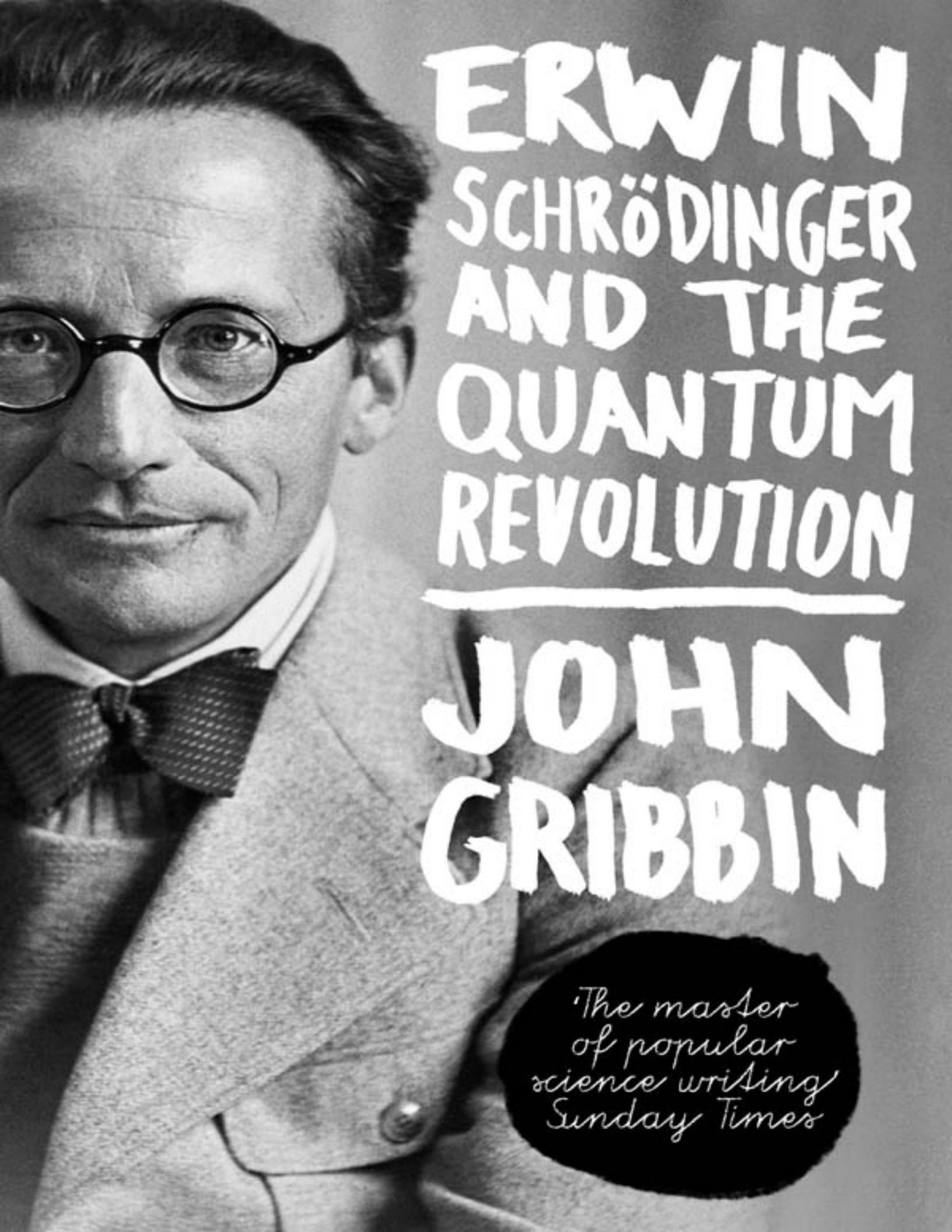

ERWIN SCHRÖDINGER AND THE QUANTUM REVOLUTION

JOHN GRIBBIN

'The master of popular science writing' Sunday Times

About the Book

Erwin Schrödinger was an Austrian physicist famous for his contribution to quantum physics. He won the Nobel Prize in 1933 and is best known for his thought experiment of a cat in a box, both alive and dead at the same time, which revealed the seemingly paradoxical nature of quantum mechanics.

