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The making of a British theoretical physicist – E. C. Stoner's early career

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RUTHERFORD AS PATRON

In 1924 Edmund Clifton Stoner (1899–1966), a 24-year-old research student at the Cavendish Laboratory, Cambridge, sought a university post in physics. Having previously studied at Cambridge as an undergraduate, Stoner was nearing the end of three years' postgraduate research under Professor Sir Ernest Rutherford's supervision. 1924 was not, however, an auspicious time to seek employment since vacancies in university physics departments were scarce. Rutherford showed a kindly interest in Stoner's career and summoned him to his residence – Newnham Cottage – one Friday afternoon in March. Acknowledging Stoner's diabetes as a major concern, he 'pointed out that I [Stoner] really wanted a job where I could take things fairly easily... He, of course, is prepared to "back me up" & was really very charming, though not very useful in any definite way.'[1] Subsequent visits to the Appointments Board proved 'quite fruitless'. Stoner declined to apply for a post at Armstrong College, Newcastle, and only in mid-July did he hear of two more attractive positions. The first, at Durham University, was advertised in the press. Rutherford, who was 'Affable – pleased with my work (!)', advised him to apply.[2] Interviewed together with several other candidates, Stoner was unsuccessful but not greatly disappointed. The other post, at the University of Leeds, was brought to his attention by Rutherford.

The vacancy at Leeds occurred unexpectedly and Richard Whiddington, the Professor of Physics, was forced to find a replacement at short notice. Whiddington, a product of the Cavendish, sought Rutherford's advice, and Rutherford suggested Stoner, particularly on the strength of his knowledge of modern theoretical physics. When Whiddington visited Cambridge on 18 June he met Stoner and one other physicist. Three weeks later a Leeds University panel interviewed just one candidate – Stoner – who was subsequently

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1 ECS to parents, 16 March 1924: MS333/103.

2 Diary, 13 June 1924: MS333/33.

appointed to the Lectureship. That autumn he joined a Physics Department consisting of Whiddington, one other lecturer and three assistant lecturers.

Although Stoner's cause was probably assisted by a friend in the Leeds Physics Department (A. C. Menzies), his appointment was due primarily to Rutherford's intervention.[3] Rutherford's high opinion of his student is evident from his assessment of Stoner's Ph.D. dissertation, submitted to the Cambridge authorities in September 1924, soon after Stoner moved to Leeds. Even prior to the oral examination news reached Leeds that Rutherford and the co-examiner, C. T. R. Wilson, were delighted with his work. Leslie Martin, his Australian co-worker at the Cavendish, wrote from Cambridge that

> R[utherford] said he & Wilson were both very thrilled with your thesis & R[utherford] broke loose for my benefit or Kapitza's[,] I[']m not sure which[,] into a long tirade of your virtues as a thinker etc etc... He seems to have the idea that I dont quite realize the height depth & width of your intellect which God furnished... Any how seriously, unless he is a jolly good actor R[utherford] is thrilled to death with your Ph D. efforts.[4]

According to Stoner the viva lasted less than half an hour and the examiners 'were most complimentary. R[utherford] said it was the most interesting thesis he had read for a long time, & W[ilson] that he had not wanted to part with it'. Stoner, who nurtured literary aspirations, was particularly pleased by the comment (which he attributed to Rutherford) that the thesis 'read like a novel'.[5]

Rutherford's patronage not only secured the Leeds Lectureship but also assisted Stoner's career three years later when he was considered for a Readership. In his letter of support Rutherford praised Stoner's work in theoretical physics and especially his paper on the distribution of electrons in atoms. Rutherford particularly commended Stoner's 'exceptional ability and originality. For so young a man, the magnitude of his contributions to physics is noteworthy... I have no hesitation in recommending him strongly for the title of Reader as regards his scientific ability and accomplishments.'[6] Stoner was soon appointed Reader in Physics. In 1937 he was elected a Fellow of the Royal Society, again with the support of Rutherford.[7] He subsequently became the first Professor of Theoretical Physics at Leeds (1939 – one of the earliest such posts in Britain)[8] and later moved to the Cavendish Chair (1951).

