NATIONAL ACADEMY OF SCIENCES

WILLIAM ZEV HASSID

1899—1974

A Biographical Memoir by

CLINTON BALLOU AND HORACE A. BARKER

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October 1, 1899–April 28, 1974

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ZEV (ZE'EV) HASSID was born in Jaffa, Palestine, probably on October 1, 1899, although he seemed uncertain about the date of his birth and sometimes gave the year as 1897 or 1901. The name William was added after he came to the United States. His parents, Mordecai and Esperanza Hassid (Chassid), were born in Poland, but were Russian citizens at the time of his birth. His father was a lumber merchant who brought lumber from Russia to Palestine. When Zev was four years old, the family moved to a farm in the vicinity of Kremenetz in the Russian Ukraine, and his childhood was spent in this rural environment. He often wandered in the adjacent woods and fields, hunted for birds' nests, and associated with shepherds, so much so that his father scolded him and said that if he did not spend more time on his studies he would qualify for nothing more than a herdsman.

Russian and Yiddish were Zev's native languages. Little is known about his early education except that he was required to study traditional Jewish religious material. He did not accept this instruction readily and in later life rebelled by dissociating himself from most formal religious activities. Nevertheless, his early training was evidenced by a familiarity with and an occasional quotation from scriptures.

In 1912, Hassid was sent back to Palestine with a group of

Jewish children to continue his education in a Hebrew language school. His parents hoped that he would be admitted to the "Gymnasia Hertzlia" in Tel Aviv, but instead he was sent to the recently founded Agricultural High School in the Jewish settlement of Petah-Tikva. The curriculum included Hebrew, French, and Arabic languages, Hebrew religious studies, history, geography, and considerable science, plus professional studies in soil, plant nutrition, subtropical horticulture, animal husbandry, laboratory practice in analytical methods, and field experience in agricultural techniques. He graduated in 1916.

With the outbreak of World War I, Hassid was cut off from communication with his parents, who had remained in Russia. Consequently, his only income was what he could earn himself. While still in school and after graduation, he worked as a laborer in the orange groves and other farms near Petah-Tikva, Nikva-Israel, and Ben Shemen. His income was small, his food and clothing correspondingly poor. For a considerable period he lived on bread, watery soup, pumpkin porridge, and oranges; he was often hungry. His clothing was worn and ragged. Once his shoes were stolen, and he had to go barefoot for a considerable time. During this period Hassid was frequently ill. He suffered repeated attacks of malaria and dysentery; he also contracted typhoid fever, which he barely survived.

Palestine was controlled by the Turks until the British army invaded the country in 1917. Following the Balfour Declaration that same year, many young Jews joined the British army to help liberate the country from the Turks and create conditions favorable for the establishment of a Jewish homeland. Hassid volunteered for army service early in 1918, partly for patriotic reasons and partly to improve his standard of living. Initially, he was rejected by the army because of his poor health, but finally, through the intervention of James de Rothschild, an officer in the British army, he was accepted into the 38th brigade of the Royal Fusiliers (1st Judeans), later referred

to as the Jewish Legion. At this time he became a British citizen and served for two years in the army, mainly as a clerk at supply depots and at General Headquarters, 3rd Echelon. He never engaged in combat; however, on at least one occasion he was close enough to the front to be within artillery range, and a large shell landed close to him but failed to explode. He also guarded prisoners and supplies in transit. The latter duty required him to travel as far as Beyreuth in Lebanon and Alexandria in Egypt. At the railway station in Beyreuth he once witnessed the ceremonial arrival of Lawrence of Arabia. In Alexandria he first heard of the University of California from a fellow soldier, Assaf Gur (Grazovsky), who had studied there.

When Hassid completed his military service with the rank of corporal in August 1920, he was awarded the British War Medal and the Victory Medal, bearing the inscription, "The great war for civilization." His superior officer provided him with the following recommendation: "Corporal Hassid has been employed as a clerk in the Battalion Orderly Room and at Records, 3rd Echelon. He is a conscientious, painstaking worker, reliable and capable, and as a soldier has borne an exemplary character."

After leaving the army, Hassid decided to use the accumulated savings from his pay to go to California to study agronomy at the University, with the intention of returning ultimately to Palestine to assist in the development of scientific agriculture. He traveled by way of Paris, New York, and Chicago, staying briefly in each city, and finally arrived in Berkeley in late 1920. His funds were almost exhausted, so he supported himself by doing odd jobs in stores and restaurants in Berkeley in the winter and by working as a farm hand in the vicinity of Fresno in the San Joaquin Valley in the spring and summer. He also taught Hebrew in the local synagogue.

Hassid first registered at the University of California in August 1921. However, his knowledge of English was so limited

that he could not follow lectures well enough to take notes, and even reading textbooks required more time than he could spare between jobs. So after a week of frustration and mounting tension, he took a leave of absence from the University and moved to Fresno where he spent two years as a student in Fresno State College, majoring in Letters and Science with an emphasis on Chemistry, French language, and Mathematics. The following year he enrolled at the Southern Branch of the University of California at Los Angeles. His course grades were about average; he even failed one course in quantitative analysis and had to repeat it later. His undistinguished record during this period probably resulted from his inadequate command of English and the fact that he had to earn a living while attending school.

In August 1924, Hassid returned to the Berkeley campus of the University. He majored first in chemistry but later changed to general literature, the field in which he obtained a Bachelor of Arts degree in December 1925. Following graduation, he immediately started graduate studies in the School of Education, and in December 1926 he received a Certificate of Completion with majors in chemistry and general literature and minors in mathematics and physics. In the same month Hassid obtained a General Secondary School Credential from the State Board of Education, but he never taught in public schools. Instead, he worked for some months as a chemical analyst in a commercial company.

By September 1927, and possibly earlier, Hassid took a position as research assistant under Professor D. R. Hoagland in the Division of Plant Nutrition of the Agricultural Experiment Station. His main duties were the routine analysis of plant materials and soils for a variety of inorganic constituents, but he also obtained experience in growing plants in culture solution and studying the absorption of various nutrients. This work renewed Hassid's interest in plant research, and in August 1928 he again enrolled in the University, this time as a graduate stu-

dent in Plant Nutrition. During the following two years, while still working half time or more, he took courses in botany, plant physiology, and plant nutrition and prepared a Master of Science thesis dealing with the structure of the four isomers of penta-*O*-acetyl-D-galactose. Professor Hoagland formally supervised his thesis research, but the nature of the problem clearly indicates that it was inspired and guided mainly by Professor Walter H. Dore, who was interested in the structure of carbohydrates and had applied X-ray diffraction methods to their elucidation. After receiving the master's degree in August 1930, Hassid started to prepare for a doctorate in Plant Physiology. While visiting the beaches south of San Francisco, he observed the abundant fleshy marine algae, which appeared to consist largely of polysaccharides, and he decided to investigate the structure of the major component. This was the subject of his Ph.D. thesis, which was completed and accepted in December 1934, with Professor Dore as the chairman of the committee. Hassid had worked almost independently, however, using the methods developed by Haworth for carbohydrate structure determination, which were unfamiliar to Dore. Professor T. D. Stewart of the chemistry department, a member of the thesis committee, was particularly impressed by the clear results and logical presentation of Hassid's thesis, and his enthusiastic reaction helped Hassid to obtain an appointment the following year as a Junior Chemist in the Division of Plant Nutrition of the Agricultural Experiment Station.