Schrödinger was working at one of the most fertile and creative moments in the whole history of science. By the time he started university in 1906, Einstein had already published his revolutionary papers on relativity. Now the baton of scientific progress was being passed to a new generation: Werner Heisenberg, Paul Dirac, Niels Bohr and, of course, Schrödinger himself.

In this riveting biography John Gribbin takes us into the heart of the quantum revolution. He tells the story of Schrödinger's surprisingly colourful life (he arrived for a position at Oxford University with both his wife and mistress). And with his trademark accessible style and popular touch, explains the fascinating world of quantum mechanics, which underpins all modern science.

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Erwin Schrödinger and the Quantum Revolution

John Gribbin

For Terry Rudolph,
even though he won’t read it

Acknowledgements

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Preface

While writing my book *In Search of the Multiverse*, I came across a prescient but little-known piece of work by the quantum pioneer Erwin Schrödinger, which pointed the way, had anyone taken notice of it at the time, towards the very modern idea of a plurality of worlds, separated from one another not in space but in some other sense – 'parallel universes', in the language of science fiction. There was no suitable way to squeeze this historical dead end into that book, but it reminded me that Schrödinger was a man of many talents, and well worth being the subject of a popular biography – a biography which would give me a chance to dust down that forgotten piece of work and give it the recognition it deserves, set in the context of Schrödinger's life and work. The more I looked into his life, the more remarkable it seemed; I hope you agree that his is very much a story worth telling.

We must not forget that pictures and models finally have no other purpose than to serve as a framework for all the observations that are in principle possible.

ERWIN SCHRÖDINGER, Frankfurt, December 1928

His private life seemed strange to bourgeois people like ourselves. But all this does not matter. He was a most lovable person, independent, amusing, temperamental, kind and generous, and he had a most perfect and efficient brain.

MAX BORN, *My Life* (1978)

INTRODUCTION

It's Not Rocket Science

ROCKET SCIENCE IS the purest expression of the laws of physics spelled out by Isaac Newton more than three hundred years ago, often referred to as 'classical' science. Newton explained that any object stays still or moves in a straight line at constant speed unless it is affected by an outside force, such as gravity. He taught us that if you push something it pushes back – action and reaction are equal and opposite, as when a rifle kicks back against your shoulder while the bullet flies off in the opposite direction. He also gave us a simple law of gravity, explaining how the force of gravity depends on mass and distance. The 'action and reaction' bit is at the heart of rocket science. A rocket throws out stuff (usually hot gas, although in principle machine-gun bullets would do the trick) in one direction, and the reaction makes the rocket accelerate in the opposite direction. When the motors are not running, the spaceprobe drifts in what would be a straight line except for the influence of gravity. All sound Newtonian physics, and not really very difficult to understand.

Classical science describes an utterly predictable world. It is possible, for example, to work out exactly how much rocket thrust in what direction is needed to set a spaceprobe with a certain mass on a trajectory, falling through space under the influence of gravity, that will take

it to intercept the planet Mars at a precise date months in the future. Assuming their engines work properly, spaceprobes only miss their target when somebody gets the sums wrong – when there is human error.

For centuries after the time of Newton classical science posed a real problem for anyone who believes in free will. In principle, if you knew the position and speed of every particle in the Universe, including the atoms we are made of, at any chosen moment of time, it would be possible not only to predict the entire future of the Universe, but to reconstruct its entire history in exquisite detail. Leaving aside the practical problems of actually doing this, it seemed to imply that everything, including human behaviour, was pre-ordained. But then came quantum physics.

Quantum physics is not like classical physics. It is definitely not rocket science; it's much harder to understand than that. It took many top scientists, working over the first three decades of the twentieth century, to work out just what quantum physics is, and when they did find out some of them, including the subject of this book, didn't like what they had found.