At first sight Rutherford's generous support for Stoner appears an uncomplicated and, one hopes, typical example of how a thesis supervisor, impressed by his student's research, can assist career advancement. When viewed from Stoner's perspective, however, this case is far more complicated and considerably more interesting than the preceding account would suggest. Drawing mainly on documents deposited in the Brotherton Library, Leeds

3 'Physics Lectureship Committee, 4 July 1924': University of Leeds Archives, Minute Book 15.70.

4 L. Martin to ECS, 5 November 1924: MS333/121.

5 ECS to parents, 23 November 1924: MS333/117. See also Diary, 22 November 1924: MS333/33.

6 E. Rutherford, 'Report on the work of Mr E. C. Stoner...', 23 March 1927: University of Leeds, Central Filing Office.

7 His certificate, first submitted in 1935, was also signed by Whiddington, Kapitza, Chadwick, Dirac, Fowler, Ellis, Eddington, Milne, Sidgwick and Hartree: Certificate of Candidature, Royal Society Library. This list includes most British theoretical physicists of the period.

8 Manchester University established a Chair in Theoretical Physics two years earlier, occupied by Douglas Hartree.

University, I shall show that throughout his researches Stoner felt alienated from Rutherford and from the academic and social norms at the Cavendish. While many writers have emphasized Rutherford's avuncular role in creating a dynamic research school, Stoner did not perceive himself as one of Rutherford's 'boys'.[9] Owing to ill-health, financial insecurity and personal inclination, he was a marginal man. His experience thus highlights the diversity and tension within the Cavendish and thereby helps to explode the prevalent mythology nurtured by some of Rutherford's closest associates.

In his analysis of the origins of the Exclusion Principle John Heilbron argues that Wolfgang Pauli's more incisive statement of the Principle both drew on and eclipsed Stoner's. Moreover, he suggests how the personality of each man affected his work, especially how each framed the exclusion principle. Pauli was an arrogant, self-assured prodigy who had worked closely with Sommerfeld, Born and Bohr and had gained their respect.[10] By contrast, Stoner was shy and insecure and was marginal to the Cavendish, where he lived in dread of Rutherford's outbursts. Furthermore, his research often foundered and he sometimes doubted his ability to complete it successfully. Building on Heilbron's article, this paper examines the personal, inter-personal and scientific dimensions of Stoner's career as a research student at the Cavendish.

But there is another, related aspect of Stoner's marginality, if not dissidence, that I wish to explore. His difficulty in coping both with Rutherford and with experimental research precipitated a personal crisis that led him to invest his energies in theoretical physics in the hope of making a significant scientific contribution. His apostasy involved, in part, a rejection of the ethos of Rutherford's experimental school[11] and it is therefore ironic that Rutherford should have acted as Stoner's patron for the Leeds post by praising his skills as a theoretical physicist. To claim that Stoner was probably the leading Cavendish-trained *theoretical* physicist of the 1920s is to highlight the paradox which this paper addresses.

FIRST VINTAGE – THERMIONIC DISCHARGE TUBES

Armed with an Open Exhibition at Emmanuel College and two local scholarships, Stoner entered Cambridge from Bolton Grammar School in 1918. Coming from a relatively poor home – his father was a cricket coach – these scholarships were of crucial importance. Financial privation was a constant worry and a recurrent theme in both his diaries and his letters to his parents. As he noted in his diary at the close of 1921, 'We are a remarkably isolated family. It is sad – but the reason is again mainly – money'.[12] His need to succeed in physics and his frequently voiced concern about finding a suitable career were also responses to this financial insecurity which contributed to his marginality and general

9 The standard account is given in A. S. Eve, *Rutherford*, Cambridge, 1939; N. Feather, *Lord Rutherford*, London and Glasgow, 1940; M. Oliphant, *Rutherford Recollections of the Cambridge Days*, Amsterdam, 1972; J. G. Crowther, *The Cavendish Laboratory, 1874–1974*, London and Basingstoke, 1974; D. Wilson, *Rutherford. Simple Genius*, London, 1983; and by several of the contributors to *Cambridge Physics of the Thirties* (ed. J. Hendry), Bristol, 1984. See also J. L. Heilbron, *H. G. J. Moseley. The Life and Letters of an English Physicist, 1887–1915*, Berkeley, 1974, 57.

