6

A Ride to Albuquerque

The term at Cornell ended in June, and Hans Bethe arranged an invitation for me to go for five weeks to a summer school at the University of Michigan in Ann Arbor. Julian Schwinger would be lecturing there and would give us a leisurely account of the theory which he had sketched in his eight-hour marathon talk at the Pocono meeting. It was a great chance for me to hear Schwinger's ideas straight from the horse's mouth. But there was a gap of two weeks between the end of term and the beginning of summer school. Dick Feynman said, "I'm driving to Albuquerque. Why don't you come along?" I looked at the map and saw that Albuquerque was not directly on the way to Ann Arbor. I said yes, I'd come along.

My stay in the United States was financed by a Commonwealth Fund Fellowship awarded by the Harkness Foundation. The foundation generously included in its stipend the funds for a summer vacation. I was expected to travel across the continent and gain a wider perspective of the United States than could be seen from a single campus. A free ride to Albuquerque would make a good beginning.

I had Dick to myself most of the time for four days. Not all the time, because Dick loved to pick up hitchhikers. I enjoyed the hitchhikers too. These were American nomads, people with restless feet, moving from one place to another carelessly and without hurry. In England we have our nomadic tribe of gypsies, but they live in a closed-off world of their own. I had never spoken to a gypsy. Dick talked with these nomads as if they were old friends. They told us their adventures and Dick told them his. As we drove farther south and west, Dick's manner of speech changed. He was adapting to the

accent and idiom of the people we picked up. Phrases like "I don't know noth'n" became more frequent. The closer we came to Albuquerque, the more Dick seemed to feel at ease with his surroundings.

We crossed the Mississippi at St. Louis and came through the Ozark country into Oklahoma. The Ozarks were the loveliest part of the trip, green hills covered with flowers and woods and an occasional quiet farmhouse. Oklahoma was a different world, rich and ugly, with new towns and factories springing up everywhere and bulldozers tearing up the earth. Oklahoma was in the middle of an oil boom. We were about halfway to Oklahoma City when we ran into a rainstorm. In that country, it seemed, not only the people were rough and raw, but nature too. It was my first taste of tropical rain. It made the heaviest rain I had ever seen in England look like a drizzle. We crawled for a while through the downpour and then ran into a traffic jam. Some boys told us there were six feet of water over the highway ahead of us and no way through. They said it had been raining like this for about a week. We turned around and retreated to a place called Vinita. There was nothing to do but get a room and wait for the floods to subside. The hotels were filled to capacity with stranded travelers. We were lucky to find a room, which Dick and I could share for fifty cents each. On the door was a notice that said, "This hotel is under new management, so if you're drunk you came to the wrong place." In that little room, with the rain drumming on the dirty window panes, we talked the night through. Dick talked of his dead wife, of the joy he had had in nursing her and making her last days tolerable, of the tricks they had played together on the Los Alamos security people, of her jokes and her courage. He talked of death with an easy familiarity which can come only to one who has lived with spirit unbroken through the worst that death can do. Ingmar Bergman in his film *The Seventh Seal* created the character of the juggler Jof, always joking and playing the fool, seeing visions and dreams that nobody else believes in, surviving at the end when death carries the rest away. Dick and Jof have a great deal in common. Many people at Cornell had told me Dick was crazy. In fact he was the sanest of the whole crowd.

Dick talked a great deal, that night in Vinita, about his work at Los Alamos. It was Bob Wilson, our good friend and the chief experimental physicist at Cornell, who had invited Dick to join the work