Quantum physics mostly describes the world of the very small – roughly speaking, things the size of atoms and smaller. What physicists painstakingly (and painfully) discovered during those first three decades of the twentieth century is that particles can behave like waves and waves like particles; that quantum entities can be in at least two places at once; that they can get from one place to another without passing through any of the space in between; and that there is no certainty in the quantum world, where everything depends on probabilities. It's as if you sent a spaceprobe on its way in the knowledge that there was a 50 per cent chance that it would arrive at Mars and a 50 per cent chance that it would arrive at Venus, but no way to tell in advance where it would end up. Great for restoring a

belief in free will, but scarcely reassuring in any other way. And yet all this baffling behaviour of the quantum world has been tested and confirmed in countless experiments.

Erwin Schrödinger's masterpiece, the work for which he received the Nobel Prize, tried to restore the common sense of classical physics to the quantum world. It isn't giving away too much of our story to say that he failed, and that his work became an integral part of the revolutionary new physics.

But there was much more to Schrödinger than the reluctant revolutionary of quantum physics. One of the most intriguing aspects of Schrödinger the physicist, and one that lies at the heart of his antipathy to the revolution he participated in, is that although he made a major contribution to the new science of the twentieth century, he was brought up in the scientific tradition of the nineteenth. He graduated from high school and started at university in 1906, the year after Albert Einstein published his classic papers on the special theory of relativity and quantum physics. But Einstein, of course, was an exception; his ideas on quantum physics, in particular, were not taken seriously for at least another ten years, and the real quantum revolution took place at the hands of Young Turks such as Werner Heisenberg (born in 1901) and Paul Dirac (born in 1902), who, along with the likes of Niels Bohr, Louis de Broglie and Einstein, all come into the story of Schrödinger's life and work.

Schrödinger wasn't just a physicist. He was a disciple of Arthur Schopenhauer, with a profound interest in philosophy and Eastern religion, particularly espousing the Hindu Vedanta and subscribing to the idea of a single cosmic consciousness of which we are all part. He studied colour vision, and wrote a book, *What is Life?*, which Francis Crick and James Watson each independently cited as a major influence on the work which led them to the discovery of the DNA double helix. Schrödinger also

addressed questions such as ‘What is a law of nature?’ and whether or not the world is in principle completely deterministic and predictable. He wrote poetry (badly) and a book about the science and philosophy of ancient Greece.

Schrödinger’s private life was no less interesting. Brought up in comfort in the last days of the Austro-Hungarian Empire, he served as an artillery officer in the First World War and suffered the consequences of the post-war blockade of Austria (a long-forgotten Allied atrocity which caused mass starvation) and the runaway inflation of the early 1920s. After these experiences, one of his main concerns was to secure his own and his wife’s financial future; he worried about pensions until his death. His first attempt to get away from Nazi-influenced Europe came to nothing when he turned up in Oxford with both his wife and his mistress, offending the academic establishment there by making no attempt to conceal their living arrangements, with which his wife, who had her own lovers, was quite happy. The possibility of a post in Princeton alongside Albert Einstein fell through for the same reason. Schrödinger eventually landed up in more tolerant Dublin, where at the behest of Éamon de Valera, the Taoiseach (Irish Prime Minister), the Dublin Institute for Advanced Studies was set up to provide him with a base.

Schrödinger was also unconventional in other respects. As a university lecturer in the last days of Prussian formality, he neglected to wear a tie, and dressed so casually that he was often mistaken for a student and sometimes for a tramp. On at least one occasion he had difficulty gaining access to an important scientific meeting because he had hiked to the venue, rather than going by train, and presented himself straight off the road, dressed for rambling and carrying a rucksack.

When he retired in 1956, Schrödinger returned to Vienna and served as Austria’s representative at the International Atomic Energy Agency before his death in

1961. Like other elderly physicists, including Einstein, he had tried unsuccessfully to find a unified theory of physics. But generations of physics students know him from the equation which bears his name, and countless non-physicists know him from the parable of Schrödinger's cat. The whole point of that parable was to demonstrate the absurdity of quantum physics, and it could only have been dreamed up by a physicist steeped in the classical tradition. So the search for Schrödinger begins with classical physics.

