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The Strangest Man:

The Hidden Life of Paul Dirac, Quantum Genius

Graham Farmelo

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[T]he amount of eccentricity in a society has generally been proportional to the amount of genius, mental vigour, and moral courage which it contained. That so few now dare to be eccentric, marks the chief danger of the time.

JOHN STUART MILL, *On Liberty*, 1869

We are nothing without the work of others our predecessors, others our teachers, others our contemporaries. Even when, in the measure of our inadequacy and our fullness, new insight and new order are created, we are still nothing without others. Yet we are more.

J. ROBERT OPPENHEIMER, Reith Lecture, 20 December 1953

Prologue

> [A] good deal of unkindness and selfishness on the part of parents towards children is not generally followed by ill consequences to the parents themselves. They may cast a gloom over their children's lives for many years.
>
> SAMUEL BUTLER, *The Way of All Flesh*, 1903

All it took was a single glass of orange juice laced with hydrochloric acid. A few minutes later, it was clear that his digestive problems were due to a chronic deficiency of stomach acid. For months, he had been admitted to hospital every few weeks to be fed vitamins intravenously, but the doctors had no idea why his digestion was so poor. Now, following the orange-juice experiment, a laboratory test on the chemical contents of his stomach confirmed the conclusion that his stomach contained far too little acid. The simple prescription of a pill to be taken after every meal ended almost eight decades of digestive problems. As a result, Kurt Hofer, the friend who suggested the experiment and made the correct diagnosis, became the reluctant health guru to Paul Dirac, one of the most revered – and strangest – figures in the history of science.

Hofer and Dirac both worked at Florida State University but otherwise appeared to have little in common. Hofer – just over forty years of age – was a top-drawer cell biologist, a spirited raconteur who told all comers of his early family life among Austrian mountain farmers and his moment of cinematic glory as a well-paid extra in *The Sound of Music*. Hofer's eyes glittered when he told his stories, his thickly accented voice swooped and surged for emphasis, his hands chopped and shaped the air as if it were dough. Even in this lively company, Dirac was unresponsive, speaking only when he had a pressing question to ask or, less often, a comment to make. One of his favourite phrases was: 'There are always more people who prefer to speak than to listen.'[1]

Dirac was one of the pre-eminent pioneers of quantum mechanics, the modern theory of atoms, molecules and their constituents. Arguably the most revolutionary scientific breakthrough of the

twentieth century, quantum mechanics uprooted centuries-old prejudices about the nature of reality and what can, in principle, be known for certain about the universe. The theory also proved to be of enormous utility: it underpins the whole of modern microelectronics and has answered many basic questions that had long defied straightforward answers, such as why electricity flows easily through wire but not through wood. Yet Dirac's eyes glazed over during talk of the practical and philosophical consequences of quantum physics: he was concerned only with the search for the fundamental laws that describe the longest strands in the universe's fabric. Convinced that these laws must be mathematically beautiful, he once – uncharacteristically – hazarded the unverifiable conjecture that 'God is a mathematician of a very high order.'[2]

The ambitions of Kurt Hofer were more modest than Dirac's. Hofer had made his name in cancer and radiation research by carefully carrying out experiments and then trying to find theories to explain the results. This was the conventional, bottom-up technique of the English naturalist Charles Darwin, who saw his mind 'as a machine for grinding general laws out of large collections of facts'.[3] Dirac, a classic example of a top-down thinker, took the opposite approach, viewing his mind as a device for conjuring laws that explained experimental observations. In one of his greatest achievements, Dirac used this method to arrange what had seemed an unlikely marriage – between quantum mechanics and Einstein's theory of relativity – in the form of an exquisitely beautiful equation to describe the electron. Soon afterwards, with no experimental clues to prompt him, he used his equation to predict the existence of antimatter, previously unknown particles with the same mass as the corresponding particles of matter but with the opposite charge. The success of this prediction is, by wide agreement, one of most outstanding triumphs of theoretical physics. Today, according to the cosmologists' standard theory of the early universe – supported by a wealth of observational evidence – antimatter made up half the material generated at the beginning of the Big Bang; from this perspective, Dirac was the first person to glimpse the other half of the early universe, entirely through the power of reason.