The circumstances of Hassid's appointment as a Junior Chemist are amusing and illustrative of the method of making appointments in 1935. Professor Hoagland lectured and taught laboratory courses in plant biochemistry during the Fall term. Hassid had served for several years as a teaching assistant in the laboratory course, and Hoagland, who directed an active research program and served as Chairman of the Division, had come to depend on him for the preparation of reagents, setting

up of equipment, and much of the instruction. But after receiving his Ph.D. in 1934, Hassid began to look for a better position than was provided by his assistantship. In the early summer of 1935, he received an offer of a position and told Professor Hoagland that he was planning to leave before the beginning of the Fall term. Hoagland was upset at this news because he was preparing to attend a botanical congress in Amsterdam and would not return to Berkeley until the beginning of the term and then would have no experienced assistant for the laboratory course. He finally asked Hassid whether he would stay on if he received an Experiment Station appointment. Hassid agreed. Hoagland consulted with Dean Hutchison, who found that the available funds were insufficient to provide the usual starting salary of $2,000 per year, but he could offer $1,800. Hassid accepted this although it was considerably below what he was offered outside the University. He never regretted his decision. In 1939 he received the additional title of Instructor, and so was launched upon his academic career.

Hassid's independent scientific research began with an investigation of the ethanol-extractable carbohydrates in the marine alga *Iridea laminarioides,* and this work led step-by-step to an interest in the biochemistry of carbohydrates that he sustained in one form or another for almost thirty-five years. In the initial study, he identified dulcitol (galactitol) as a major component of this plant extract and observed that reducing sugars were notably absent from acid hydrolysates. He then purified and characterized an abundant polysaccharide from the same organism and showed it to be a sulfated polygalactan. From methylation studies, he was able to conclude that the galactosyl units were probably joined by 1→4 glycosidic linkages and that the sulfate was probably esterified with the hydroxyl group on carbon 6. These results led him to speculate that the metabolism in this alga might involve a relationship between galac-

titol and galactan analogous to that between glucose and starch in higher plants, but he never followed up this idea.

Hassid's study of the structure of the algal galactan was the first of a long series of investigations of polysaccharides. Many of the preparations were provided by colleagues with whom he was always happy to collaborate. C. B. Lipman called his attention to a very viscous substance produced from mannitol by an unidentified bacterium that had been isolated "from a mud brick taken from a wall in an old Roman village which was built about 400 AD in the western desert of Egypt." In a paper with W. L. Chandler (1937), Hassid characterized the viscous material as a polysaccharide containing about ten anhydroglucose units. In the following years he published papers dealing with the molecular structure of canna starch (with W. H. Dore), dog liver glycogen (with I. L. Chaikoff), the dextran formed from sucrose by *Betacoccus arabinosaceus* (with H. A. Barker), an insoluble polysaccharide derived from *Saccharomyces cerevisiae* (with M. A. Joslyn and R. M. McCready), and glycogen and starch derived from sweet corn (*Zea mays*) (with R. M. McCready).

The existence of the enzyme phosphorylase that converts glycogen and inorganic phosphate to α-D-glucose 1-phosphate had been demonstrated by C. F. Cori and G. Cori in 1936, and the reversal of this reaction was reported in 1939 by W. Kiessling. Hassid and R. M. McCready (1941) undertook the structural analysis of the biosynthetic product and showed that it had starchlike properties but that the molecules were unbranched in contrast to the highly branched natural polymer. In a short review for *Chronica Botanica* published in 1942, Hassid related the prevalent view that "the enzyme phosphorylase, and not amylase as had been previously assumed, is chiefly responsible for the synthesis and breakdown of starch in the plant." McCready and Hassid developed a convenient method for prepar-

ing pure α-D-glucose 1-phosphate on a relatively large scale, thus making this important compound readily available for biochemical studies. They also developed a procedure for determining the relative amounts of amylose and amylopectin in starch based upon the large difference in the absorption coefficients of iodine complexes of the two components. The absorption coefficients of different starch samples were found to correlate well with the degree of hydrolysis of the components by β-amylase. Their results supported the conclusion of K. H. Meyer that amylose consists of long unbranched chains of glycosyl units.

This experience with carbohydrates prepared Hassid for an important collaborative effort with S. Ruben and M. D. Kamen (1939) representing the first application of radioactive carbon to the study of photosynthesis. The short-lived ^{11}C-isotope (20.5 minutes half-life) had become available through Kamen's association with the Radiation Laboratory at the University in Berkeley, and a study was carried out to determine the distribution of the label from ^{11}C-carbon dioxide when fed to barley leaves in the light or after they had been kept in the dark for various periods of time. Although some of the label was incorporated into carbohydrate, the results indicated that most of it was present in the plant in a water-soluble noncarbohydrate form. In an extension of this work, the green alga *Chlorella pyrenoidosa* was utilized in place of barley leaves, allowing a much more efficient incorporation of the radiocarbon label. Studies of the kinetics of incorporation in the light and dark, and on the reversibility of the reaction, were carried out with Ruben and Kamen (1940). Although it was concluded that "the greater fraction if not all the C^*O_2 has been reduced to $-C^*OOH$," no specific identification of the initial product of photosynthesis was made other than that there were "at least one alcoholic hydroxyl and one carboxyl group in the active

molecules." The product was later identified as phosphoglyceric acid by M. Calvin and his associates.

Other than a brief collaboration with S. Aronoff, A. Benson, and M. Calvin (1947) on the distribution of label from $^{11}CO_2$ in photosynthesizing plant tissue, Hassid's research on photosynthesis was not continued and his involvement appears to have been based more on an interest in carbohydrate structural analysis than in the fundamentals of carbon fixation in plants. However, it is apparent from the later turn of events that this introduction to the utility of radioactive tracer techniques for elucidation of biochemical processes had a strong influence on his development.

Hassid's initial appointment as a Junior Chemist in the Agricultural Experiment Station was followed by promotion to the academic staff as an Instructor in Plant Nutrition (1939) and as Assistant Professor in 1941. About this time, he developed an association with fellow colleagues H. A. Barker and M. Doudoroff that grew into a close scientific collaboration and a lifelong friendship. His first joint study with Barker concerned the structure of an extracellular (1→6) dextran produced by the bacterium *Leuconostoc mesenterioides* when grown on sucrose. Less than three years later, he was involved with Doudoroff and N. Kaplan in the beginning of an important study on the biosynthesis of sucrose. Doudoroff had been interested in the bacterium *Pseudomonas saccharophila* because it oxidized sucrose faster than the component monosaccharides—glucose and fructose. This was demonstrated to result from the presence of an enzyme that converts sucrose to α-D-glucose 1-phosphate and D-fructose. Doudoroff, Kaplan, and Hassid found that this reaction can be reversed, leading to the formation of sucrose as detected by the production of a nonreducing substance that yielded reducing sugar on acid hydrolysis. That it was indeed sucrose was proved by Hassid, Doudoroff, and Barker (1944)

when they prepared 2.5 grams of the crystalline disaccharide by the action of sucrose phosphorylase on a mixture of 15 grams each of α-D-glucose 1-phosphate and D-fructose and showed that its properties were identical with those of commercial sucrose.

The enzymatic synthesis of sucrose resulted in some publicity that came to the attention of officials of the Coca-Cola company, who were having difficulty obtaining sucrose because of wartime rationing. The company sent a representative to Berkeley to ascertain whether commercial quantities of sucrose could be made by the enzymatic method. Hassid and his associates were away on vacation at the time, so the Coca-Cola emissary discussed the problem with Professor Hoagland and reported that his company was prepared to provide $500,000 for research on this enzyme if a commercial process of sucrose synthesis seemed feasible. Unfortunately, Professor Hoagland was pessimistic about the possibility of sweetening Coca-Cola by this method, and so further support of research of sucrose phosphorylase was left to the University and the U.S. Public Health Service.