Chapter One

Nineteenth-Century Boy

ERWIN SCHRÖDINGER WAS the only child of a wealthy Viennese family in the last decades of the Austro-Hungarian Empire. This upbringing naturally affected the kind of person he grew up to be; it also affected the way he thought about science and influenced the development of his greatest scientific idea, for which he received the Nobel Prize.

Antecedents

Erwin was the son of Rudolf and Georgine (Georgie) Schrödinger, who married in 1886. Rudolf's parents were profoundly affected by the almost casual way in which death could strike even in the most affluent parts of the civilized world in the nineteenth century. At the time of her marriage in 1853 his mother, Maria, was a nineteen-year-old orphan. Just five years later, she died following the birth of a stillborn baby. She had already produced a son, Erwin, who died as a child, a daughter, Marie, and another son, Rudolf, born on 27 January 1857. Her husband Josef, whose family came originally from Bavaria but had lived in Vienna for several generations, brought up the surviving children on his own, without (as would have been more usual at the time) re - marrying. But although the children may have lacked a mother, their material needs were well catered for. Josef owned a modest but profitable business, a factory

manufacturing linoleum and oilcloth; this family business would in due course be passed on to his surviving son, Erwin's father, Rudolf.

Socially, Georgie's family were a cut above the Schrödingers; indeed, they had aristocratic pretensions. They were descended from a minor nobleman, Anton Wittmann-Denglass, who had been born into a Catholic family in 1771. Such were the religious strictures of the time that when his daughter Josepha fell in love with a Protestant, she was forced to abandon her love-match and marry the family doctor, a good Catholic. She had three children before, perhaps to her relief, she was widowed and able to marry again. This time she chose – or had chosen for her – Alexander Bauer, the manager of her father's estates. The eldest son of this second marriage, another Alexander Bauer, was born in 1836. He would become Erwin Schrödinger's maternal grandfather. Alexander Bauer was the first in the family to show an interest in science, studying mathematics and chemistry in Vienna and Paris, and moving on to become a research chemist.

Erwin's maternal grandmother, Emily, was English and also came from a family with upper-class connections. They claimed descent from the Norman Forestière family, although the name had long since been anglicized to Forster, and had been associated with Bamburgh Castle in north-east England. Thomas Forster, born in 1772, was the son of the governor of Portsmouth, and his eldest daughter, Ann, born in 1816 and one of five children, would become Erwin's great-grandmother. He had met her when visiting England as a child. Ann married a solicitor, William Russell, and they had three children – William, Emily and Ann (known as Fanny).

The younger William Russell became an analytical chemist. In 1859–60, while studying chemistry in Paris, he met fellow student Alexander Bauer. The two became friends, and when Emily (nicknamed Minnie) and her

mother visited William in France, Alex met Minnie, then just nineteen years old, and the couple fell in love. Once Alexander had completed his studies and obtained his first (very junior) academic post, they were able to marry. After their wedding in Leamington Spa, on 21 December 1862, they lived in Vienna, where their first daughter, Rhoda, was born in 1864, followed by Georgie in 1867; soon after the birth of a third daughter, another Emily/Minnie, in 1874, Emily died of pneumonia.

Alexander Bauer's career continued to flourish until 1866, when he lost an eye in an explosion at the laboratory. From then on he concentrated on teaching, his studies in the history of chemistry, and the inevitable administrative duties associated with his rise to become Professor of General Chemistry at the Vienna Polytechnic (later the Technical University of Vienna), a post he held until his retirement in 1904. He was also a curator of the Museum of Art and Industry and a member of the Theatre Commission for Lower Austria, and took pleasure in introducing his grandson Erwin to the theatrical arts at an early age.

Alexander was devoted to his daughters, all of whom married men they had met through their father's connections. Rhoda, the eldest, married the Director of the Viennese Pharmaceutical Commission, Hans Arzberger, but had no children. Minnie, the youngest, married Max Bamberger, who later succeeded Alexander as Professor of General Chemistry, and had a daughter, Helga. Georgie married Rudolf Schrödinger.