on the bomb. Dick had answered at once by instinct, "No, I won't do it." Then he thought it over, and persuaded himself intellectually that he ought to work on it to make sure that Hitler did not get it first. So he joined the project, first in Princeton and then in Los Alamos. He threw himself furiously into the work and quickly became a leader. He was only twenty-six when they made him head of the computing section. The computers in those days were not electronic machines but human beings. Dick knew how to coach his team of computers so that they put their hearts and souls into the work. After he took over the section the output of computed problems went up ninefold. The section was going full steam ahead, racing against time to have all the calculations done before the first bomb test in July 1945. Dick was organizing them and cheering them on. It was like a grand boat race. They were racing so hard that nobody noticed when the Germans dropped out of the war and left them racing alone. When they passed the finish line, the day of the Trinity bomb test, Dick sat on the hood of a jeep and banged his bongo drums in joy. Only later he had time to think and to wonder whether perhaps his first instinctive answer to Bob Wilson had not been the right one. Since those days, he refused ever again to have anything to do with military work. He knew that he was too good at it and enjoyed it too much.

Dick had his own view of the future of nuclear weapons. Two illusions were current at that time. The conservative illusion was that American leadership in development and production of these weapons could be maintained indefinitely and would give America lasting military and political supremacy. The liberal illusion was that when all governments became aware of the dangers of nuclear annihilation they would abandon war as an instrument of national policy. Either way, nuclear weapons would become in some sense a guarantee of perpetual peace. Dick believed in neither illusion. He thought that wars would continue to occur from time to time, and that nuclear weapons would be used. He felt we were fools to think that we deserved to get away scot-free after letting these weapons loose in the world. He expected that somebody would sooner or later come back to give us a taste of our own medicine. He saw no reason to believe that other countries would be wiser or kinder than we had been. He found it amazing that people would go on living calmly in places like New York as if Hiroshima had never happened. As we

drove through Cleveland and St. Louis, he was measuring in his mind's eye distances from ground zero, ranges of lethal radiation and blast and fire damage. His view of the future was bleak indeed. I felt as if I were taking a ride with Lot through Sodom and Gomorrah.

And yet Dick was never gloomy. He had absolute confidence in the ability of ordinary people to survive the crimes and follies of their rulers. Like Jof the juggler, he would sit quietly sharing his fresh milk and wild strawberries with his guests on the eve of the Day of Judgment. He knew how tough ordinary people are, how death and destruction often brings out the best in us.

It happened that just a year earlier, in the summer of 1947, I had lived for three weeks in a city of rubble, the bombed-out German city of Münster. The University of Münster had invited a group of foreign students to come there to give the German students their first contact with the world outside. We had a street plan of the city to help us find our way around the mountains of rubble. "Even a city of rubble," it said on the street plan, "in a time of poverty and misery, can express in the appearance of its streets and sidewalks and parks and gardens the pride and the resilience and the public spirit of its people." That was true. Every evening when the weather was not too bad, the hungry people of Münster emerged from their cellars with violins and cellos and bassoons to give first-rate orchestral concerts in the open air. One night they even put on an opera, *Cavalleria Rusticana.* The opera was not the greatest, but the theater, a grassy amphitheater overshadowed by magnificent beech and chestnut trees, and the beauty of the evening, and the silhouette of the ruined castle, amply made up for the imperfections of the performance. By that time I had become so accustomed to being hungry and walking over piles of rubble that I did not notice it any more. Even in three weeks you get completely used to living in a world of hunger and rubble. I talked to Dick about these experiences in Germany, and he said it was just as he would have expected. He could not imagine that any bombs, even nuclear bombs, could crush the spirit of humanity for long. "When you just think of all the crazy things we have survived," he said, "the atomic bomb is not such a big deal." Death is not such a big deal if you are Jof the juggler and can see the black wings of the angel of death flying over your head as you drive your wagon through the storm.