10 J. L. Heilbron, 'The origins of the exclusion principle', *Historical Studies in the Physical Sciences* (1983), **13**, 261–310.

11 This is not, of course, to imply that Rutherford was opposed to theorizing in physics.

12 Diary, late December 1921: MS333/30.

unhappiness at Cambridge. Other contributory factors include his shyness (particularly with women), sensitivity and poor health – he was diagnosed diabetic at the end of his first undergraduate year and was subsequently forced to monitor carefully what he ate, how much and when he ate it. Although he played tennis, he was never 'vigorous' and frequently complained about lack of energy. He read extensively and was active in various scientific societies but did not participate to any great extent in other aspects of Cambridge student life. It is significant that his closest friend at the Cavendish was another outsider, a Muslim student from India named Nazir Ahmad, who likewise felt neglected by Rutherford and his inner circle.[13] Politically Stoner was also in a minority since he supported the Labour party in a university with strong Tory and Liberal traditions.[14]

Stoner's first encounters with Rutherford were from a safe distance in the lecture theatre. As an undergraduate in 1918–21 he attended Rutherford's lectures on the properties of matter, on electrical oscillation and ionization and, after he graduated, on radioactivity. 'Rutherford', he noted, 'lectures as though thinking of something else (α rays?) all the time, so most amusing... Maths discursive, very hurried (maths purely an aid to gett[in]g results). But lectures quite worth going to. Very keen on us having idea of magnitudes.'[15] Some years later he was less charitable when he recalled that Rutherford's lectures 'seemed to be given because as a new Professor he felt he would be expected to give them. They were unsystematic, and often casual and ill-prepared, but they were stimulating when Rutherford could bring in themes connected with his own research activities.'[16] Stoner also heard Rutherford speak on other occasions; for example, in 1921 he attended a meeting of the Cavendish Physical Society where Rutherford delivered a 'most wonderful paper' on his research into the disruption of atoms by α particles.[17]

Towards the end of his undergraduate course the inevitable problem of career choice became pressing. 'Sometimes [I] wish I had definitely decided what to do. It is a nuisance not knowing', he confided to his diary at the beginning of April 1921.[18] One possibility was to enter the Cavendish as a research student. With the approach of his Finals examinations in the summer of 1921, he therefore enquired about the possibility of obtaining an award from the DSIR (Department of Scientific and Industrial Research), having '[d]ecided, if poss. to do research on Radioactivity [about which he had been reading] under Rutherford!'[19] This seemed an appropriate subject in the light of Rutherford's earlier successful researches on radioactivity. An encouraging interview with the 'great man' raised his hopes and soon after hearing that he had secured first-class honours in the Natural Sciences Tripos, but before the financial situation had been clarified, Stoner was assigned as assistant to Gilbert Stead, a more experienced research worker than himself. Stead was not engaged in radioactivity but had been studying the glow in long thermionic

13 'Autobiographical sketch' deposited in the Library of the Royal Society. Extensive selections from this document are quoted in L. F. Bates, 'Edmund Clifton Stoner 1899–1968', *Biographical Memoirs of Fellows of the Royal Society* (1969), **15**, 201–37.

14 T. E. B. Howarth, *Cambridge between Two Wars*, London, 1978.

15 Diary, 2 February 1921: MS333/30.

16 ECS, 'Comments on notebooks, lectures and classes of the Cambridge period, 1919–1924': MS333/2.

17 Diary, 9 March 1921: MS333/30.

18 Diary, 1 April 1921: MS333/30.

19 Diary, 23 April 1921: MS333/30.

tubes filled with mercury to ascertain how their electrical characteristics varied with the pressure of the gas. In mid-July a grant had been secured and Stoner proceeded enthusiastically with this project.