Hofer liked to compare Dirac with Darwin: both English, both uncomfortable in the public eye, both responsible for changing the way scientists think about the universe. A decade before, Hofer was

amazed when he heard that Dirac was to move from one of the world's leading physics departments, at the University of Cambridge in England, to take up a position at Florida State University, whose physics department was ranked only eighty-third in the USA. When the possibility of his appointment was first mooted, there were murmurings among the professors that it was unwise to offer a post to an old man. The objections ended only after the Head of Department declared at a faculty meeting: 'To have Dirac here would be like the English faculty recruiting Shakespeare.'[4]

Around 1978, Hofer and his wife Ridy began to pay visits to the Diracs on most Friday afternoons, to wind down for a couple of hours after the week's work. The Hofers set off from their home near the campus in Tallahassee at about 4.30 p.m. and took the two-minute walk to 223 Chapel Drive, where the Diracs lived in a modest, single-storey house, a few paces from the quiet residential street. At the front of the house was a flat, English-style lawn, planted with a few shrubs and a Pindo palm tree. The Hofers were always welcomed warmly by Dirac's smartly dressed wife Manci, who laughed and joked as she dispensed sherry, nuts and the latest faculty gossip. Dirac was painfully spare and round-shouldered, dressed casually in an open-necked shirt and an old pair of trousers, content to sit and listen to the conversation around him, pausing occasionally to sip his glass of water or ginger ale. The chatter ranged widely from family matters to local politics at the university, and from the earnest utterances of Mrs Thatcher on the steps of Downing Street to the most recent sermon from Jimmy Carter in the White House garden. Although Dirac was benign and receptive during these conversations, he was so reserved that Hofer often found himself trying to elicit a response from him – a nod or a shake of the head, a few words, anything to make the conversation less one-sided. Just occasionally, Dirac would be moved to contribute a few words about one of his private enthusiasms – Chopin's waltzes, Mickey Mouse and any television special featuring Cher, the brassy chanteuse.

During the first two years or so of these visits, Dirac showed no sign of wanting to talk about himself or of having any deep feelings, so Hofer was ill prepared when, one Friday evening in the spring of 1980, Dirac's vacuum-packed emotions burst into the open. 'I remember it well. It was pretty much like all my other visits except that I was

alone,' Hofer says. 'My wife decided not to come as she was tired, heavily pregnant with our first child.' At the beginning of the visit, Dirac behaved normally and looked alert and ready to absorb the conversations around him. After the customary pleasantries, the Diracs took Hofer by surprise when they ushered him through the formal front room – where they always talked during their Friday chats – to the less formal family room at the rear of the house, adjoining the kitchen and overlooking the garden. The Diracs' pre-war taste was reflected in the decor of this room, dominated by the wood of the floorboards, the panelling on all four walls, and the huge 1920s sideboard covered with framed photographs of Dirac in his prime. A mock-Baroque chandelier hung from the ceiling and, on most of the walls, there were paintings with no trace of modernity.

As usual, Manci and Hofer chatted convivially while the frail Dirac sat motionless in his favourite old chair, occasionally looking through the glass sliding doors to the garden. For the first half an hour or so of the conversation, he was, as usual, mute but came vibrantly to life when Manci happened to mention his distant French ancestors. Dirac corrected one of Manci's historical facts and began to speak about his family origins and his childhood in Bristol, talking fluently in his quiet, clear voice. Like a well-rehearsed actor, he spoke confidently, in carefully articulated sentences, without pausing or correcting himself. 'I was startled – for some reason, he had decided to take me into his confidence,' Hofer says. 'I'd never seen him talk so eloquently in private.'

Dirac described his roots in the rural villages of Bordeaux, in western France, and how his family migrated to the Swiss canton of Valais at the end of the eighteenth century. It was in Monthey, one of the region's industrial towns, that his father was born. As soon as Dirac began to talk about his father, he became agitated, and he turned away from his wife and Hofer, adjusting his pose so that he was staring straight into the fireplace. Hofer was now looking directly at the profile of the top half of Dirac's body: his hunched shoulders, his high forehead, his straight and upward-pointing nose, his white smudge of a moustache. The air conditioning and television were switched off, so the room was silent except for the occasional rumblings of traffic, the barking of neighbourhood dogs, the rattling of the lid on the simmering casserole in the kitchen. After spelling out his ancestry with the precision of a genealogist, Dirac reached the

part of his story where his father arrived in Bristol, married Dirac's mother and started a family. His language remained simple and direct, but, as he began to talk about his childhood, his voice tightened. Hofer, watching Dirac's silhouette sharpen with the fading of the early evening light, was transfixed.

'I never knew love or affection when I was a child,' Dirac said, the normally neutral tone of his voice perceptibly tinged with sorrow. One of his main regrets was that he, his brother and younger sister had no social life but spent most of their time indoors: 'we never had any visitors'. The family was dominated, Dirac recalled, by his father, a tyrant who bullied his wife, day in, day out, and insisted that their three children speak to him in his native French, never in English. At mealtimes, the family split into two: his mother and siblings would eat in the kitchen and speak in English, while Dirac sat in the dining room with his father, speaking only in French. This made every meal an ordeal for Dirac: he had no talent for languages, and his father was an unforgiving teacher. Whenever Dirac made a slip – a mispronunciation, a wrongly gendered noun, a botched subjunctive – his father made it a rule to refuse his next request. This caused the young Dirac terrible distress. Even at that time, he had digestive problems and often felt sick when he was eating, but his father would refuse him permission to leave the table if he had made a linguistic error. Dirac would then have no option but to sit still and vomit. This did not happen just occasionally, but over and over again, for years.