After the bombs, we talked of science. Dick and I were always

disagreeing about science. We fought against each other's ideas, and that helped us both to think straight. Dick distrusted my mathematics and I distrusted his intuition. He had this wonderful vision of the world as a woven texture of world lines in space and time, with everything moving freely, and the various possible histories all added together at the end to describe what happened. It was essential to his view of things that it must be universal. It must describe everything that happens in nature. You could not imagine the sum-over-histories picture being true for a part of nature and untrue for another part. You could not imagine it being true for electrons and untrue for gravity. It was a unifying principle that would either explain everything or explain nothing. And this made me profoundly skeptical. I knew how many great scientists had chased this will-o'-the-wisp of a unified theory. The ground of science was littered with the corpses of dead unified theories. Even Einstein had spent twenty years searching for a unified theory and had found nothing that satisfied him. I admired Dick tremendously, but I did not believe he could beat Einstein at his own game. Dick fought back against my skepticism, arguing that Einstein had failed because he stopped thinking in concrete physical images and became a manipulator of equations. I had to admit that was true. The great discoveries of Einstein's earlier years were all based on direct physical intuition. Einstein's later unified theories failed because they were only sets of equations without physical meaning. Dick's sum-over-histories theory was in the spirit of the young Einstein, not of the old Einstein. It was solidly rooted in physical reality. But I still argued against Dick, telling him that his theory was a magnificent dream rather than a scientific theory. Nobody but Dick could use his theory, because he was always invoking his intuition to make up the rules of the game as he went along. Until the rules were codified and made mathematically precise, I could not call it a theory.

I accepted the orthodox view of the nature of physical theories. According to the orthodox view, grand unifying principles are not theories. We may hope one day to find a grand unifying principle for the whole of physics, but that is a job for future generations. For the present, nature divides itself conveniently into well-separated domains, and we are content to understand one domain at a time. A theory is a detailed and precise description of nature that is valid in one particular domain. Theories that belong to different domains use

different concepts and illuminate our world from different angles.

At present we see the world of physics divided into three principal domains. The first is the domain of the very large, massive objects, planets and stars and galaxies and the universe considered as a whole. In this domain, gravitation is the dominant force and Einstein's general relativity is the triumphantly successful theory. The second is the domain of the very small, the short-lived particles that are seen in high-energy collisions and inside the nuclei of atoms. In this domain, the strong nuclear forces are dominant and there is not yet any complete theory. Fragments of theories come and go, describing more or less satisfactorily some of the things the experimenters observe, but the domain of the very small remains today what it was in 1948, a world of its own still waiting to be thoroughly explored. Between the very large and the very small there is the third domain, the middle ground of physics. The middle ground is an enormous domain, including everything intermediate in size between an atomic nucleus and a planet. It is the domain of everyday human experience. It includes atoms and electricity, light and sound, gases, liquids and solids, chairs, tables and people. The theory that we called quantum electrodynamics was the theory of the middle ground. Its aim was to give a complete and accurate account of all physical processes in the third domain, excluding only the very large and the very small.

So Dick and I argued through the night. Dick was trying to understand the whole of physics. I was willing to settle for a theory of the middle ground alone. He was searching for general principles that would be flexible enough so that he could adapt them to anything in the universe. I was looking for a neat set of equations that would describe accurately what happens in the middle ground. We went on arguing back and forth. Looking back on the argument now from thirty years later, it is easy to see that we were both right. It is one of the special beauties of science that points of view which seem diametrically opposed turn out later, in a broader perspective, to be both right. I was right because it turns out that nature likes to be compartmentalized. The theory of quantum electrodynamics turned out to do all that I expected of it. It predicts correctly, with enormous accuracy, the results of all the experiments that have been done in the domain of the middle ground. Dick was right because it turns out that his general rules of space-time trajectories and sum-over-histo-

ries have a far wider range of validity than quantum electrodynamics. In the domain of the very small, now known as particle physics, the rigid formalism of quantum electrodynamics turned out to be useless, while Dick's flexible rules, now known as Feynman diagrams, are the first working tool of every theorist.

That stormy night in our little room in Vinita, Dick and I were not looking thirty years ahead. I knew only that somewhere hidden in Dick's ideas was the key to a theory of quantum electrodynamics simpler and more physical than Julian Schwinger's elaborate construction. Dick knew only that he had larger aims in view than tidying up Schwinger's equations. So the argument did not come to an end, but left us each going his own way.