Rudolf was a frustrated scientist who had studied under Alexander Bauer at the Technical University, but was obliged to take over the family business rather than pursue a career in chemistry. He married Georgie on 16 August 1886, when he was twenty-nine and she was nineteen. Although Rudolf, like most Austrians, was at least nominally a Catholic, the wedding took place at a Lutheran church (Georgie and her sisters had been brought up in the

Lutheran tradition, the nearest thing in Austria to the Anglican religion of their mother), making their son Erwin nominally a Protestant, although as we shall see this meant little in practice. The family was essentially irreligious, attending church only for weddings and funerals. Indeed, when Erwin Rudolf Josef Alexander Schrödinger, named after his father's dead brother, his father and his two grandfathers, was born in Vienna on 12 August 1887 and baptized five days later, even the naming ceremony took place at the Schrödingers' home, not in church.

Early years

Although Erwin's English grandmother had died thirteen years before he was born, her influence on the Schrödinger family was strong. His aunt Rhoda had grown up hearing only English spoken at home, and had spent years with her own grandparents in Leamington Spa. His mother's younger sister, Minnie, who was similarly fluent in English, was only fourteen years older than Erwin, and played with him as a child. So Erwin grew up hearing both English and German spoken at home; according to some accounts, he spoke good English before he learned to speak 'proper' German.

Erwin was an only child with two doting aunts, a female first cousin (Dora, the daughter of his father's sister), and a succession of nurses and maids attending almost to his every whim. It is tempting to see here the origin of patterns in Erwin's adult relationships with women. He grew up to expect women to dance attendance on him, while being somewhat insensitive to their needs. According to the psychiatrist Dennis Friedman, a boy brought up with both his mother and a nanny to look after him is predisposed to become a philanderer in later life: the experience

> creates a division in his mind between the woman he knows to be his natural mother and the woman with

> whom he has a real hands-on relationship: the woman who bathes him and takes him to the park and with whom he feels completely at one . . . he grows up with the idea that although he will one day go through all the social and sexual formalities of marriage, he will have at the back of his mind the notion of this other woman, who not only knows, but caters for, all his needs.[1]

Although this suggestion has been challenged (for example, by child psychologist Linda Blair), Friedman could have used Schrödinger as a case study in support of his hypothesis. But any such consequences lay far in the future when the boy Erwin was growing up in Vienna.

At the time Erwin was born, his grandfather Alexander owned a new town house in the centre of Vienna. The five-storey building was divided into five separate apartments, and in 1890 ‘our’ Schrödinger and his parents moved in to the spacious fifth-floor accommodation, with views overlooking St Stephan’s Cathedral.

Most of what we know about Erwin’s early life comes from the recollections of his aunt Minnie, which should be taken with the same pinch of proverbial salt as similar recollections made (much later in life) by relatives of Albert Einstein about his precocious childhood. But in both cases the reminiscences surely contain seeds of truth. From an early age, Erwin was interested in astronomy: he would persuade Minnie to stand representing the Earth while he ran round her to be the Moon, and then make her walk in a circle around a light representing the Sun while he continued to run round her. He also kept a kind of daily diary even before he could write, dictating his insights to Minnie. A surviving entry from 1891 reads: ‘In the evening Aunt Emmy [Minnie] cooked a good supper and then we spoke all about the world.’ Recording his thoughts and activities on paper was to become a lifetime habit.[2]

Erwin did not have to leave his cosy family circle even to go to school until he was ten, since up to that time he was tutored privately at home for two mornings a week. According to Minnie, he began to read almost as soon as he could talk, thanks to a maid who explained the names on street signs to him; but apart from such basics, the purpose of his early tuition was to prepare him for the entrance examination for the *Gymnasium* (equivalent to an English grammar school), where his real education would begin. But while the Schrödingers enjoyed the stereotypical life of the upper middle classes in Vienna, the empire around them was showing signs of the strains that would soon alter all of their lives, not least the young Erwin's, for the worse.