Later studies on sucrose phosphorylase showed that it could transfer D-glucose to L-sorbose and D-*threo*-pentulose to form nonreducing disaccharide analogs of sucrose and to L-arabinose to yield 3-*O*-α-D-glucopyranosyl-L-arabinose. The mechanism of the phosphorylase reaction was investigated by isotope exchange reactions with ^{32}P-orthophosphate, which was shown to exchange into nonradioactive α-D-glucose 1-phosphate. With alternative monosaccharide acceptors such as L-sorbose, the enzyme was shown to transfer D-glucose from sucrose in the absence of orthophosphate. Clearly, the reaction involved an intermediate D-glucosyl-enzyme that could be formed either from α-D-glucose 1-phosphate or from an α-D-glucosyl derivative such as sucrose.

Near the end of the 1940s, Hassid's research began to take

a new direction as he concentrated on the synthesis of radiocarbon-labeled sugars and on the chemical preparation of sugar phosphates. E. W. Putman was a major collaborator in developing methods for preparing labeled sugars from plant tissue after their biosynthesis by the photosynthetic fixation of ^{14}C-carbon dioxide. They applied the new methods of paper chromatography to the preparation of uniformly ^{14}C-labeled carbohydrates of high specific activity, including glucose, fructose, galactose, sucrose, and starch. Hassid generously supplied radioactive sugars both to his colleagues and to many scientists throughout the country before they became commercially available. These studies on the preparation of labeled sugars were extended to investigations of the route by which the carbon dioxide, once fixed as glyceric acid phosphate, was converted into various carbohydrates, as well as the processes by which labeled hexose was taken up and utilized for synthesis of sucrose and cellulose.

About this time, Hassid was joined by two graduate students, V. Ginsburg and E. F. Neufeld, in an active program dealing with the role of sugar nucleotides in the interconversion of carbohydrates in higher plants. In the initial studies they were joined by P. K. Stumpf, who had been appointed to the Department of Plant Nutrition in 1948, and who, as an undergraduate student at Harvard University, had worked on purification of potato phosphorylase with D. E. Green. Although Stumpf is best known for his investigations on lipid metabolism in plants, his earlier studies in sugar metabolism were influential in the development of Hassid's interests in this field. The discovery by L. F. Leloir (1951) of uridine diphosphate D-glucose and the demonstration that this substance served as a glucosyl donor for synthesis of disaccharides focused attention on the sugar nucleotides as intermediates in the interconversion of carbohydrates, and Hassid directed his concern to these substances in higher plants. With Ginsburg and Stumpf (1956), he

investigated the occurrence of uridine diphosphate derivatives of D-glucose, D-galactose, D-xylose, and L-arabinose in mung bean (*Phaseolus aureus*), the latter two derivatives being found for the first time in nature. The same source yielded the uridine diphosphate derivatives of *N*-acetyl-D-glucosamine and D-glucuronic acid (with J. Solms and D. S. Feingold), whereas the guanosine diphosphate derivatives of L-galactose and D-mannose later were identified in the red alga *Porphyra perforata* (with J. C. Su), and guanosine diphosphate D-mannuronic acid was isolated from the brown alga *Fucus gardneri* (with T. J. Lin).

These studies on the natural occurrence of sugar nucleotides in plants were paralleled by investigations of their biosynthesis by the pyrophosphorylase reaction. A series of papers with Neufeld, Putman, Feingold, Ginsburg, and others delineated the presence in higher plants of pyrophosphorylases that formed the respective uridine diphosphate hexoses from reaction of uridine triphosphate with the 1-phosphate esters of α-D-galactose, α-D-xylose, β-L-arabinose, α-D-glucuronic acid, α-D-galacturonic acid, and *N*-acetyl-α-D-glucosamine. Because these studies required the sugar 1-phosphates as substrates and such substances were not generally available at the time, considerable effort was devoted to the improvement of published syntheses and the development of new ones for the preparation of glycosyl phosphates. Later studies dealt with the enzymic phosphorylation of several sugars, including D-galactose, L-arabinose, D-glucuronic acid, and D-galacturonic acid (with Neufeld, Feingold, and others).

Hassid's international reputation attracted senior scientists from around the world to work in his Berkeley laboratory. One of these was Winifred N. Watkins from the Lister Institute of Preventive Medicine in London, who is noted for her studies on the structure and biosynthesis of the blood group antigens. In 1961 Watkins and Hassid undertook a study of the biosynthesis of lactose in mammary tissue. It had been claimed by

J. G. Gander, W. E. Petersen, and P. D. Boyer (1957) that bovine mammary tissue contained enzymes that converted uridine diphosphate D-galactose and α-D-glucose 1-phosphate to lactose 1-phosphate, and that the latter was hydrolyzed to free lactose. However, since uridine diphosphate D-galactose and α-D-glucose 1-phosphate are in ready equilibrium by way of uridine diphosphate D-glucose, one would expect ^{14}C-D-glucose to be incorporated equally into the two parts of lactose by this pathway, an expectation that was contrary to recorded observations by other workers. Watkins and Hassid reinvestigated this matter and established that uridine diphosphate D-galactose and free D-glucose were the precursors of lactose in lactating guinea pig and bovine mammary tissue and that the product was lactose rather than lactose 1-phosphate.

In addition to these results on lactose synthesis, Watkins and Hassid (1962) also made the important observation that mammary tissue contained an enzyme activity that transfers D-galactose to *N*-acetyl-D-glucosamine. Noting the occurrence in milk of oligosaccharides that contained this lactosamine unit, and finding that different mammary gland preparations gave different relative amounts of ^{14}C-lactose and *N*-acetyl-^{14}C-lactosamine when incubated with uridine diphosphate ^{14}C-D-galactose, they concluded that "different enzymes are responsible for the synthesis of the two compounds." This conclusion, and a later one by Helene Babad and Hassid (1966) that the soluble, purified lactose synthetase from milk was "very labile to further purification," proved to be incorrect, for it was found subsequently by K. E. Ebner and others (1967) that the mammary gland β-D-galactosyltransferase is under the control of a specificity-altering protein, α-lactalbumin. In the presence of α-lactalbumin, the preferred acceptor is D-glucose, and lactose is the product, whereas in absence of the protein, *N*-acetyl-D-glucosamine acts as the acceptor to yield *N*-acetyl-lactosamine. The observations of Watkins and Hassid can be explained by the

presence of variable amounts of α-lactalbumin in their lactose synthetase preparations, and the results of Babad and Hassid are explained as reflecting the first successful fractionation of these two proteins.

The existence of enzymes that interconverted sugar nucleotides without degrading the molecule had become recognized by the latter part of the 1950s, and Hassid turned to the study of some of these reactions in plants. With Neufeld and Feingold, he demonstrated the enzymic conversion of uridine diphosphate D-glucuronic acid to the nucleotide derivatives of galacturonic acid, xylose, and arabinose. In a later study, the enzyme activities that catalyzed these reactions were separated so that it was possible to show the 4-epimerization of uridine diphosphate D-glucuronic acid to the galacturonic acid derivative as an isolated step and to demonstrate the decarboxylation of uridine diphosphate D-glucuronic acid to uridine diphosphate xylose. An enzyme activity was also found that epimerized the xylose derivative to the arabinose derivative.

Throughout his career, Hassid was concerned with the fundamental question of how the sugar that is formed in a photosynthesizing plant is converted to disaccharides such as sucrose and into polysaccharides such as starch and cellulose. His earliest experiments dealt with the infiltration of radiocarbon-labeled sugars into plant leaves, but later they became more sophisticated with the utilization of well-defined sugar nucleotides as specific donors in cell-free enzyme systems. It was known that uridine diphosphate D-glucose was a precursor of a β-1→4-glucan in *Acetobacter xylinum* (L. Glaser, 1957) and of the α-1→4-glucan, glycogen, in liver (Leloir, 1957). Feingold, Neufeld, and Hassid (1958) reported the synthesis of a β-1→3-glucan from this sugar nucleotide by a digitonin-treated particulate transferase from mung bean, the product apparently being identical to laminarin, whereas R. A. Dedonder and Hassid (1964) observed formation of a β-1→2-glucan in *Rhizobium japonicum*.

