetate and butyric anhydride, the latter then condensing with the aldehyde to give the main product, ethylcinnamic acid. The fact that at 180° cinnamic acid is the main product[2] is to be explained on the basis that at this temperature the acetic anhydride not only undergoes condensation more readily than at 100°, but enters into the exchange reaction with sodium butyrate to a smaller extent.[6] We feel justified in explaining all of Fittig's results with benzaldehyde and anhydride-salt mixtures on the same basis.

The reaction of benzaldehyde, acetic anhydride and sodium phenylacetate also should be considered. When a mixture of these compounds is heated at 180–195°, a good yield of phenylcinnamic acid is obtained, with only a very small yield of cinnamic acid. This result considered together with the fact that only about one-third[17]

(14) The rate of condensation also depends upon the strength of base or basicity of the medium, but this factor need not be considered here.

(15) Ishikawa and Kojima, Sci. Repts. of Tokyo Bunrika Daigaku, 1, 289 (1934).

(16) This statement presupposes that there would be no great difference in the temperature coefficients of the condensations of the two anhydrides with benzaldehyde.

(17) Bakunin and Fisceman [Gazz. chim. ital., 46, I, 77 (1916)] reported that at 130°, the equilibrium mixture contains approximately one-third phenylacetic anhydride and sodium acetate.

of the acetic anhydride and sodium phenylacetate (even when heated without the benzaldehyde) is converted into sodium acetate and phenylacetic anhydride, might appear to indicate that sodium phenylacetate condenses. However, this result cannot be used as evidence that the salt condenses, because when benzaldehyde is heated with phenylacetic anhydride and sodium acetate, phenylcinnamic acid is again practically the only product obtained.[18] The explanation for the relatively large yield of phenylcinnamic acid obtained in these experiments is found in the fact that phenylacetic anhydride is considerably more reactive than acetic anhydride; consequently, when competing with acetic anhydride in the reaction with benzaldehyde, phenylacetic anhydride can be present in smaller amount and yet undergo the main reaction. Ishikawa and Kojima[15] have shown by the Zerevitinov method that phenylacetic anhydride is several times more reactive than acetic anhydride. Bakunin and Fisceman[17] have shown that phenylacetic anhydride condenses with benzaldehyde (Perkin type) under conditions (in the absence of a base) under which acetic anhydride does not condense, and we have found that phenylacetic anhydride undergoes self-condensation (Claisen type) in the presence of salts more readily than acetic anhydride. When acetic and butyric anhydrides in the presence of their salts were heated for several hours at 180° (see Table I), very little self-condensation could have occurred, since on heating the resulting mixture with benzaldehyde, good yields of the Perkin condensation products, cinnamic and ethylcinnamic acids, were obtained. On the other hand, when acetic anhydride and sodium phenylacetate were heated under the same conditions, followed by the addition of benzaldehyde, only a small yield of the Perkin condensation product (phenylcinnamic acid) was obtained, much benzaldehyde being recovered. A considerable amount of high-boiling oil was obtained from which dibenzyl ketone was isolated. This product undoubtedly resulted from self-condensation of the phenylacetic anhydride (formed by the anhydride–salt exchange), followed by decarboxylation. This reaction must have occurred during the preliminary heating of the anhydride–salt mixture, since, as pointed out above, when the preliminary heating is omitted and benzalde-

(18) Bakunin and Peccerillo, *Gazz. chim. ital.*, **65**, 1145 (1935). These workers used acetic anhydride also but this does not invalidate our argument.

hyde heated directly with the anhydride and salt a high yield of phenylcinnamic acid is obtained. The relationship between the Perkin and Claisen types of condensation will be discussed in a later paper.

Summary of Evidence that Anhydride Condenses.—There no longer need be any doubt that the anhydride condenses in the Perkin synthesis. The only result that formerly could not be explained on the basis that the anhydride condenses, namely, the condensation of sodium malonate with benzaldehyde, has now been shown to be erroneous. The evidence presented in this paper, together with that reported by others, shows convincingly that the anhydride, and not the salt, condenses. The principal evidence may be summarized as follows.