An empire's last hurrah

Vienna had been the capital of a great empire for centuries, ruled since 1276 by the Habsburg family. The geographical extent of this empire varied considerably over time. During the sixteenth and seventeenth centuries its fortunes ebbed and flowed, and in 1683 the expanding Ottoman Empire reached as far as Vienna before being repulsed. But even after the incursions of the Napoleonic Wars the Emperor (then Franz) ruled not only over much of the German-speaking world but also over Hungary, much of Poland and what became Czechoslovakia, parts of Italy, and, crucially for European history, the Slavic states in Balkan Dalmatia.

Towards the end of the eighteenth century the French Revolution had started a fire that would slowly spread across Europe to end the age of the great European empires. In 1848 the continent was rocked by a series of political upheavals so widespread and significant that it became known as 'the year of revolutions'. In the Austrian Empire, risings in Italy, Bohemia, Hungary and Vienna itself were put down by force, but concessions had to be made;

the Emperor, Ferdinand (who had succeeded Franz in 1835), was forced to abdicate.

The new Emperor was Ferdinand's nephew, Franz Josef, who had been born in 1830 but, in spite of his youth, at first looked backward rather than forward, dreaming of recreating an absolute monarchy ruling over a strong, expanding Austrian Empire. The harsh reality of military and political failures, including the Crimean War and the loss of Lombardy and Venice, forced him to change his approach, and from the mid-1860s onward Franz Josef became less autocratic and granted his people a greater degree of freedom. In 1867 Hungary achieved (at least nominally) equal status with Austria in what became called the Austro-Hungarian Dual Monarchy or more succinctly Austria-Hungary. But while the empire lost some territory, it gained elsewhere. In 1878 it took over the administration of the Balkan states Bosnia and Herzegovina, although these remained nominally part of the Turkish Empire until Austria-Hungary annexed them in 1908.

So the Vienna in which Erwin Schrödinger was raised was the capital of an empire that was visibly fraying at the edges. It contained people of many different nationalities and political allegiances, many of them dreaming of, or working for, independence. This was also, of course, a time of great social change, with industrialization, improved communications and the consequent movement of people into the cities. Increasingly, as Franz Josef aged he became a relic of times long gone, losing his power and influence to a bureaucratic system which rumbled on as much through inertia as anything else.

Vienna, to some extent insulated from these realities, remained a glamorous city famous for the arts. The Viennese loved opera and music, and in the nineteenth century the tradition of Haydn, Mozart and Beethoven was carried forward here by Schubert, Liszt, Brahms and Bruckner. And, of course, the Strauss family. But the people

who now enjoyed these cultural delights were increasingly, like Rudolf Schrödinger, the new bourgeoisie, rather than the old aristocratic class. Among the most important of these upwardly mobile groups were the Jews. Like all non-Catholics in Austria, they had had few rights (let alone privileges) before 1848, but as the grip of the authorities eased, Jews from all over the empire were among the people attracted to the capital. They made an economic and artistic impact out of all proportion to their numbers, in a society where casual anti-Semitism was common and 'the Jews' often got the blame for anything wrong with society. But this was not a prejudice that Erwin would grow up to share.

Scientific stirrings

Already famous for the arts, Austria, and Vienna in particular, also had a burgeoning scientific reputation in the second half of the nineteenth century. Among the changes that took place after 1848 was the establishment of a Physics Institute at the University of Vienna; its Director, Johann Christian Doppler, also became the first Professor of Experimental Physics at the university. Born in Salzburg and educated in Vienna, Doppler served in academic posts around the Austrian Empire before being appointed to head the new institute. Although he also did important work in mathematics and the study of electricity, he is remembered today for his investigation of the way in which the pitch of a sound or the colour of a light is affected by the relative movement of the source and the person observing it. His calculations were famously confirmed in 1845 by the Dutch meteorologist Christoph Buys Ballot, who arranged for trumpeters standing on an open car blowing a single note with all their might to be towed by a train past musicians with perfect pitch standing at the side of the track listening to the change in the note

they heard as the train, and the trumpeters, passed them. It is this ‘Doppler effect’ that explains the change in pitch of the siren of an emergency vehicle as it rushes past, and its optical equivalent is used to measure the speed with which stars are moving towards or away from us.