Hofer was aghast, scarcely able to believe his ears. 'I felt extremely embarrassed, like I was witnessing a friend pouring out his most terrible secrets to his psychiatrist,' he recalls. 'Here he was, a man famous for equability and his almost pathological reticence, openly talking of the demons that had haunted him for nearly seventy years. And he was as angry as if these awful events had happened yesterday.'

Manci barely stirred, except once to bring nibbles and alcohol, and to slow down the preparations for dinner. She knew that on the very rare occasions her husband chose to tell his story, it was best to keep well out of his way and to let him get it off his chest. As the evening turned colder, she brought him a blanket and draped it over his legs, covering him from his lap down to his ankles. Hofer braced himself as Dirac resumed and explained why he was so quiet, so ill at ease with normal conversation: 'Since I found that I couldn't express myself in French, it was better for me to stay silent.'

Dirac then moved on to talk about other members of his family: 'I was not the only one to suffer,' he said, still agitated. For thirty-seven years, his mother was locked in a disastrous marriage to a man who treated her like a doormat. But it was Dirac's brother who felt the brunt of their father's insensitivity: 'It was a tragedy. My father bullied him and frustrated his ambitions at every turn.' In what appeared to be a change of tack, Dirac mentioned that his father always appreciated the importance of a good education and that he was respected by his colleagues as a conscientious, hard worker. But this was only a brief respite. Seconds later, Dirac was struggling to control his rage when he spelt out the conclusion he eventually reached about the extent of his debt to his father: 'I owe him absolutely nothing.' That final rasp made Hofer flinch; he could not help but grimace. Dirac hardly ever spoke an unkind word about anyone, but here he was, denouncing his own father with a vehemence most people reserve for the cruellest abusers.

Dirac stopped talking abruptly, just after nightfall. His monologue had lasted over two hours. Hofer knew that any words from him would be inappropriate, so he said his subdued goodbyes and walked home, numb and drained. Soon to be a father himself, he reflected on his own youth as part of a close and loving family: 'I simply could not conceive of any childhood as dreadful as Dirac's.'[5] Time tends to embellish, distort and even create childhood memories: could it be that Dirac – usually as literal-minded as a computer – was exaggerating? Hofer could not help asking himself, over and again: 'Why was Paul so bitter, so obsessed with his father?'

Later that night, after talking with his wife Ridy about Dirac's account of his young life, Hofer made up his mind to find out more about it. 'I thought he might open up again during our later get-togethers.' But Dirac never mentioned the subject again.

One

> English home life to-day is neither honorable, virtuous, wholesome, sweet, clean, nor in any creditable way distinctively English. It is in many respects conspicuously the reverse [. . .].
>
> GEORGE BERNARD SHAW, Preface to *Getting Married*, 1908

As Kurt Hofer had seen, the elderly Paul Dirac was fixated on his father Charles. But most of Dirac's acquaintances knew nothing of this: at home, he allowed no photographs of his father to be displayed, and he kept his father's papers locked in his desk. Dirac examined them from time to time and talked with distant relatives about his father's origins, apparently still trying to understand the man he believed had blighted his life.[1]

Dirac knew that his father had endured a childhood no less miserable than his own. By the time Charles Dirac was twenty, in 1888, he had done three stints of national service in the Swiss army, dropped out of university in Geneva and left home, without telling his family where he was heading.[2] He became an itinerant teacher of modern languages – the subject he had studied at university – and held posts in Zurich, Munich and Paris, before he fetched up two years later in London. English was one language that he did not speak well, so it is not clear why he chose to live in Britain; perhaps it was because it was the world's wealthiest economy, with plenty of teaching jobs at relatively high salaries.

Six years later, Charles Dirac had acquired a sheaf of complimentary references. One, written by the headmaster of a school in Stafford, stated that Monsieur Dirac 'is possessed of very great patience combined with firmness [. . .] I believe he is much liked both by his colleagues and pupils.' His employer in Paris had praised 'his capacity to analyze and generalize, which enabled him to point out my mistakes and help me to ascertain scientifically why they were mistakes'. Charles settled in Bristol, a city famous for the high quality of its schools, and he became Head of Modern Languages at the rapidly expanding Merchant Venturers' School on 8 September 1896, contracted to teach thirty-four hours a week for an annual

salary of one hundred and eighty pounds.[3] He stood out among the teachers because of his conscientiousness, his thick Swiss-French accent and his appearance: a short, stocky, slow-moving man with a drooping moustache, a receding hairline and a face dominated by a huge forehead.