(1) When either acetic anhydride and sodium butyrate or butyric anhydride and sodium acetate are heated for several hours and the resulting mixture heated with benzaldehyde, the same relative yields of cinnamic and ethylcinnamic acids are obtained. This shows that the anhydrides and salts undergo double decomposition to give the same equilibrium mixtures in the two experiments.

(2) When the experiments described in (1) are carried out at 100°, at which temperature the equilibrium mixture contains much more butyric anhydride than acetic anhydride, the yield of ethylcinnamic acid is four times greater than that of cinnamic acid. Since there appears to be no great difference in the rates of condensation of benzaldehyde with acetic and butyric anhydrides, the fact that a greater yield of ethylcinnamic acid is obtained when there is much more butyric anhydride than acetic anhydride present in the equilibrium mixture gives rather strong support to the view that the anhydrides condense.

(3) When the experiments described in (1) are carried out at 100 and at 180° and the relative yields of cinnamic and ethylcinnamic acids compared, it is found that, although more ethylcinnamic acid than cinnamic acid is formed at both temperatures, the yield of cinnamic acid is higher and that of ethylcinnamic acid correspondingly lower at 180 than at 100°. Since in the equilibrium mixture there is relatively more acetic anhydride present at 180 than at 100°, this result shows that the anhydride condenses.

(4) Kalnin has shown that benzaldehyde condenses readily with acetic anhydride in the absence

of sodium acetate or other organic salts, if certain amines or inorganic bases, for example, potassium carbonate, are used. On the other hand, benzaldehyde does not condense with sodium acetate in the presence of amines or inorganic bases. Neither will benzaldehyde condense with sodium acetate in the presence of inorganic dehydrating agents, such as calcium chloride or phosphorus pentoxide.[18]

While Meyer and Beer[19] have condensed a more reactive aldehyde, o-chlorobenzaldehyde, with potassium acetate, such drastic conditions (heating in a sealed tube at 240° for thirty-six hours) were required to effect the condensation that this result actually supports the view that, under the ordinary conditions of the Perkin reaction, the anhydride condenses.

(5) Finally, in addition to the above experimental evidence, there is theoretical evidence supporting the view that in the Perkin synthesis the anhydride condenses. According to the modern theory, the condensation involves first the formation of an enolate which condenses with the aldehyde. Obviously, the anhydride should form the enolate more readily than the salt, since enolization of the latter would amount to a secondary ionization. The mechanism of the Perkin condensation is discussed in the following paper.

Experimental[20]

Preparation and Purification of Materials and Reagents.—Acetic anhydride was distilled over phosphorus pentoxide. The fraction boiling at 138.5–139.5° was used in this work. Eastman best grade of butyric anhydride was used without further purification.

Sodium acetate (C. P.) was recrystallized from water containing a small amount of acetic acid to prevent hydrolysis. It was then either carefully fused just above its melting point or dried for forty-eight hours at 180°, both methods giving the same results.

Sodium butyrate was made by adding a slight excess of redistilled butyric acid to a solution of sodium carbonate (C. P.) in distilled water; after carefully evaporating the mixture to dryness, the residue was heated for four hours at 180°.

Benzoic anhydride (Eastman) was recrystallized by dissolving 100 g. of it in 50 cc. of benzene, adding 100 cc. of ligroin (until cloudy), chilling the solution, and filtering.

Sodium malonate (Eastman) was dried for forty-eight hours at 180°. Attempts to fuse sodium malonate resulted in decomposition.

Sodium phenylacetate was prepared by exactly neutralizing a suspension of recrystallized phenylacetic acid in water with sodium hydroxide, using phenolphthalein as

an indicator. The solution was evaporated and the salt dried for twenty-four hours at 140°.

Acetic acid was purified by fractional crystallization. The fraction melting at 16.50° was used.