In a similar fashion, uridine diphosphate xylose was shown to be the precursor of a β-1→4-xylan in asparagus (*Asparagus officinalis*). Hassid also investigated the synthesis of alginic acid (with T.-Y. Lin), the synthesis of pectin (with C. L. Villemez), and the methylation of the latter polysaccharide to form the ether and ester derivatives (with H. Kauss).

This interest in polysaccharide formation in plants led Hassid naturally to an investigation of cellulose biosynthesis and perhaps to the culminating point of his scientific career. Even today the study of cellulose biosynthesis in higher plants is fraught with technical difficulties that have hindered the definition of this system in the same detail that has been possible with other polysaccharide-forming reactions. In 1964, A. D. Elbein, G. A. Barber, and Hassid reported the formation of cellulose from guanosine diphosphate D-glucose and a particulate enzyme preparation from mung bean seedlings. Contrary to the finding of Glaser with a bacterial system, the plant synthetase had no activity with uridine diphosphate D-glucose. The polysaccharide product was characterized primarily on the basis of its alkali insolubility, which was similar to that of cellulose, and on the formation of radioactive cellobiose and cellodextrins by acid hydrolysis and by acetolysis. The study was complicated by the concomitant formation of a glucomannan from endogenous guanosine diphosphate mannose. However, a soluble enzyme system that made cellulose was eventually obtained (with H. M. Flowers, K. K. Batra, and J. Kemp, 1969), and this product was only slightly contaminated by mannose.

Some controversy concerning cellulose biosynthesis arose when D. O. Brummond and A. P. Gibbons (1964) reported that uridine diphosphate D-glucose was a precursor of a cellulose-like polymer in *Lupinus albus,* and L. Ordin and M. A. Hall (1967) observed a similar reaction in *Avena sativa.* These reports stimulated Hassid to restudy the roles of both uridine and guanosine diphosphate D-glucose in the synthesis of alkali-insoluble poly-

saccharides in *Phaseolus aureus.* He eventually established, with H. M. Flowers, K. K. Batra, and J. Kemp (1968), that the polymer formed with uridine diphosphate D-glucose in *L. albus* was an alkali-insoluble β-1→3-glucan rather than cellulose, whereas that produced by *A. sativa* was a mixed β-1→3- and β-1→4-glucan. C. M. Tsai and Hassid (1971) succeeded in separating the two enzymic activities of *A. sativa* that make the two polysaccharides, and they found that the type of glucan made was dependent on the concentration of the sugar nucleotide donor.

From this brief survey, we can see that there were few features of carbohydrate metabolism in plants that escaped Hassid's touch, and much that we know about the role of sugar nucleotides in the interconversion of carbohydrates in plants is a direct result of his persistent effort. From the incorporation of labeled precursors into monosaccharides, to the conversion of the monosaccharides to their glycosyl 1-phosphates, to the action of the pyrophosphorylases in the synthesis of the nucleoside diphosphate sugars, to the interconversion of the resulting sugar nucleotides, to the polymerization of the activated monosaccharides yielding disaccharides and the homopolysaccharides, and finally to the modification of the polysaccharides by methylation—in summary, to almost every aspect of carbohydrate metabolism—Hassid contributed his full and devoted attention. Nor did his efforts slacken with age, for he continued working and writing and thinking science as though it was among the most important things in life, and to him it was. He also believed in the importance of communication as a force in scientific progress, for he was a prolific writer of reviews and contributed heavily to books and serials dealing with carbohydrates, the total of such articles being almost fifty.

Hassid's many contributions on the structure and synthesis of plant carbohydrates were recognized by a number of honors and awards. He received the first Sugar Research Award (1945) of the National Academy of Sciences (jointly with M. Doudoroff

and H. A. Barker), the Charles Reid Barnes Honorary Life Membership Award of the American Society of Plant Physiologists (1964), and the C. S. Hudson Award of The American Chemical Society (1967). He was elected to membership in the National Academy of Sciences (1958) and the American Academy of Arts and Sciences (1969), and he was honored at the 6th International Symposium on Carbohydrate Chemistry (1972) as one of three outstanding senior American carbohydrate chemists. He was elected Chairman of the Division of Carbohydrate Chemistry (1949–1950), American Chemical Society, and he served as a member of numerous editorial boards, including those of the *Journal of Biological Chemistry, Annual Review of Biochemistry, Carbohydrate Research, Phytochemistry,* and *Analytical Biochemistry.*

Hassid married Lila Berlin Fenigston in 1936. They had no children, but any void this may have created in their lives was filled by the many friends who shared the warm hospitality of their home in the Berkeley hills. Lila was a gracious and vivacious hostess and an accomplished violinist who made their home a center for friendly social gatherings and for the performance of chamber music. She also had a talent for making fine English translations of Yiddish poetry, which were either published in Jewish periodicals or presented orally in a series of radio programs. Lila's appreciation and contributions to the arts provided a happy counterpoint to the scientific life of her husband.

Perhaps as a result of his severe childhood illnesses and early deprivations, Hassid never enjoyed robust health. For many years, he suffered from the effects of high blood pressure, and he had debilitating attacks of hyperthyroidism and hepatitis. In his early sixties, he suffered a severe coronary occlusion from which he never fully recovered. As he grew older he developed increasing coronary complications that finally resulted in his death on April 28, 1974. He left many friends who will remem-

ber him as a friendly, gentle, and soft-spoken person, but one who on rare occasions, when sufficiently annoyed, could display a strong temper. His personal warmth and generosity, coupled with his sincerity and modesty, attracted many friends, whom he treasured and often regarded as somewhat larger than life. He took pride in the accomplishments of his colleagues and students and spent much time and effort in helping to further their careers and in nominating them for promotions, awards, and honors of various sorts. He never tired nor stinted in helping those who he felt were deserving.

THE INFORMATION in this memoir relating to Hassid's early life in Russia and Palestine was obtained from my (H.A.B.) conversations with him, from letters (dated June 2, 1974 and June 25, 1974), and from an unpublished account of Hassid's early life written by Dr. Rivka Ashbel (prepared for the celebration of Petah-Tikva's seventieth anniversary and based on conversations between Hassid and Ashbel in 1949). Additionally, we had available a number of documents including Hassid's passport application, naturalization papers, and records of his service in the British army and service medals. Most of this material and some of Hassid's manuscripts and letters are kept in a file in the Bancroft Library at the University of California, Berkeley.

BIBLIOGRAPHY

1933

Occurrence of dulcitol in *Irideae laminarioides* (Rhodophyceae). Plant Physiol., 8:480–82.

The isolation of a sodium sulfuric acid ester of galactan from *Irideae laminarioides* (Rhodophyceae). J. Am. Chem. Soc., 55:4163–67.

1935

The structure of sodium sulfuric acid ester of galactan from *Irideae laminarioides* (Rhodophyceae). J. Am. Chem. Soc., 57:2046–450.

1936

Determination of reducing sugars and sucrose in plant materials. Ind. Eng. Chem. Anal. Ed., 8:138–40.

Carbohydrates in *Irideae laminarioides* (Rhodophyceae). Plant Physiol., 11:461–63.

Comparison of the total nitrogen in wheat seeds by the Gunning (modified Kjeldahl) and the Dumas combustion methods. J. Am. Chem. Soc., 58:2075.

1937

With W. L. Chandler. The isolation of a new polysaccharide synthesized by a soil microorganism. J. Biol. Chem., 117:203–7.

Determination of sugars in plants. Ind. Eng. Chem. Anal. Ed., 9:228–29.