Mellowest of British industrial cities, Bristol was known for the friendliness of its people, its mild and wet climate and the hilly roads that wend their way down to the moorings on the river Avon, eight miles from the coast. Bristol was then a thriving manufacturing centre, producing Fry's chocolate, Wills's cigarettes, Douglas motorcycles and many other commodities. Together, these industries had eclipsed the declining trade in shipping, which had been the city's main source of wealth for centuries, some of it based on the slave trade.[4] Most of the city's wealthiest maritime figures were members of the Merchant Venturers' Society, a secretive group of industrialists with a strong philanthropic tradition. It was the generosity of the Society that had made possible the founding of Charles's school together with the high standard of its workshop and laboratory facilities.[5]

During a visit to the Central Library a few months after his arrival in Bristol, Charles met Florence Holten, the guileless nineteen-year-old librarian who would become his wife. Though no beauty, she was attractive and possessed features that she would later pass on to her most famous child: her oval face was framed by dark, curly hair, and a firm nose darted out from between her dark eyes. Born into a family of Cornish Methodists, she was brought up to believe that Sunday should be a day of rest, that gambling was sinful and that the theatre was decadent and best avoided.[6] She had been named after the nurse Florence Nightingale, whom her father Richard met during the Crimean War, where he served as a young soldier before becoming a seaman.[7] He was often away for months at a time, leaving behind his wife and six children, of whom Flo was second eldest.[8]

Flo Holten and Charles Dirac were an odd couple. She was twelve years younger than him, a daydreamer uninterested in pursuing a career, whereas Charles was strong-minded and industrious, devoted to his job. The couple had been raised in different, scarcely compatible religions. She was from a family of devout Methodists and so had been raised to frown on alcohol, whereas Charles had been brought up in a Roman Catholic home and liked a glass of wine with his meals. Catholicism had been the cause of riots in Bristol and other

English cities, so Charles may at first have kept his religious beliefs to himself. If he did disclose them, his relationship with the young Flo would have raised eyebrows in her circle.[9]

Despite the possible sectarian tensions, by August 1897 Charles and Flo were engaged, though Flo was feeling sore. Charles had chosen to 'break the spell' of their relationship to visit his mother Walla, a dressmaker in Geneva, leaving his fiancée to sulk in Bristol's incessant rain. His father had died the year before. He had been a highly strung junior schoolteacher and later a stationmaster at Monthey station in south-west Switzerland but was dismissed for repeatedly being drunk on duty, leaving him plenty of time to pursue his interest in writing romantic poetry.[10] The Swiss stretch of the Rhône valley had been home to the Dirac family since the eighteenth century, when – according to family lore – they moved from the Bordeaux area in western France. The names of many of the towns in this region and its vicinity end in *-ac*, such as Cognac, Cadillac and the little-known village, about ten kilometres south of the Angoulême, called Dirac.[11] Charles believed his family had originated there, but there is no evidence for this among the family records, now stored in the town hall of Saint Maurice (near Monthey), where the colourful Dirac coat of arms – featuring a red leopard with a three-leaf clover in its right paw, below three downward-pointing pine cones – is one of many painted on the walls.[12]

Uneven postal delays caused Charles's letters from Switzerland to arrive out of order, infuriating Flo, who wished that 'letters went by electricity like tram cars'; a century would elapse before long-distance lovers benefited from the type of communication she was vaguely envisioning – electronic mail.[13] Lonely and disconsolate, she repeatedly read Charles's notes and, when her family was not looking over her shoulder, replied with newsy letters of how they could not resist teasing her about her pining for 'my own boy'. Struggling to put her longing into words, she sent him a poem full of ardour; in return, he sent a posy of Alpine flowers which she hung round his photograph.

Almost two years later, Flo and Charles were married 'according to the rites and ceremonies of the Wesleyan Methodists' in Portland Street Chapel, one of the oldest and grandest of Bristol's Methodist churches. The couple moved into Charles's residence in 42 Cotham Road – probably in rented rooms – a short walk from Flo's family

home in Bishopston, in the north of the city. Following custom and practice, Flo stopped doing paid work and stayed at home to do the housework and read about the first skirmishes of Britain's latest imperial venture, the Boer War in South Africa. Soon, she had other things on her mind: the Diracs' first son Felix was born on the first Easter Sunday of the new century.[14] Nine months later, the country mourned the passing of an era when Queen Victoria, having reigned for an unprecedented sixty-three years, died in the arms of her grandson, Kaiser Wilhelm II. Soon after a period of national grief, mitigated only by relief at the ending of the war, the family prepared for a new beginning of its own. In July 1902, they moved into a slot in one of the new terraces on Monk Road, to a roomier, two-storey home that Charles named after his native town of Monthey. The Diracs would soon need extra space as Flo was again pregnant, with only a few weeks to go before the birth.[15]