Benzaldehyde (Eastman) was extracted with a dilute sodium carbonate solution, washed with water until neutral, dried over Drierite, and distilled in an atmosphere of nitrogen; b. p. 178–179°.

Condensation of Benzaldehyde with Anhydride–Salt Mixtures. (a) Benzaldehyde, Acetic Anhydride and Sodium Butyrate at 180°.—Sodium butyrate (55.0 g., 0.50 mol) and acetic anhydride (25.5 g., 0.25 mol) were placed in a 200-cc. round-bottomed flask connected to a reflux condenser to which was attached a drying tube, and heated for four hours at 180° in an oil-bath. Benzaldehyde (26.5 g., 0.25 mol) was then added through the condenser and the mixture heated for another eight hours. A mixture of yellow solid and liquid was formed. Water was added and the solution steam-distilled until no more benzaldehyde passed over. The residue was made alkaline with sodium carbonate and extracted with ether, the ether solution being colored red. The alkaline solution was acidified strongly with hydrochloric acid and the mixture of cinnamic and ethylcinnamic acids filtered off. The method of separating these acids is based on the fact that cinnamic acid is less soluble in ligroin and more soluble in water than ethylcinnamic acid. The mixture of acids was dissolved in 500 cc. of hot ligroin (90–100°), filtered to remove inorganic salts, and cooled. The precipitate obtained was recrystallized from another 150 cc. of ligroin. Cinnamic acid (5.17 g.) was obtained as white crystals melting at 133.0–133.5°. The generally accepted melting point of cinnamic acid is 133°.[21]

The ligroin solutions were combined and evaporated under a partial vacuum. The residue was heated with six liters of water. A portion of the material remained undissolved. The mixture was cooled and filtered. The precipitate consisted of impure ethylcinnamic acid while the aqueous filtrate contained some cinnamic acid, which was recovered by extracting with ether, evaporating the ether, and recrystallizing the residue from ligroin. In this way 2.14 g. of cinnamic acid, melting at 132.0–133.5°, was obtained. An attempt was made to recrystallize the impure ethylcinnamic acid from a mixture of alcohol and water, but this was found to be undesirable. The impure ethylcinnamic acid was satisfactorily recrystallized from a dioxane–water mixture. This gave 7.65 g. of ethylcinnamic acid, melting at 104.5–105°. Fittig[4] gives 104° as the melting point of ethylcinnamic acid. More water was added and an additional 2.43 g., melting at 103.5–104.5°, was obtained. An excess of water was then added and the precipitate recrystallized from hot water, 0.19 g., melting at 103.5–104.5°, being obtained. The total yields consisted of 7.31 g. (19.8% yield) of cinnamic acid and 10.27 g. (23.3% yield) of ethylcinnamic acid.

(b) Benzaldehyde, Butyric Anhydride and Sodium Acetate at 180°.—This experiment was carried out as described under (a), using 41.0 g. (0.50 mol) of sodium acetate, 39.5 g. (0.25 mol) of butyric anhydride and 26.5

(19) Meyer and Beer, Monatsh., **34**, 649 (1913).

(20) All melting and boiling points are corrected.

(21) See Shriner and Fuson, "Systematic Identification of Organic Compounds," John Wiley and Sons, Inc., New York, N. Y., 1935, p. 99.

g. (0.25 mol) of benzaldehyde. The mixture of cinnamic and ethylcinnamic acids was separated by essentially the same method as used in (a). The total yields consisted of 7.61 g. (20.6%) of cinnamic acid and 12.06 g. (27.4%) of ethylcinnamic acid.