With W. H. Dore. The molecular structure of canna starch. J. Am. Chem. Soc., 59:1503–8.

1938

With I. L. Chaikoff. Phosphorylation of glycogen *in vitro*. Science, 88:15–16.

With I. L. Chaikoff. The molecular structure of liver glycogen of the dog. J. Biol. Chem., 123:755–59.

Isolation of hexosemonophosphate from pea leaves. Plant Physiol., 13:641–47.

1939

With S. Ruben and M. D. Kamen. Radioactive carbon in the study of photosynthesis. J. Am. Chem. Soc., 61:661–63.

A water-soluble glucosan from barley roots. J. Am. Chem. Soc., 61:1223–25.

With S. Ruben, M. D. Kamen, and D. C. deVault. Photosynthesis with radio-carbon. Science, 90:570–71.

1940

With R. M. McCready. Determination of starch in plants. Ind. Eng. Chem., 12:142–44.

With M. D. Kamen and S. Ruben. Radioactive nitrogen in the study of N_2 fixation by non-leguminous plants. Science, 91:578–79.

With H. A. Barker. The structure of dextran synthesized from sucrose by *Betacoccus arabinosaceus*, Orla-Jensen. J. Biol. Chem., 134:163–70.

With S. Ruben and M. D. Kamen. Photosynthesis with radioactive carbon. II. Chemical properties of the intermediates. J. Am. Chem. Soc., 62:3443–50.

1941

With M. A. Joslyn and R. M. McCready. The molecular constitution of an insoluble polysaccharide from yeast, *Saccharomyces cerevisiae*. J. Am. Chem. Soc., 63:295–98.

With R. M. McCready. The molecular constitution of glycogen and starch from the seed of sweet corn (*Zea mays*). J. Am. Chem. Soc., 63:1632–35.

With R. M. McCready. Transformation of sugars in excised barley shoots. Plant Physiol., 16:599–610.

With R. M. McCready. The molecular constitution of enzymatically synthesized starch. J. Am. Chem. Soc., 63:2171–73.

1942

Recent work on the structure of plant polysaccharides. Chronica Botanica, 7:135–37.

With R. M. McCready. Semimicrodetermination of carbon. Ind. Eng. Chem. Anal. Ed., 14:525–26.

With R. M. McCready. Identification of sugars by microscopic appearance of crystalline osazones. Ind. Eng. Chem., 14:683–86.

1943

With M. Doudoroff and N. Kaplan. Phosphorolysis and synthesis of sucrose with a bacterial preparation. J. Biol. Chem., 148:67–75.

With G. T. Cori and R. M. McCready. Constitution of the polysaccharide synthesized by the action of crystalline muscle phosphorylase. J. Biol. Chem., 148:89–96.

With R. M. McCready. The separation and quantitative estimation of amylose and amylopectin in potato starch. J. Am. Chem. Soc., 65:1154–57.

With R. M. McCready. The molecular constitution of amylose and amylopectin of potato starch. J. Am. Chem. Soc., 65:1157–61.

With E. E. Baker and R. M. McCready. An immunologically active polysaccharide produced by *Coccidioides immitis*, Rixford and Gilchrist. J. Biol. Chem., 149:303–11.

The molecular constitution of starch and the mechanism of its formation. Quarterly Review of Biology, 18:311–30.

1944

With R. M. McCready. The preparation and purification of glucose 1-phosphate by the aid of ion exchange adsorbents. J. Am. Chem. Soc., 66:560–63.

With H. A. Barker and M. Doudoroff. Enzymatic synthesis of crystalline sucrose. Science, 100:51.

Chemistry of carbohydrates. Annual Review of Biochemistry, 13: 59–92.

With M. Doudoroff and H. A. Barker. Enzymatically synthesized crystalline sucrose. J. Am. Chem. Soc., 66:1416–19.

With M. Doudoroff and H. A. Barker. Synthesis of two new carbohydrates with bacterial phosphorylase. Science, 100:315–16.

With W. L. McRary, W. H. Dore, and R. M. McCready. Inulin in guayule. *Parthenium argentatum* Gray. J. Am. Chem. Soc., 66: 1970–72.

1945

Review of the Annual Review of Biochemistry, Vols. 12 and 13. J. Am. Chem. Soc., 67:505.

The molecular constitution of starch. Wallerstein Lab. Commun., 8:34–45.

With M. Doudoroff and H. A. Barker. Isolation and structure of an enzymatically synthesized crystalline disaccharide, d-glucosido-L-sorboside. J. Am. Chem. Soc., 67:1394–97.

Recent advances in the molecular constitution of starch and glycogen. Fed. Proc., 4:227–34.

Review of the Annual Review of Biochemistry, Vol. 14. Ann. Revs. Inc., of Stanford. J. Am. Chem. Soc., 67:2277–78.

1946

The mechanism of breakdown and formation of starch and glycogen. Wallerstein Lab. Commun., 9:135–44.

With M. Doudoroff, H. A. Barker, and W. H. Dore. Isolation and structure of an enzymatically synthesized crystalline disaccharide, D-glucosido-D-ketoxyloside. J. Am. Chem. Soc., 68:1465–67.

With W. R. Meagher. Synthesis of maltose 1-phosphate and D-xylose 1-phosphate. J. Am. Chem. Soc., 68:2135–37.

1947

With M. Doudoroff and H. A. Barker. Studies with bacterial sucrose phosphorylase. I. The mechanism of action of sucrose phosphorylase as a glucose-transferring enzyme (trans-glucosidase). J. Biol. Chem., 168:725–32.

With M. Doudoroff and H. A. Barker. Studies with bacterial sucrose phosphorylase. II. Enzymatic synthesis of a new reducing and of a new non-reducing disaccharide. J. Biol. Chem., 168:733–46.

With S. Arnoff, A. Benson, and M. Calvin. Distribution of C^{14} in photosynthesizing barley seedlings. Science, 105:664–65.

With M. Doudoroff. Enzymatically synthesized disaccharides. Arch. Biochem., 14:29–37.

With M. Doudoroff and H. A. Barker. Studies with bacterial sucrose phosphorylase. III. Arsenolytic decomposition of sucrose and of glucose 1-phosphate. J. Biol. Chem., 170:147–50.

1948

With J. Katz and M. Doudoroff. Arsenolysis and phosphorolysis of the amylose and amylopectin fractions of starch. Nature, 161:96–97.

With M. Doudoroff, A. L. Potter, and H. A. Barker. The structure of an enzymatically synthesized reducing disaccharide, D-glucosido-L-arabinose. J. Am. Chem. Soc., 70:305–10.

With E. W. Putman, G. Krotkov, and H. A. Barker. Preparation of radioactive carbon-labeled sugars by photosynthesis. J. Biol. Chem., 173:785.

With A. L. Potter, J. C. Sowden, and M. Doudoroff. Alpha-L-glucose-1-phosphate. J. Am. Chem. Soc., 70:1751–52.

With A. L. Potter. Starch. I. End-group determination of amylose and amylopectin by periodate oxidation. J. Am. Chem. Soc., 70:3488–90.

With A. L. Potter. Starch. II. Molecular weights of amyloses and amylopectins from starches of various plant origins. J. Am. Chem. Soc., 70:3774–77.

With M. Doudoroff. Enzymatically synthesized polysaccharides and disaccharides. Fortschr. Chem. Organ. Naturstoffe, 5:101–27.

1949

With M. Doudoroff, E. W. Putman, A. L. Potter, and J. Lederberg. Direct utilization of maltose by *Escherichia coli*. J. Biol. Chem., 179:921–24.

With H. Wolochow, E. W. Putman, M. Doudoroff, and H. A. Barker. Preparation of sucrose labeled with C^{14} in the glucose or fructose component. J. Biol. Chem., 180:1237.