On Friday, 8 August 1902, Bristol's eyes were on London, where King Edward VII was to be crowned on the following day. Thousands took the train from Bristol to the capital to see the coronation procession, but the celebrations were a sideshow in the Dirac household. On that Friday morning, Flo gave birth at home to a healthy six-pound boy, Paul Adrien Maurice Dirac. He was, as his mother later recalled, a 'rather small', brown-eyed baby, who slept contentedly for hours in his pram in the patch of the front garden.[16] His mother worried that he ate less food than most children, but the family doctor reassured her that Paul 'was OK, perfectly proportioned'.[17] His parents nicknamed him 'Tiny'.

When Felix and Paul were young, they resembled each other, each a quiet, round-faced cherub with a thick bonnet of black, curly hair. Flo dressed them stylishly in thick woollen waistcoats topped with stiff, white-lace Eton collars that reached out to their shoulders, like the wings of a huge butterfly. From family letters and Flo's later testimony, it appears that the boys were close and liked to be with their father, whose top priority was to encourage them to learn. With the virtual absence of visitors and opportunities to mix outside their immediate family, Paul and Felix probably did not appreciate they were being brought up in a singularly unusual environment, a hothouse of private education overseen by a father who would speak to them only in French and a mother who would talk only in English.

According to one witness, the young Paul Dirac believed that men and women spoke different languages.[18]

But Paul and Felix were let off the leash occasionally. Their mother sometimes took them to the Bristol Downs so that they could play on the vast expanse of grassy parkland stretching from the cliffs of the Avon Gorge to the edges of the city's suburbs.[19] From their favourite spot on the Downs, the Dirac boys had an excellent view of the Clifton Suspension Bridge, one of the most famous creations of Isambard Kingdom Brunel, the charismatic engineer who also left Bristol with its Floating Harbour and Temple Meads railway station, two of the city's finest monuments.

In the summer, the family would take a bus trip to the beach at nearby Portishead, where the boys learned to swim. Like most families of their modest means, the Diracs rarely took vacations, but, in 1905, they went to Geneva to visit Charles's mother, who had an apartment a stone's throw from the lake and ten minutes' stroll from the railway station.[20] The brothers spent hours by the lakeside statue of the philosopher Jean-Jacques Rousseau, playing together and watching the artificial geyser shoot its jet of water ninety metres towards the sky. When the seventy-year-old Dirac told this story, one of his earliest memories, he liked to point out that his first trip to Switzerland took place at the same time as Einstein was having his most successful spurt of creativity in Berne, only a short train journey from Geneva. That year, Einstein wrote four papers that changed the way people think about space, time, energy, light and matter, laying the foundations of quantum theory and relativity. Twenty-three years later, Dirac would be the first to combine the theories successfully.

There exist two vivid snapshots of life in the Dirac household in the summer of 1907, shortly before Paul started school, a year after the birth of his sister Betty. The first is the correspondence between Charles Dirac and his family when he was in Trinity College, Cambridge, attending the International Esperanto Congress. Earlier in the year, Charles had qualified to teach the language, which he championed in Bristol for the rest of his life.[21] When Charles was away, his family showered him with loving notes. Flo's affectionate gusto was almost as intense as it had been in the heat of their passion, ten years before. Up to her ears in the chaos of having to look after the three children – taking them for walks, feeding the pet mice,

cooking Paul his favourite jam tarts – she had the undivided attention of her boys: 'It is very quiet without you, the boys are sticking to me for a change.' She assured her husband that his family at home 'all had a nice dinner, mutton, peas, junkets [a sweet dessert]'. The boys missed Charles terribly, Flo told him, just as she did: 'I shall miss you in the bye-bye [i.e. bed] tonight.'[22] Flo enclosed in her letters to Charles notes from Felix and from Paul, who wrote in stick-letter capitals of the welfare of the mice and, most importantly, his love for him: 'Tiny hopes Daddie has not forgotten little Tiny' and 'I love you very much. Come home soon to your own Tiny Dirac xxxxx.' Charles replied with a postcard, written mainly in English but with a little French, promising to bring home some Esperanto chocolate and concluding, 'I would not go out if I did not have to.'

Nothing in this loving correspondence bears any sign of the terrible home life that Dirac described to Kurt Hofer. Charles's use of English words appears to be inconsistent with the French-only linguistic regime that Paul claimed his father practised, and his father's tone bears no sign of the heartlessness that Paul remembered.