Before dawn we succeeded in sleeping a little, and in the morning we started again in the direction of Oklahoma City. The rain continued, more gently than the day before. We came through Sapulpa, a town bursting at the seams as a result of the oil boom, and then the road was blocked again. Trying to detour, we arrived at the water's edge and saw the road disappear into a huge lake. On our way back through Sapulpa we saw a Cherokee Indian and his wife walking groggily along the roadside in the rain. They were soaked to the skin and jumped happily into the car. They were able to guide us onto an unpaved and muddy road which kept to high ground clear of the floods. They soon got dry and cheerful in the car and stayed with us most of the day. They were trying to make their way to Shawnee, where they were working in an oil-field construction camp. Somehow they had acquired five quarts of hooch whiskey, so they walked off the job in Shawnee and took the whiskey home to their family and friends in Sapulpa for a celebration. The celebration ended when the five quarts were gone, the day before we picked the pair up. The floods forced us to detour along the high ground to the north, farther and farther away from Shawnee. When the Indians finally left us and bade us a friendly goodbye, they were much farther from Shawnee than they had been when we found them.

Our last hurdle was the crossing of the Cimarron River. The river was about half a mile wide, the water brick red and flowing furiously with large standing waves. I was expecting the bridge to be swept away every minute as we crawled across it. On the other side the skies gradually cleared and we came peacefully into Texas for our last overnight stop.

The cactuses were blooming red in the desert and Dick was beside himself with joy as we sailed into Albuquerque. The sun was shining for us and the police cars were screaming their welcome. It took Dick some time to realize that the police cars were signaling to us to stop. They told us politely that we had violated all the traffic rules in the book and that we should appear forthwith before the justice of the peace. Fortunately the J.P. was on duty and could handle the case immediately. The J.P. informed us that we should pay a fine of fifty dollars, since we had been doing seventy in a twenty-mile-an-hour zone and the fine was one dollar for every mile per hour over the limit. He said that this was the largest speeding fine he had ever imposed. We had broken the Albuquerque record. Dick then put on one of his finest performances, explaining how he had driven two thousand miles from Ithaca to Albuquerque to visit this girl that he intended to marry, and telling what a great city Albuquerque was and how happy he was to be back again after being away for three years. Soon Dick and the J.P. were swapping stories about the wartime days in Albuquerque, and the end of it was that we were let off with a fine of $14.50, ten dollars for speeding and $4.50 for the expenses of the court. Dick and I split the fine and we all three shook hands on it. Then we said goodbye and went our separate ways.

I took a Greyhound bus to Santa Fe and made my way by easy stages back to Ann Arbor. I soon found out that the way to enjoy long bus rides is to travel at night and rest or explore the countryside by day. People talk more and are friendlier on the night runs. On the long overnight stretch from Denver to Kansas City I fell in with a couple of teen-agers, a young sailor from San Francisco and a girl from Kansas. We talked the night away, beginning with love affairs, continuing with family histories and God, and ending with politics. It occurred to me that if I had been listening to a conversation between strangers in England, the same subjects would have come up in the opposite order. The two of them were great talkers and kept it up in fine style until the sun broke through on the horizon ahead of us. At times they made me feel very old, and at times very young.

In the five weeks in Ann Arbor I made a host of new friends. The Ann Arbor summer school was in those days, as it had been in the 1930s, the main gathering place for itinerant physicists in summer-

time. Julian Schwinger's lectures were a marvel of polished elegance, like a difficult violin sonata played by a virtuoso, more technique than music. Fortunately, Schwinger was friendly and approachable. I could talk with him at length, and from these conversations more than from the lectures I learned how his theory was put together. In the lectures his theory was a cut diamond, brilliant and dazzling. When I talked with him in private, I saw it in the rough, the way he saw it himself before he started the cutting and polishing. In this way I was able to grasp much better his way of thinking. The Ann Arbor physicists generously gave me a room to myself on the top floor of their building. Each afternoon I hid up there under the roof for several hours and worked through every step of Schwinger's lectures and every word of our conversations. I intended to master Schwinger's techniques as I had mastered Piaggio's differential equations ten years before. Five weeks went by quickly. I filled hundreds of pages with calculations, working through various simple problems with Schwinger's methods. At the end of the summer school, I felt that I understood Schwinger's theory as well as anybody could understand it, with the possible exception of Schwinger. That was what I had come to Ann Arbor to do.