With A. L. Potter and M. A. Joslyn. Starch. III. Structure of apple starch. J. Am. Chem. Soc., 71:4075.

1950

With E. W. Putnam. Transformation of sugars in plants. Annu. Rev. Plant Physiol. 1:109–24.

With M. Doudoroff. Synthesis of disaccharides with bacterial enzymes. Advances in Enzymology, 10:123–43.

With E. W. Putman, A. L. Potter and R. Hodgson. The structure of crown-gall polysaccharide. I. J. Am. Chem. Soc., 72:5024.

Enzymatic synthesis of sucrose and other disaccharides. Advances in Carbohydrate Chemistry, 5:29–48.

1951

With A. L. Potter. Starch. IV. The molecular constitution of amylose subfractions. J. Am. Chem. Soc., 73:593.

With A. L. Potter. Starch. V. The uniformity of the degree of branching in amylopectin. J. Am. Chem. Soc., 73:997.

With J. Katz. Arsenolysis of amylose and amylopectin. Arch Biochem. 30:272–81.

With D. A. Rappoport and H. A. Barker. Fermentation of L-arabinose-1-C^{14} by *Lactobacillus pentoaceticus*. Arch. Biochem. Biophys., 31:326.

With S. Nussenbaum. Enzymatic synthesis of amylopectin. J. Biol. Chem. 190:673–83.

With D. A. Rappoport. Preparation of L-arabinose-1-C^{14}. J. Am. Chem. Soc., 73:5524.

Metabolism of polysaccharides and disaccharides. In: *Phosphorus Metabolism*, ed. W. D. McElroy and B. Glass, vol. 1, pp. 11–42. Baltimore: Johns Hopkins Press.

With H. A. Barker. Degradation and synthesis of complex carbohydrates. In: *Bacterial Physiology*, ed. C. H. Werkman and P. W. Wilson, pp. 548–65. N.Y.: Academic Press.

With M. Doudoroff and H. A. Barker. Phosphorylases—phosphorolysis and synthesis of saccharides. In: *The Enzymes*, ed. J. B. Sumner and K. Myrbäck, vol. 1, part 2, 1014–39. N.Y.: Academic Press.

1952

With S. Nussenbaum. Estimation of molecular weight of starch polysaccharides. Determination of their reducing end groups. Analytical Chemistry, 24:501.

With S. Abraham and I. L. Chaikoff. Conversion of C^{14}-palmitic acid to glucose. II. Specific glucose carbons labeled. J. Biol. Chem., 195:567–81.

With E. W. Putman. Isolation and purification of radioactive sugars by means of paper chromatography. J. Biol. Chem., 196:749–52.

With S. Nussenbaum. Mechanism of amylopectin formation by the action of Q-enzyme. J. Biol. Chem., 196:785–92.

With S. Abraham and E. W. Putman. Distribution of radioactivity

in photosynthetically prepared C^{14}-labeled glucose. Arch. Biochem. Biophys., 41:61–63.

1953

Starch. In: *Organic Chemistry, An Advanced Treatise,* ed. H. Gilman, vol. 4, pp. 901–50. N.Y.: John Wiley and Sons.

With R. C. Bean, E. W. Putman, and R. E. Trucco. Preparation of ^{14}C-labeled D-galactose and glycerol. J. Biol. Chem., 204:169.

Mechanisms of complex saccharide formation. Biologisch Jaarboek, 20: 50–55.

1954

With E. W. Putman. Structure of galactosylglycerol from *Irideae laminarioides.* J. Am. Chem Soc., 76:2221.

With M. Heidelberger and M. D. Aisenberg. Glycogen, an immunologically specific polysaccharide. Journal of Experimental Medicine, 99:343–53.

With W. H. Wadman and A. B. Anderson. The structure of an arabogalactan from Jeffrey Pine (*Pinus Jeffreyi*). J. Am. Chem. Soc., 76:4097–100.

Biosynthesis of complex saccharides. In: *Chemical Pathways in Metabolism,* ed. D. M. Greenberg, pp. 235–75. N.Y.: Academic Press.

With E. W. Putman. Sugar transformation in leaves of *Canna indica.* I. Synthesis and inversion of sucrose. J. Biol. Chem., 207: 885–902.

1955

With R. C. Bean. Assimilation of $C^{14}O_2$ by a photosynthesizing red alga, *Iridophycus flaccidum.* J. Biol. Chem., 212:411–25.

With J. Edelman and V. Ginsburg. Conversion of monosaccharides to sucrose and cellulose in wheat seedlings. J. Biol. Chem., 213: 843–54.

With R. C. Bean. Glucose oxidase in *Iridophycus flaccidum.* Fed. Proc. 14:179.

With E. W. Putman and C. F. Litt. The structure of D-glucosyl-D-xylose synthesized by maltose phosphorylase. J. Am. Chem. Soc., 77:4351.

With R. C. Bean. Synthesis of disaccharides with pea preparations. J. Am. Chem. Soc., 77:5737–38.

With R. C. Bean. Assimilation of C^{14}-labeled carbon dioxide by a photosynthesizing red alga, *I. laminarioidies*. Fed. Proc., 13:179.

With R. McCready. α-D-Glucose 1-phosphate. In: *Biochemical Preparations*, ed. W. W. Westerfield et al., vol. 4. pp. 63–70. N.Y.: John Wiley and Sons, Inc.

1956

With E. F. Neufeld. Hydrolysis of amylose by β-amylase and Z-enzyme. Arch. Biochem. Biophys., 59:405–519.

With R. C. Bean. Carbohydrate oxidase from a red alga, *Iridophycus flaccidum*. J. Biol. Chem., 218:425–36.

With V. Ginsburg and P. K. Stumpf. Uridine diphosphate pentoses in mung bean seedlings. Fed. Proc., 15:262.

With E. W. Putman and V. Ginsburg. Metabolism of galactose in *Canna* leaves and wheat seedlings. Biochem. Biophys. Acta, 20: 17–22.

With V. Ginsburg and E. F. Neufeld. Enzymatic synthesis of uridine diphosphate xylose and uridine diphosphate arabinose. Proc. Natl. Acad. Sci. U.S.A., 42:333–35.

With R. C. Bean. Enzymatic oxidation of glucose to glucosone in a red alga. Science, 124:171–72.

With V. Ginsburg. Pentose metabolism in wheat seedlings. J. Biol. Chem., 223:277–84.

With V. Ginsburg and P. K. Stumpf. The isolation of uridine diphosphate derivatives of D-glucose, D-galactose, D-xylose and L-arabinose from mung bean seedlings. J. Biol. Chem., 223: 977–83.

1957

With J. Solms and D. S. Feingold. Uridine diphosphate N-acetylglucosamine and uridine diphosphate glucuronic acid in mung bean seedlings. J. Am. Chem. Soc., 79:2342–43.

With S. Abraham. Chemical procedures for analysis of polysaccharides. In: *Methods in Enzymology*, ed. S. P. Colowick and N. O. Kaplan, vol. 3, pp. 34–50. N.Y.: Academic Press.

With R. M. McCready. Preparation of α-D-glucose 1-phosphate by means of potato phosphorylase. In: *Methods of Enzymology*, ed. S. P. Colowick and N. O. Kaplan, vol. 3, pp. 137–43. N.Y.: Academic Press.

With E. F. Neufeld, V. Ginsburg, E. W. Putman, and D. Fanshier. Formation and interconversion of sugar nucleotides by plant extracts. Arch. Biochem. Biophys., 69:603–16.

With E. W. Putman. Anomeric 1-dicyclohexylammonium phosphate esters of D-glucopyranose, D-galactopyranose, D-xylopyranose, and L-arabinopyranose. J. Am. Chem. Soc., 79:5057.