It is clear that Charles was as keen as any other father to keep a photographic record of his children. At about this time, he purchased a camera – probably one of the fashionable Kodak box Brownies – to take pictures of his children, many of them showing Felix, Paul and Betty reading avidly. Charles also wanted a portrait of his family to be taken by a professional and for the result to be printed on postcards for family and friends. The photograph, the only surviving image of the entire family, was taken on 3 September and gives us the second impression of the Diracs in 1907.[23] Flo looks demure and serious, her long hair tied up at the back, baby Betty on her lap. Felix is leaning towards her, smiling broadly and looking directly into the camera like Paul, whose left arm rests on his father's right leg, apparently seeking reassurance. Charles leans forward to the camera, eagerly, his alert eyes shining. He steals the picture.

This photograph of a happy family is subverted by Dirac's later memories of trauma and unhappiness. In one stinging memory, his parents bawled at each other in the kitchen while he and his siblings stood in the garden, frightened and uncomprehending. He once remarked in an interview that his parents 'usually ate separately', though twenty years later friends wrote that he told them he 'never'

saw his parents have a meal together – apparently a rare example of his being caught exaggerating.[24] The rift between his parents was, according to Dirac, responsible for his dining-table ordeals. Three times every day, the tinkling of cutlery, the clatter of saucepans on the gas stove, the waft of cooking smells through the house presaged the ritual that he loathed. In none of the surviving accounts of the dining arrangements did he explain why he alone sat with his father, while his brother and sister ate with their mother in the kitchen. The only partial explanation that Dirac ever gave was that he could not sit in the kitchen because there were insufficient chairs.[25] But this says nothing about the mystery of why Charles singled out him, not Felix or Betty, for special treatment.

The dining ritual was particularly harrowing on winter mornings, Dirac remembered. He would sit at the table with his father in the silent room, warmed by the burning coal in the fireplace and lit by a few oil lamps. Charles would be dressed in his three-piece suit, ready to cycle to the Merchant Venturers' School, always anxious not to be late for Assembly. His wife, scrambling and disorganised in the kitchen, made his anxieties worse by serving breakfast – usually large portions of piping-hot porridge – much too late for comfort. While he was waiting for his breakfast, Charles gave his first French lesson of the day to his younger son. Quite apart from Dirac's hatred of these arrangements, he grew to dislike eating mainly because his parents insisted, even when his appetite had been sated and he felt sick, that he must eat every morsel of food on his plate.[26]

For the young Dirac, this was normality. In his early thirties, he wrote to a close friend of the sourness of his home life: 'I did not know of anyone who liked someone else – I thought it did not happen outside novels.'[27] In another letter, he wrote: 'I found it to be the best policy as a child [. . .] to make my happiness depend only on myself and not on other people.'[28] According to Dirac, his best defence against the unpleasantness and hostility he perceived all around him was to retreat into the bunker of his imagination.

Dirac first experienced the company of children outside his family shortly after his fifth birthday, when he started at the small and intimate Bishop Road Junior School.[29] This was his first opportunity to socialise, to get a sense of other children's lives, of other domestic customs and practices. But he apparently made no attempt to talk to

other children: he remained silent and continued to live in his own private world.

The school was round the corner from his home, so close that he could hear its bell ringing at the start of the day. Despite the daily hurry of the breakfast routine, he and his brother always arrived on time.[30] Dirac's class typically consisted of about fifty children crammed into a room about twenty-five feet square, the pupils sitting in rows of identical wooden desks, learning in an atmosphere that was, by today's standards, extremely disciplined and competitive.[31] At the end of their time at school, children had to compete for scholarships that would help to pay for their senior education. Success meant that the child's parents would have to pay little or nothing; failure often meant that the child would be sent out to work.

Paul and Felix were recognisably brothers, but Felix had a rounder face, was a few inches taller and was more heavily built.[32] He was placid and well behaved, though given to lapses of concentration, as his headmaster pointed out when he wrote across his school report: 'The boy appears to me to be a perpetual dreamer. He must wake up!' Felix appears to have taken the advice, as he soon improved and did well in most subjects, especially drawing.[33]

From Dirac's later descriptions of his early life, we might expect him to have been an unhappy child, but there are no signs of this in the extant descriptions of him at the time. Twenty-seven years later, when his mother wrote a short poem about him for her own amusement, she described him as 'a cheerful little schoolboy', and added that he was 'contented' and 'happy'.[34] In official reports written when he was eight, teachers at Bishop Road do not comment on his demeanour, saying only that he was 'well behaved', 'an intelligent boy' and 'a very steady worker'. But there are indications that Dirac was not performing to his potential. A few teachers allude to this, most notably the Headmaster, who, on seeing that Dirac had only just managed to be ranked in the top third of the class, wrote on his report in November 1910, 'I expected to find you higher.'[35]