Doppler died in 1853 at the age of only forty-nine, and was succeeded as Director of the Physics Institute by Andreas von Ettinghausen. When von Ettinghausen, an undistinguished scientist, became ill in 1862 an acting director had to be appointed; and the man chosen was the rising star of Viennese physics, 27-year-old Josef Stefan, then a junior member of the university (a *Privatdozent*, the first rung on the academic ladder). Stefan became a full professor a year later, and in 1866 was officially appointed Director of the Institute. A pioneer in the study of thermodynamics (discussed in Chapter 2), Stefan investigated the way electromagnetic energy (heat and light) is radiated from a hot object. His findings, refined by his student Ludwig Boltzmann (himself Viennese), became known as the Stefan–Boltzmann Law of black body radiation, a key step on the road to what became the first version of quantum physics.

As well as being a first-rate scientist, Stefan was also a first-rate teacher, and one of his students, Fritz Hasenöhrl, would have a profound influence on Erwin Schrödinger, so that in an academic sense Stefan was Schrödinger’s ‘grand - father’. Schrödinger’s other academic grandfather was Stefan’s colleague Josef Loschmidt, whose particular claim to fame lay in calculating how molecules bouncing off the walls of a container produce pressure, thereby convincing his contemporaries of the reality of molecules, although he did a great deal more work in the young science of thermodynamics. His student Franz Exner, who was to succeed him as professor at the university (and was, incidentally, instrumental in persuading the Viennese authorities to give Marie and Pierre Curie the pitchblende

in which they discovered radium), was Schrödinger's mentor in experimental physics, while Hasenöhrl was his mentor in theoretical matters.

By the end of the nineteenth century, physics was thriving in Vienna. But while the Austrian physicists were honoured in their own country, their renown was much less abroad – not least because Stefan and Loschmidt, in particular, never travelled to spread the word about their achievements. As Boltzmann commented in 1905:

> Neither Stefan nor Loschmidt went, according to my knowledge, on a travel beyond the borders of [their] Austrian homeland. At any rate, they never visited a [scientific conference] and did not establish closer personal relationships with foreign scientists. I cannot approve of that, for I believe that they could have achieved still more if they had closed themselves off less. At least they would have made their achievements known faster.[3]

This was not a mistake that Boltzmann himself made. He led the way in promoting Austrian – or at least, his own – achievements among the wider scientific community. Boltzmann appreciated that by the end of the nineteenth century science was an international endeavour in which it was essential to maintain contact with colleagues in different countries. Nobody would epitomize the international nature of physics in the twentieth century better than Erwin Schrödinger, who arrived at the university just a year after Boltzmann made those remarks.

From schoolboy to undergraduate

He might have entered university in 1905, but Erwin's formal education was delayed by a year because he sat the entrance examination for the *Gymnasium* later than usual, having taken a long holiday in England with Georgie and

her sister Minnie in the spring of 1898, when he was ten. It was on this trip that he met his great-grandmother Ann, who had been born the year after Napoleon's final defeat at the Battle of Waterloo. Minnie tells us that he also learned to ride a bicycle, rode a donkey on the sandy beach at Ramsgate and visited a great-aunt who kept six Angora cats.

The holiday did not end when the party left England from Dover by steamer. From Ostende they travelled to Bruges and Cologne, and then up the Rhine by boat as far as Frankfurt-am-Main before completing the journey home by train. In order to prepare him for the examination (which he passed with ease), Erwin briefly attended St Niklaus School, his first experience of formal education. He entered the *Gymnasium* in the autumn of 1898, a few weeks after his eleventh birthday. The school was the most secular one of its kind in Vienna, and numbered Boltzmann among its former pupils. But probably neither factor played a part in the Schrödingers' choice; more relevant was the fact that it was just ten minutes' walk from the family home, on the Beethoven Platz. Erwin would be a pupil there for the next eight years.