With J. Solms. Isolation of uridine diphosphate N-acetylglucosamine and uridine diphosphate glucuronic acid from mung bean seedlings. J. Biol. Chem., 228:357–64.

With C. E. Ballou. Phosphate esters. In: *The Carbohydrates*, ed. W. Pigman, pp. 172–87. N.Y.: Academic Press.

With C. E. Ballou: Oligosaccharides. In: *The Carbohydrates*, ed. W. Pigman, pp. 473–533. N.Y.: Academic Press.

1958

Enzymatic synthesis (including brief review of formation in photosynthesis) and interconversion of the monosaccharides. In: *Handbuch der Pflanzenphysiologie*, ed. W. Ruhland, vol. 6, pp. 47–62. Berlin: Springer Verlag.

The synthesis and transformation of the oligosaccharides in plants, including their hydrolysis. In: *Handbuch der Pflanzenphysiologie*, ed. W. Ruhland, vol. 6, pp. 125–36. Berlin: Springer Verlag.

With E. F. Neufeld and D. S. Feingold. Enzymatic conversion of uridine diphosphate D-glucuronic acid to uridine diphosphate galacturonic acid, uridine diphosphate xylose, and uridine diphosphate arabinose. J. Am. Chem. Soc., 80:4430.

With D. S. Feingold and E. F. Neufeld. Synthesis of a β-1,3-linked glucan by extracts of *Phaseolus aureus* seedlings. J. Biol. Chem., 233:783–88.

With D. S. Feingold and E. F. Neufeld. Enzymic synthesis of uridine diphosphate glucuronic acid and uridine diphosphate galacturonic acid with extracts from *Phaseolus auresus* seedlings. Arch. Biochem. Biophys., 78:401–6.

1959

With D. S. Feingold and E. F. Neufeld. Xylosyl transfer catalyzed by an asparagus extract. J. Biol. Chem., 234:488–89.

With E. F. Neufeld and D. S. Feingold. Sugar nucleotides in the interconversion of carbohydrates in higher plants. Proc. Natl. Acad. Sci. U.S.A., 45:905–15.

With E. F. Neufeld and D. S. Feingold. Enzymic phosphorylation of D-glucuronic acid by extracts from seedlings of *Phaseolus aureus*. Arch. Biochem. Biophys., 83:96–100.

1960

With E. F. Neufeld and D. S. Feingold. Phosphorylation of D-galactose and L-arabinose by extracts from *Phaseolus aureus* seedlings. J. Biol. Chem., 235:906–9.

With D. S. Feingold and E. F. Neufeld. The 4-epimerization and decarboxylation of uridine diphosphate D-glucuronic acid by extracts from *Phaseolus aureus* seedlings. J. Biol. Chem., 235: 910–13.

With G. Kessler and D. S. Feingold. Utilization of exogenous sugars for biosynthesis of carbohydrates in germinating pollen. Plant Physiol., 35:505–9.

With J. C. Su. Identification of guanosine diphosphate l-galactose, guanosine diphosphate D-mannose, and adenosine 3′,5′-pyrophosphate from red alga, *Porphyra perforata*, J. G. Agardh. J. Biol. Chem., 235:36–7.

Biosynthesis of complex saccharides. In: *Metabolic Pathways*, ed. D. M. Greenberg, vol. 1, pp. 251–300. N.Y.: Academic Press.

Carbohydrate. In: *Encyclopedia of Science and Technology*, pp. 451–58. N.Y.: McGraw-Hill.

Monosaccharide. In: *Encyclopedia of Science and Technology*, pp. 578–83. N.Y.: McGraw-Hill.

1961

With G. Kessler, E. F. Neufeld, and D. S. Feingold. Metabolism of D-glucuronic acid by *Phaseolus aureus* seedlings. J. Biol. Chem., 236:308–12.

With W. M. Watkins. Enzymatic synthesis of lactose from uridine

diphosphate D-galactose and D-glucose. Biochem. Biophys. Res. Commun., 5:260-64

With E. F. Neufeld, D. S. Feingold, S. M. Ilves and G. Kessler. Phosphorylation of D-galacturonic acid by extracts from germinating seeds of *Phaseolus aureus*. J. Biol. Chem., 236:3102–5.

1962

The biosynthesis of polysaccharides from nuceloside disphosphate sugars. In: *Biochemical Society Symposium No. 21,* pp. 63–79. Cambridge, Eng.: Cambridge University Press.

With Jong-Ching Su. Carbohydrates and nucleotides in the red alga *Porphyra perforata*. I. Isolation and identification of carbohydrates. Biochemistry, 1: 468–74.

With J. C. Su. Carbohydrates and nucleotides in the red alga *Porphyra perforata*. II. Separation and identification of nucleotides. Biochemistry, 1:474–80.

With W. Watkins. The synthesis of lactose by particulate enzyme preparations from guinea pig and bovine mammary glands. J. Biol. Chem., 237:1432–40.

With E. F. Neufeld. Glycosidic bond exchange (survey). In: *The Enzymes,* ed. P. D. Boyer, H. Lardy, and K. Myrback, vol. 6, pp. 277–315. N.Y.: Academic Press.

1963

With G. A. Barber. *In vivo* oxidation of L-rhamnose and L-glucose by higher plants. Bulletin of the Research Council of Israel, 11A4:249–52.

With R. B. Frydman. Biosynthesis of sucrose with sugar cane leaf preparations. Nature, 199:382–83.

With R. B. Frydman and E. F. Neufeld. Thymidine diphosphate D-galactose pyrophoshorylase of *Phaseolus aureus*. Biochim. Biophys. Acta, 77:332–34.

With E. F. Neufeld. Biosynthesis of saccharides from glycopyranosyl esters of nucleotides ("sugar nucleotides"). In: *Advances in Carbohydrate Chemistry,* ed. M. L. Wolfrom, vol. 18, pp. 309–56. N.Y.: Academic Press.

With D. S. Feingold and E. F. Neufeld. Preparation of UDP-D-xylose and UDP-L-arabinose. In: *Methods in Enzymology,* ed.

S. P. Colowick and N. O. Kaplan, vol. 6, pp. 782–87. N.Y.: Academic Press.

1964

With D. S. Feingold and E. F. Neufeld. Enzymes of carbohydrate synthesis. In: *Modern Methods of Plant Analysis*, ed. H. F. Linskens, B. D. Sanwal, and M. N. Tracy, vol. 7, pp. 474–519. Berlin: Springer-Verlag.

With D. B. E. Stroud. Synthesis of 4-keto sugar phosphates. Biochem. Biophys. Res. Commun., 15:65–69.

With A. D. Elbein and G. A. Barber. The synthesis of cellulose by an enzyme system from a higher plant. J. Am. Chem. Soc., 86: 309–10.

With E. F. Neufeld. Quantitative determination of starch in plant tissues. In: *Methods of Carbohydrate Chemistry*, ed. R. L. Whistler, vol. 4, pp. 33–35. N.Y.: Academic Press.

Carbohydrates. In: *McGraw-Hill Yearbook of Science and Technology*, pp. 169–73. McGraw-Hill Book Co.

With T. Y. Lin. Isolation of guanosine diphosphate D-mannuronic acid from the marine brown alga, *Fucus gardneri* Silva. J. Biol. Chem., 239:945–46.

With Helene Babad. A soluble lactose-synthesizing enzyme from bovine milk. J. Biol. Chem., 239:PC946–48.

With G. A. Barber. The formation of guanosine diphosphate D-glucose by enzymes of higher plants. Biochim. Biophys. Acta, 86:399–402.

With R. A. Dedonder. The enzymatic synthesis of a (β-1,2-)-linked glucan by an extract of *Rhizobium japonicum*. Biochim. Biophys. Acta, 90:239.

With G. A. Barber and A. D. Elbein. The synthesis of cellulose by enzyme system from higher plants. J. Biol. Chem., 239:4056.