Among the boys Dirac did not get to know at Bishop Road School was Cary Grant, then known as Archie Leach and living in poverty about half a mile from Monk Road. In the classrooms and playground of the Bishop Road School, Dirac acquired the distinctively warm Bristol accent, which sounds slightly hickish to other native English speakers, evocative of farmers in the south-west of the

country. Like other young natives of Bristol, Dirac and Grant added an L to the pronunciation of most words that end in the letter A, a practice that is now dying out, though many English people still recognise Bristol as the only city in Britain to be able to turn ideas into ideals, areas into aerials.[36] Cary Grant shed this accent when he emigrated to the United States, but Dirac kept it all his life. He spoke with a gentle intonation and an unassuming directness that would surprise the many people who expected him to talk like the plummy-voiced English intellectual of popular caricature.

Like his brother, Dirac's ranking in the class gradually improved. He was good though not exceptional at arithmetic, and he did well in most subjects that did not involve his meagre practical skills. Soon after his eighth birthday, his teacher described him as 'An intelligent boy, but must try hard with his hand-work', drawing attention to his poor marks for handwriting (45 per cent) and drawing (48 per cent). His disappointed teacher commented that he should have done better than thirteenth in the class. Two years later, Dirac was consistently at or near the top of his class, his overall grade occasionally lowered by his relatively weak performance in history and brushwork.[37] At home, he pursued his extra-curricular hobby of astronomy, standing in his back garden at night to check the positions of the visible planets and constellations and, occasionally, to follow the track of a meteor hurtling across the sky.[38]

The school did not teach science but did give classes in freehand drawing and also technical drawing, a subject that provided Dirac with one of the foundations for his unique way of thinking about science. His mother later drew attention to his 'most beautiful hands', suggesting that his long and bony fingers equipped him well to be an artist.[39] Technical drawing, used by engineers to render three-dimensional objects on a flat piece of paper, is now taught at very few English junior schools, and rarely at senior level. Yet, in the early twentieth century, it was a compulsory subject for half the pupils: for a few lessons each week, the class would split into two: the girls studied needlework, while the boys were taught technical drawing. In these classes, Dirac learned to make idealised visualisations of various manufactured products by showing them from three orthogonal points of view, making no allowance for the distortions of perspective.[40]

Britain was among the slowest of the wealthier European countries to introduce technical drawing into its schools and did so only in the

wake of the Great Exhibition in 1851. Although the Exhibition was a great popular success, the most perceptive of its 6.2 million visitors saw evidence that mass technical education in Britain would have to improve substantially if the country were to retain its economic hegemony against growing competition from the USA and Germany. The Government agreed, enabling the Great Exhibition's prime mover Sir Henry 'King' Cole to change the technical curriculum of English schools so that boys were taught technical drawing and given an appreciation of the beauty of manufactured objects as well as natural forms.[41] There was, however, a backlash to this practical notion of beauty in the form of the Aesthetic Movement, which flourished in England from the mid-1850s. The movement's leader in France was the flamboyant poet and critic Théophile Gautier, a weight-lifting habitué of the Louvre's Greek galleries.[42] His phrase 'Art for art's sake' became the motto of the English aesthetes, including Oscar Wilde, who shared Gautier's belief that formal, aesthetic beauty is the sole purpose of a work of art. This view would later be distantly echoed in Dirac's philosophy of science.

Sir Henry Cole's reforms endured: the guidelines set out by him and his associates were being used in Bishop Road School when Dirac began his formal schooling. In 1909, the educationist F. H. Hayward summarised the prevailing philosophy that underlies the contemporary teaching of art: 'drawing aims at truth of conception and expression, love of beauty, facility in invention, and training in dexterity [. . .] nature study and science lessons cannot proceed far without it.'[43] Hayward urged that students should practise their drawing skills by trying to represent accurately both natural and manufactured objects, including flowers, insects, tables, garden sheds and penknives. In autumn 1912, Dirac was asked to draw a penknife, and he did it competently enough – like all his other drawings, it includes not a line of embellishment.[44]

The school took pains to teach its pupils how to write legibly, according to textbook rules that Dirac and his brother apparently studied closely.[45] They developed a similar style of handwriting – consistent with the rules set out in the books they studied – neat, easy to read and virtually devoid of flourishes, except for the unusual forming of D, with a characteristic curl at the top left. Dirac did not change this calligraphy one iota for the rest of his life.