The *Gymnasium* offered a classical education dominated by the study of Latin and Greek language and civilization. Lessons took place from 8 a.m. until 1 p.m., six days a week, with an additional two afternoons a week for the study of Lutheranism. 'From this,' says Schrödinger, 'I learned many things, but not religion.' His favourite question was, 'Sir, do you really believe that?'

In the first three years of school, there were eight hours of Latin a week, reduced to five hours when the pupils started Greek. There were also courses in German language and literature, geography, music and history. All of this left just three hours a week for mathematics and science. Hardly surprisingly, the maths never got as far as calculus, but covered the mathematical equivalent of the

classics: geometry and algebra. Much of the physics would have been familiar to Newton, and although there were classes in biology (mostly botany), the only mention made of Darwin's theory of evolution by natural selection was in the religious class, where it was denounced. The young Schrödinger learned more about the natural world from his father, a keen amateur botanist who published articles in learned journals (and who always regretted having had to give up an academic career for the family business); but he, too, was cautious about accepting all of Darwin's ideas. One of Rudolf's friends, however, was a zoologist at the Natural History Museum, and much more enthusiastic about natural selection. Under his influence, Erwin soon also became an enthusiastic Darwinian.

It was while he was at the *Gymnasium* that the first signs of Erwin's remarkable intelligence became evident outside his family. He was a good student who tells us that he loved mathematics and physics, but also enjoyed the logic of grammar and philology; he loved poetry but hated 'the pedantic dissection' of literature. He was always top of the class, in every subject, and a schoolmate later recalled the deep impression made on the pupils by the only occasion on which Erwin failed to answer a question from the teacher – it was 'What is the capital of Montenegro?'[4] In the afternoons (when not required to attend religious instruction), Erwin studied English and French. Perhaps because of his upbringing in a bilingual household, he became an excellent linguist who could lecture in German, French, English and Spanish, switching between them to answer questions from polyglot audiences; as an adult he also translated Homer into English and Old Provençal poetry into modern German.

The student who had the frustrating experience of being second in class to Erwin throughout his eight years at the *Gymnasium* was Tonio Rella. In spite (or perhaps because) of this, they became firm friends. The Rella family owned

an inn in the mountainous countryside, and Erwin often spent holidays there, developing, with Tonio, his love of hiking and the outdoor life. He also developed his first adolescent crush, on Tonio's sister Lotte, although in the circumstances of the time this could not develop much beyond holding hands. Tonio went on to become Professor of Mathematics at the Viennese Technical University, and remained friends with Erwin; he was killed by the shelling during the Russian advance on Vienna at the end of the Second World War.

Erwin's other great love as an adolescent was the theatre, one of the highlights of Viennese life at the beginning of the twentieth century. He usually went at least once a week, often taking advantage of the special matinees held on Sunday afternoons for students and workers. The main theatre was the splendid Hofburg, on the Ringstrasse, one of the most important German-language theatres in the world; but even the lesser Volkstheater could seat 1,900 people, while smaller theatres offered operetta, farce and even Hungarian vaudeville. Always an obsessive note-taker, Erwin even kept a record, with mini-reviews, of his visits to the theatre. Of one leading actor, he wrote: 'Much better than I had expected, not so much by what he does as by what he has left undone.'

The visual arts were also at a peak in turn-of-the-century Vienna, although not always appreciated. Gustav Klimt, at the height of his powers, was creating a storm of controversy with what were perceived as his overly sexual, even pornographic, paintings. In 1906, the year that Erwin Schrödinger and his friend Tonio Rella entered university, Egon Schiele, one of Klimt's friends, was gaoled for twenty-four days for painting a 'lewd' picture. But if Vienna was at the cutting edge of theatre and art in 1906, it was certainly not at the cutting edge of physics. While Stefan and Boltzmann were beginning to make interesting advances in

their own research, the teaching of physics was lagging sorely behind. Most of what Schrödinger would learn at the university as an undergraduate had a distinctly old-fashioned flavour, even in 1906.