With G. A. Barber and A. D. Elbein. Synthesis of cellulose by an enzyme system from a higher plant. Sixth International Congress of Biochemistry, New York. (Abstract)

1965

Cellulose, synthesis of. In: *McGraw-Hill Yearbook of Science and Technology*, p. 137. N.Y.: McGraw-Hill Book Co.

With E. G. Castanera. Properties of uridine diphosphate D-glucuronic acid decarboxylase from wheat germ. Arch. Biochem. Biophys., 110:462–74.

With S. Haq. Biosynthesis of sucrose phosphate with sugar cane leaf chloroplasts. Plant. Physiol., 40:591–94.

With G. A. Barber. Synthesis of cellulose by enzyme preparations from the developing cotton boll. Nature, 207:295–96.

Biosynthese von cellulose. Umschau in Wissenschaft und Technik. No. 21, p. 681.

With J. B. Pridham. Biosynthesis of raffinose. Plant Physiol. 40: 984–86.

1966

With C. L. Villemez and T. Y. Lin. Biosynthesis of the polygalacturonic acid chain of pectin by a particulate enzyme preparation from *Phaseolus aureus* seedlings. Proc. Natl. Acad. Sci. U.S.A., 54:1626–32.

With T. Y. Lin. Isolation of guanosine diphosphate uronic acids from a marine brown alga, *Fucus gardneri* Silva. J. Biol. Chem., 241:3282–83.

With T. Y. Lin, A. D. Elbein, and J. C. Su. Substrate specificity in pectin synthesis. Biochem. Biophys. Res. Commun., 22:650–57.

With A. D. Elbein. The enzymatic synthesis of a glucomannan. Biochem. Biophys. Res. Commun., 23:311–18.

With Helene Babad. Soluble uridine diphosphate D-galactose: D-glucose β-4-D-galactosyltransferase from bovine milk. J. Biol. Chem., 241:2672–78.

With J. B. Pridham. A preliminary study on the biosynthesis of hemicelluloses. Proceedings of the Biochemical Society. Biochemical Journal, 100:21P.

With C. L. Villemez and A. L. Swanson. Properties of a polygalacturonic acid-synthesizing enzyme system from *Phaseolus aureus* seedlings. Arch. Biochem. Biophys., 116:446–52.

With R. W. Bailey. Xylan synthesis from uridine-diphosphate-D-xylose by particulate preparations from immature corn cobs. Proc. Natl. Acad. Sci. U.S.A., 56:1586–93.

With T. Y. Lin. Pathway of alginic acid synthesis in the marine brown alga, *Fucus gardneri* Silva. J. Biol. Chem., 241:5284–97.

Some aspects of sugar nucleotide metabolism. In: *Current Aspects of*

Biochemical Energetics, ed. N. O. Kaplan and E. P. Kennedy, pp. 351–69. N.Y.: Academic Press.

1967

With H. Kauss and A. L. Swanson. Biosynthesis of the methyl ester groups of pectin by transmethylation from S-adenosyl-L-methionine. Biochem. Biophys. Res. Commun., 26:234–40.

With R. W. Bailey and S. Haq. Carbohydrate composition of particulate preparations from mung bean (*Phaseolus aureus*) shoots. Phytochemistry, 6:293–301.

With H. Kauss. Biosynthesis of the 4-O-methyl-D-glucuronic acid unit of hemicellulose B by transmethylation from S-adenosyl-L-methionine. J. Biol. Chem., 242:1680–84.

With G. Franz. Biosynthesis of digitoxose and glucose in the purpurea glycosides of *Digitalis purpurea*. Phytochemistry, 6:841–44.

Transformation of sugars in plants. Annu. Rev. Plant Physiol., 18: 253–80.

With H. Kauss. Enzymatic introduction of the methyl ester groups of pectin. J. Biol. Chem., 242:3449–53.

With C. L. Villemez, Jr., and G. Franz. Biosynthesis of alkali insoluble polysaccharide from UDP-D-glucose with particulate enzyme preparations from *Phaseolus aureus*. Plant Physiol., 43: 1219–23.

1968

With F. C. Mayer and I. Bikel. Pathway of uridine diphosphate N-acetyl-D-glucosamine biosynthesis in *Phaseolus aureus*. Plant Physiol., 43:1097–107.

With H. M. Flowers, K. K. Batra, and J. Kemp. Biosynthesis of insoluble glucans from *Phaseolus aureus* and *Lupinus albus*. Plant Physiol., 43:1703–9.

1969

With K. K. Batra. Determination of linkages in β-D-glucans from *Phaseolus aureus* by exo-β-(1→3)-D-glucanase. Plant Physiol., 44:755–58.

Biosynthesis of oligosaccharides and polysaccharides in plants. Science, 165:137–44.

With H. M. Flower, K. K. Batra, and J. Kemp. Biosynthesis of cellulose *in vitro* from guanosine diphosphate D-glucose with enzymic preparations from *Phaseolus aureus* and *Lupinus albus*. J. Biol. Chem., 244:4969–74.

1970

With K. K. Batra. Determination of linkages of β-(1 3)-D-glucanase from *Lupinus albus* and *Avena sativa* by exo β-(1→3)-D-glucanase. Plant Physiol., 45:233–43.

With T. Y. Liu. Solubilization and partial purification of cellulose synthesis from *Phaseolus aureus*. J. Biol. Chem., 245:1922–25.

1971

Biosynthesis of cellulose and related plant cell-wall polysaccharides. High Polymers, 5:679–93.

With C. M. Tsai. Solubilization and separation of uridine diphospho-D-glucose: β-(1→4) glucan and uridine diphospho-D-glucose: β-(1→3) glucan glucosyltransferases from coleoptiles of *Avena sativa*. Plant Physiol., 47:740–44.

With H. Nikaido. Biosynthesis of saccharides from glycopyranosyl esters of nucleoside pyrophosphates ("sugar phosphates"). Advances in Carbohydrate Chemistry and Biochemistry, 26:351–483.

1972

With M. Vessal. Partial purification and properties of L-glutamine D-fructose 6-phosphate amidotransferase from *Phaseolus aureus*. Plant Physiol., 49:977–81.

Biosynthesis of polysaccharides from sugar nucleotides in plants. In: *Biochemistry of Glycosidic Linkage. Pan-American Association of Biochemical Societies Symposium*, 2:315–35. N.Y.: Academic Press.

With D. L. Storm. The role of a D-mannosyl-lipid as an intermediate in the synthesis of polysaccharide in *Phaseolus aureus* seedlings. Plant Physiol., 50:473–76.

1973

With D. L. Storm and R. C. Buri. Enzymatic glucosylation of dithiothreitol by uridine diphosphate D-glucose and particulate

preparations from germinating seeds of *Phaseolus aureus* and *Pisum sativum*. Plant Physiol., 50:147–54.

With M. Vessal. Partial purification and properties of D-glucosamine 6-phosphate N-acetyltransferase from *Phaseolus aureus*. Plant Physiol., 51:1055–60.

With C. M. Tsai. Substrate activation of β-(1→3) glucan synthetase and its effect on the structure of β glucan obtained from UDP-D-glucose and particulate enzyme of oat coleoptiles. Plant Physiol., 51:998–1001.

The role of sugar phosphate in the biosynthesis of complex saccharides. Advances in Chemistry Series, 117:362-73.

1974

With D. L. Storm. Partial purification and properties of a β-D-glucosyltransferase occurring in germinating *Phaseolus aureus* seeds. Plant Physiol., 54:840–45.

1975

With P. H. Chan. One step purification of D-galactose and L-arabinose kinases from *Phaseolus aureus* seedlings by ATP-sepharose affinity chromatograph. Analytical Biochemistry, 64: 372–79.