In the early summer of 1911, school inspectors noted that 'the

boys who are particularly bright and responsive are being carefully trained in habits of self-reliance and industry.' Nearly three years later, when Dirac was in his final year at the school, the inspectors visited Bishop Road again and wrote warmly of this 'progressive' school and the practical education it offered: 'a keen, vigorous and thoughtful head [teacher]. Staff [are] earnest, painstaking [. . .] Drawing is well taught and handwork is resourceful, the boys make a number of useful models and are allowed considerable freedom in their choice while the work is so taken as to train them in habits of self reliance, observation and careful calculation and measurement.'[46]

Bishop Road School wanted to give its pupils the skills they needed to get good jobs. But, for Dirac, the most important consequence of this practical approach was that it helped to shape his thinking about how the universe works. As he was sitting at his desk in his tiny Bristol classroom, producing an image of a simple wooden object, he had to think geometrically about the relationships between the points and lines that lie in a flat plane. In his mathematics classes, he also learnt about this type of Euclidean geometry, named after the ancient Greek mathematician who reputedly discovered it. So, Dirac studied geometry using both visual images and abstract mathematical symbols. Within a decade, he would transfer this geometric approach from concrete technological applications to the abstractions of theoretical physics – from an idealised, visual representation of a wooden fountain-pen stand to an idealised, mathematical description of the atom.

Later in life, Dirac would say that he never had a childhood. He knew nothing of the rites of passage of most other young boys – long weekend afternoons spent stealing eggs from birds' nests, scrumping from nearby orchards, dashing out in front of trams. In many ways, as a child he seems to have behaved much as Newton had done. 'A sober, silent, thinking lad [. . .] never was known scarce to play with the boys abroad' was how one of Newton's friends described him: the description applies equally well to Dirac as an infant.[47]

Dirac was not interested in sport, with the exception of ice-skating, which he learned with Betty and Felix at the nearby Coliseum rink, the talk of Bristol when it opened in 1910.[48] Decades later, his mother recalled that he would sit quietly, reading books that he had

placed neatly around him and learning long poems that he would recite to his family.[49] She shed some light on his sheltered childhood when she spoke to reporters in 1933: '[his father's] motto has always been to work, work, work, and if the boy had showed any other tendencies, then they would have been stifled. But that was not necessary. The boy was not interested in anything else.'[50] There is little doubt that Charles Dirac impressed his sedulous work ethic on his younger son, who later wrote admiringly of his father's conscientiousness:

> One day while cycling [to school, my father fell off his bike], trying to avoid a child who ran out in front of him, and broke his arm. He was very conscientious, so he continued to the school and continued with his teaching, in spite of the broken arm. Eventually, the head master found out about it and sent him home, and told him not to come back until he was better.[51]

Paul was also aware that his father was exceptionally careful with money. In April 1913, Charles took the biggest financial decision of his life by purchasing a more expensive and more spacious home. The family moved from the cramped terrace of Monk Road to a neat semi-detached residence a few minutes' walk away in a slightly more salubrious part of Bristol, at 6 Julius Road. The Diracs now had a home befitting Charles's status in the community, with separate rooms for their two boys so that Dirac now had a place to escape, a private place where he could work alone. The family still kept themselves to themselves, inviting no visitors into their home, apart from Flo's family, her guests – all female – at a monthly afternoon tea party and the steady stream of pupils who took private language lessons from her husband.[52]

Like many parents, Charles entered all his children for scholarship exams.[53] When Felix was nine years old, he failed one of these exams, leading his father to demand an explanation from his teachers; Betty also failed the exam a few years later. Paul had no such problems: he passed every scholarship exam with flying colours and, thus, unlike Felix and Betty, ensured he was educated at minimal expense to his parents.

Dirac could see new technology making its imprint on Bristol. The city centre was a patchwork of centuries-old buildings and brand-new ones, many of them emblazoned with advertisements for new

services and products.[54] Open-topped motor cars vied for space on the roads with horse-drawn carriages, bone-shaking bicycles and the trams that made their jerky way round the city. When a programme of road construction began, in the early years of the century, cars began to dominate the city. In late 1910, Dirac had witnessed the beginnings of the Bristol aviation industry, one of the first and largest in Britain. The leading figure in this new Bristol industry was the local entrepreneur Sir George White, who founded the British and Colonial Aeroplane Company and supervised the building of some of the earliest aircraft in a tram shed in Filton, a few miles north of the Diracs' home. Long afterwards, Dirac told his children that he would rush out into the back garden to see aeroplanes precariously taking off from the new airfield less than a mile away.[55] It seems that he wanted to find out more about this new technology: among the papers he kept from his youth were details of a programme at a local technical college, beginning in December 1917: 'Ten Educational Lectures on Aeronautics'.[56]

Dirac and his brother stood out among the boys in Bishopston as they both spoke good French even before they started school. According to one report, local boys would stop the Dirac brothers on the streets and ask them to speak a few sentences of French.[57] This knowledge of French was also obvious to the students at their next school, where the language was taught by the school's most feared disciplinarian – their father.