(c) **Benzaldehyde, Acetic Anhydride and Sodium Butyrate at 100°.**—Sodium butyrate (55.0 g., 0.50 mole) and acetic anhydride (25.5 g., 0.25 mol) were placed in a 200-cc. round-bottomed flask equipped with two side-arms, one being made of capillary glass tubing and the other of 7-mm. tubing. Dry nitrogen (from which oxygen had been removed by means of alkaline pyrogallol) was passed into the reaction mixture through the capillary tube. A dropping funnel was attached to the other side-arm. The flask was connected to a reflux condenser and heated for fifty hours on a boiling water-bath. Benzaldehyde (26.5 g., 0.25 mol) was then added through the dropping funnel and the flask heated for an additional hundred hours. The reaction mixture was solid and faintly yellow. Water was added and the solution steam-distilled until no more benzaldehyde passed over. The residue was made alkaline with sodium carbonate and extracted with ether. The alkaline solution was then acidified with hydrochloric acid and the precipitate of cinnamic and ethylcinnamic acids filtered off.

The mixture of acids was refluxed with 500 cc. of ligroin, the inorganic salts filtered off while hot, and the solution cooled. No precipitate formed. The ligroin was evaporated and the residue boiled with three liters of water. Solution was incomplete. The mixture was cooled and filtered, giving precipitate (A) and filtrate (B). On recrystallization of precipitate (A) from a dioxane–water mixture, 8.75 g. of ethylcinnamic acid, melting at 101–102.5°, was obtained. The addition of excess water to the dioxane solution gave a low-melting precipitate (C). Filtrate (B) was extracted with ether, the ether evaporated, and the residue recrystallized from 50 cc. of hot ligroin. The precipitate consisted of 1.54 g. of cinnamic acid, melting at 133–134°. The ligroin filtrate was evaporated, the residue combined with the low-melting precipitate (C), and dissolved in three liters of hot water. The solution was cooled and filtered, the precipitate being ethylcinnamic acid (0.98 g.), melting at 103–104.5°. The aqueous filtrate was extracted with ether, the ether was evaporated, and the residue recrystallized from 25 cc. of ligroin. Cinnamic acid (0.92 g.), melting at 134–135°, was obtained. The ligroin solution yielded a negligible residue on evaporation. A total yield of 2.46 g. (6.65%) of cinnamic acid and 9.73 g. (22.1%) of ethylcinnamic acid was obtained.

(d) **Benzaldehyde, Butyric Anhydride and Sodium Acetate at 100°.**—This experiment was carried out as described under (c), using 41.0 g. (0.50 mol) of sodium acetate, 39.5 g. (0.25 mol) of butyric anhydride and 26.5 g. (0.25 mol) of benzaldehyde. Cinnamic and ethylcinnamic acids were separated essentially as described under (c). The yield of cinnamic acid was 2.26 g. (6.10%) and that of ethylcinnamic acid was 10.14 g. (23.0%).

It should be noted that in experiments (a), (b), (c) and (d), the yields are based on practically pure compounds, the cinnamic acid never melting below 131.5° and the ethylcinnamic acid never melting below 101°. It has been found that when 1.00 g. of ethylcinnamic acid (m. p.

103–104°) is mixed with 0.05 g. of cinnamic acid (m. p. 133–134°), the melting point is lowered to 93–99°. The yields of cinnamic and ethylcinnamic acids obtained in these experiments are tabulated in Table I. With the exception of experiment (a), the probable experimental error is ±0.4 g.

(e) **Benzaldehyde, Acetic Anhydride and Sodium Phenylacetate at 180°.**—Sodium phenylacetate (79.0 g., 0.50 mol) and acetic anhydride (25.5 g., 0.25 mol) were placed in the 200-cc. flask with two side-arms and heated for four hours under purified nitrogen at 180°. Benzaldehyde (26.5 g., 0.25 mol) was then added and the mixture heated for another eight hours. The reaction mixture on cooling was a deep red solid mass. Water was added and the solution made strongly alkaline with sodium carbonate. The solution was extracted with ether, the ether solution being colored a deep red. The alkaline solution was then acidified with hydrochloric acid and filtered. The precipitate was boiled with 500 cc. of hot water and filtered hot. The precipitate yielded 1.36 g. (only 2.4%) of phenylcinnamic acid, melting at 173.5–174.5°. Bakunin[22] gives 172° as the melting point of this compound. The water solution, on cooling, was shown to contain nothing but phenylacetic acid.