During the Ann Arbor days another beautiful thing happened. A long letter came from Münster, from one of the girls that I had got to know in the hungry time a year earlier. We had exchanged letters intermittently during the winter. She wrote in German, but the letter ended with a quotation from Yeats:

> I would spread the clothes under your feet,
> But I am poor, and have only my dreams.
> I have spread my dreams under your feet;
> Tread softly, because you tread on my dreams.

I wondered whether a girl to whom English is a foreign language could possibly understand how good that stanza is as poetry. I decided she probably understood. I promised myself I would tread softly.

From Ann Arbor I took another Greyhound bus all the way to San Francisco. On this trip the most memorable part was the winding descent down Echo Creek from Wyoming to the Salt Lake basin. We passed through the mountain valleys in which the Mormon pioneers had settled a hundred years before. These valleys were tended and

cared for like mountain valleys in Switzerland. Nowhere else in America had I seen land so cherished. You could see at once, these people believed they had reached the promised land, and they intended to leave it beautiful for their great-grandchildren.

I stayed ten days in San Francisco and Berkeley, taking a holiday from physics. I read Joyce's *Portrait of the Artist as a Young Man* and Nehru's autobiography. I explored California a little and decided I liked Utah better. Comparing the achievements of the settlers in Utah and California, who were building their civilizations at the same time, I felt that Utah achieved greatness while California had greatness thrust upon it. There is nothing in California to equal the Mormon valleys, with each village clustering around its big temple and the mountains on each side sweeping straight up to heaven.

At the beginning of September it was time to go back East. I got onto a Greyhound bus and traveled nonstop for three days and nights as far as Chicago. This time I had nobody to talk to. The roads were too bumpy for me to read, and so I sat and looked out of the window and gradually fell into a comfortable stupor. As we were droning across Nebraska on the third day, something suddenly happened. For two weeks I had not thought about physics, and now it came bursting into my consciousness like an explosion. Feynman's pictures and Schwinger's equations began sorting themselves out in my head with a clarity they had never had before. For the first time I was able to put them all together. For an hour or two I arranged and rearranged the pieces. Then I knew that they all fitted. I had no pencil or paper, but everything was so clear I did not need to write it down. Feynman and Schwinger were just looking at the same set of ideas from two different sides. Putting their methods together, you would have a theory of quantum electrodynamics that combined the mathematical precision of Schwinger with the practical flexibility of Feynman. Finally, there would be a straightforward theory of the middle ground. It was my tremendous luck that I was the only person who had had the chance to talk at length to both Schwinger and Feynman and really understand what both of them were doing. In the hour of illumination I gave thanks to my teacher Hans Bethe, who had made it possible. During the rest of the day as we watched the sun go down over the prairie, I was mapping out in my head the shape of the paper I would write when I got to Princeton. The title of the paper would be "The Radiation Theories of Tomonaga, Schwinger and

Feynman." This way I would make sure that Tomonaga got his fair share of the glory. As we moved on into Iowa, it grew dark and I had a good long sleep.

A few days later I collected my belongings from Ithaca and went on to Princeton. I had grown so attached to Greyhound buses I was almost sorry to be at the end of the journey. But I had work to do in Princeton. On a fine September morning I walked for the first time the mile and a half from my room in Princeton to the Institute for Advanced Study. It was exactly a year since I had left England to learn physics from the Americans. And now here I was a year later, walking down the road to the institute on a fine September morning to teach the great Oppenheimer how to do physics. The whole situation seemed too absurd to be credible. I pinched myself to make sure I wasn't dreaming. But the sun still shone and the birds still sang in the trees. I had better be careful, I said to myself. Tread softly, because you tread on my dreams.