The ether solution was evaporated, leaving approximately 40 g. of red, oily residue. This consisted partly of benzaldehyde and partly of a higher-boiling oil. Water was added and the benzaldehyde steam-distilled off. The oily residue was refluxed two hours with a sodium hydroxide solution in order to decompose any anhydride present, but no phenylcinnamic acid could be isolated from the alkaline solution. The oil was extracted with ether, the ether evaporated, and the oil steam-distilled. It distilled very slowly. After collecting seven liters, the distillate was extracted with ether and the ether solution evaporated. The residue (2.5 g.) melted in the neighborhood of room temperature and was identified as dibenzyl ketone by its phenylhydrazone, m. p. 119–120°. Shriner and Fuson[21] (p. 111) give 34° as the melting point of dibenzyl ketone and 120° as the melting point of its phenylhydrazone.

(f) **Benzaldehyde, Acetic Anhydride and Sodium Phenylacetate at 195°.**—In this experiment a mixture of 15.8 g. (0.10 mol) of sodium phenylacetate, 10.2 g. (0.10 mol) of acetic anhydride and 10.6 g. (0.10 mol) of benzaldehyde were heated together under nitrogen for six hours at 195° as described by Bakunin.[22] On cooling, the reaction mixture consisted of a yellow solid, smelling only slightly of benzaldehyde. Water was added (no oil being present) and the solution made alkaline with sodium carbonate. The alkaline solution was extracted with ether. The ether solution was evaporated and the residue recrystallized from alcohol. Stilbene (2.50 g.) was obtained, melting at 124.5–125.5°. Bakunin[22] gives 126° as the melting point of stilbene.

The alkaline solution was acidified with hydrochloric acid and the mixture filtered. The precipitate consisted of a mixture of cis- and trans-phenylcinnamic acids. These were separated by boiling with 700 cc. of water and cooling. The precipitate consisted of 12.55 g. of trans-phenylcinnamic acid (56.0%), melting at 171–172°. The cis-acid was precipitated from the water solution by the addi-

(22) Bakunin, Gazz. chim. ital., **31**, II. 77 (1901).

tion of concentrated hydrochloric acid. On recrystallizing the precipitate from a small amount of hot water, 1.35 g. of cis-phenylcinnamic acid (6.0%), melting at 139–140°,[23] was obtained. The combined water solutions were extracted with ether, the ether evaporated, and the residue recrystallized several times from water. Cinnamic acid (0.25 g., 1.7%), melting at 131–133°, was obtained.

(g) **Benzaldehyde, Acetic Anhydride and Sodium Malonate.**—A mixture of sodium malonate (14.8 g., 0.10 mol), acetic anhydride (10.2 g., 0.10 mol) and benzaldehyde (10.6 g., 0.10 mol) contained in a 200-cc. round-bottomed flask was allowed to stand at room temperature as described by Stuart.[7] In order to detect any evolution of carbon dioxide, the reaction flask was connected through a drying tube filled with Drierite to a barium hydroxide solution. On standing at room temperature, the mixture turned orange after an hour and was semi-solid at the end of a week. Little if any carbon dioxide was given off. The reaction mixture was treated with water and made alkaline with sodium carbonate. The alkaline solution was then extracted with ether. On shaking the ether solution with a saturated solution of sodium bisulfite, 80% of the benzaldehyde was recovered as the addition product. The alkaline solution was acidified with dilute sulfuric acid and chilled. Contrary to Stuart's results no precipitate separated; only a cloudy solution was obtained. This was extracted with ether and the ether evaporated. The residue obtained was treated with a small amount of water in order to dissolve malonic acid. The solid remaining undissolved was filtered off; it weighed 0.05 g. Recrystallization of this from hot water gave only a trace of cinnamic acid, m. p. 132–133°.

This experiment was repeated several times, always with the same result. No benzalmalonic acid and not more than a trace of cinnamic acid was found in any experiment. In one case, a gram of anhydrous sodium carbonate was added to the reaction mixture, but the same result was obtained.

We have confirmed Stuart's observation that when the benzaldehyde was omitted and equimolar portions of acetic anhydride and sodium malonate allowed to stand at room temperature, the mixture turned orange after an hour and became a deep brick-red solid at the end of twenty-four hours. No carbon dioxide, however, was evolved during the course of a week.

(h) **Benzaldehyde, Acetic Acid and Sodium Malonate at 100°.**—In this experiment, which also has been carried out previously by Stuart,[7] glacial acetic acid was used instead of acetic anhydride. A mixture of 14.8 g. (0.10 mol) of sodium malonate, 6.0 g. (0.10 mol) of acetic acid and 10.6 g. (0.10 mol) of benzaldehyde was heated under nitrogen for twelve hours on a boiling water-bath. The reaction mixture, a pale yellow solid, was treated with water and made alkaline with sodium carbonate. The alkaline solution was extracted with ether. On shaking the ether solution with sodium bisulfite, 43% of the benzaldehyde was recovered as the addition complex. The alkaline solution was acidified and filtered. The precipitate (4.75 g.) of benzalmalonic acid obtained melted at

190–195°. The acid solution was extracted with ether and the ether evaporated. The residue obtained was treated with a small amount of water to dissolve malonic acid and the insoluble benzalmalonic acid (1.05 g.) filtered off; m. p. 190–195°. The total yield of crude benzalmalonic acid was 5.8 g., corresponding to 30% of the theoretical yield based on the benzaldehyde started with. Stuart reported that he obtained only cinnamic acid. Recrystallization of the crude benzalmalonic acid from hot (not boiling) water gave 2.2 g. of pure acid, melting at 195–196° with decomposition. This melting point agrees with that recorded in the literature.[24] Neutral equivalent calculated for $C_{10}H_8O_4$: 96.0. Found: 96.1.

(i) **Benzaldehyde, Acetic Acid and Sodium Malonate at Room Temperature.**—The above experiment (h) was duplicated at room temperature. The reaction mixture solidified at the end of one hour, but it was allowed to stand for a week. The final reaction mixture was colored a pale yellow. Water was added and the solution made alkaline with sodium carbonate. Extraction of the alkaline solution with ether yielded 7.8 g. (73.5%) of benzaldehyde recovered as the sodium bisulfite addition complex. The alkaline solution was acidified with hydrochloric acid, but no precipitate was formed. The acid solution was therefore extracted with ether and the ether solution evaporated. To the residue was added a small amount of water to dissolve malonic acid, and the solid filtered off. This solid (3.92 g.) melted at 150–180°. On recrystallization from 50 cc. of hot water, 3.0 g. (15.6% of theory) of benzalmalonic acid, melting at 190–195°, was obtained. After another recrystallization the substance melted at 195–196° with decomposition, and showed no depression of the melting point when mixed with an authentic sample of benzalmalonic acid.

Summary

1. Contrary to the result of an earlier worker, we have shown that in the presence of acetic anhydride sodium malonate does not condense to any appreciable extent with benzaldehyde at room temperature.

2. A mixture of acetic anhydride and sodium butyrate was heated until the equilibrium of the anhydride-salt exchange was established; benzaldehyde was then added and the mixture heated further. Cinnamic and ethylcinnamic acids were isolated from the reaction mixture. This experiment was carried out at 100 and at 180°.

3. The experiments described in (2) were repeated using butyric anhydride and sodium acetate instead of acetic anhydride and sodium butyrate.

4. The results obtained in this paper, together with results of other workers, show that the anhydride condenses in the Perkin synthesis.

(23) Bakunin[22] gives 137° as the melting point of cis-phenyl-cinnamic acid.

(24) Claisen and Crismer. Ann., 218, 136 (1883).