Throughout the autumn he spent much of his time at the Cavendish. As 1921 drew to a close he noted that some progress had been made, 'though at times slow'. Yet he remained certain that his future lay in physics.[20] Soon, however, his enthusiasm began to wane, since progress in experimental research proved painfully slow and often seemed non-existent. Research 'has been very disappointing & unfruitful', he noted at the end of the Lent term.[21] Much to his annoyance the apparatus crashed and had to be redesigned. As the months slipped by, Stoner found himself ever more isolated and lacking direction from his seasoned co-worker who rarely participated in the project. Towards the end of his first year in the Cavendish he recorded in his diary – 'Stead: After coming to Lab 1ce [once] last week has not been at all this... If working with someone expect them *never* to come. There will be an occasional pleasant surprise.'[22] Moreover, Rutherford rarely visited Stoner's room in the Cavendish. On one of his occasional visits he 'made several suggestions (not of very much use – though one was pleased at his coming at all)'.[23] Despite such disappointments Stoner persevered with the project, which resulted in a rather tedious co-authored publication.[24] In contrast to his research, which he often found boring, he revelled in Bohr's lectures on 'Quantum Theory and Atomic Structure' which he attended in March 1922. As he reported excitedly to his parents, 'Quantum Theory is absolutely at variance with previous scientific views (& apparently irreconcileable with them) & yet, when applied to the atom, leads to results which are borne out by experiment with extraordinary accuracy... Such a state of affairs, as you can imagine, is very exciting.'[25] Bohr ranged over such issues as the Correspondence Principle, the Zeeman effect, X-ray spectra and the orbits of electrons within the atom.[26]

As the Lent term drew to a close Stoner, despondent because of lack of progress, was also worried lest his DSIR grant should be terminated. He thus resolved to approach Rutherford after the Easter vacation in order to try to secure a continuation of his grant. Moreover, he sought a transfer to a project on X-ray absorption which he had formulated at Rutherford's suggestion. The aim of this project was to resolve problems raised by Bohr's quantum theory of the atom.[27] These problems had probably been suggested by Bohr's lectures earlier that year and by his reading of Sommerfeld's *Atombau und Spektrallinien*. Rutherford consented to this change in direction and also ensured the continuation of Stoner's grant. Thus by late July 1922 he forsook both Stead and thermionic tubes and turned his attention to X-rays, a subject which was not central to the Cavendish experimentalist tradition under Rutherford.

20 Diary, late December 1921: MS333/30.

21 Diary, 20 March 1922: MS333/32.

22 Diary, 7 June 1922: MS333/32.

23 ECS to parents, 26 February 1922: MS333/101.

24 G. Stead and E. C. Stoner, 'Low voltage glows in mercury vapour', *Proceedings of the Cambridge Philosophical Society* (1922–23), **21**, 66–74.

25 ECS to his parents, 12 March 1922: MS333/101; ECS's notes on Bohr's lectures: MS333/27.

26 ECS's notes on Bohr's 'The Quantum Theory and Atomic Structure': MS333/27.

27 'Autobiographical sketch', op. cit. (13), 33.

CONFLICTS WITH RUTHERFORD AND AN ELECTROMETER

The new project was attacked with great enthusiasm. Working alone Stoner built much of the apparatus himself and learnt the necessary practical skills. 'I have actually been using a plane and saw!', he wrote with pride to his parents.[28] He even found Rutherford 'quite affable'.[29] Reflecting on his new situation he wrote that 'there could be no better apprenticeship [in physics] than in attempting experimental research'.[30] This positive attitude did not last long, since working alone produced long periods of anguish and uncertainty, especially when his apparatus failed. Most fickle was a quadrant electrometer with an indicator needle suspended by an exceedingly fine quartz thread. The thread broke on numerous occasions. After one such accident Stoner wrote, 'Result of morning – 1 fibre (= 2/6) poorer... & very annoyed'.[31] After the needle was eventually mounted Stoner found, much to his chagrin, that the fibre failed to conduct electricity!

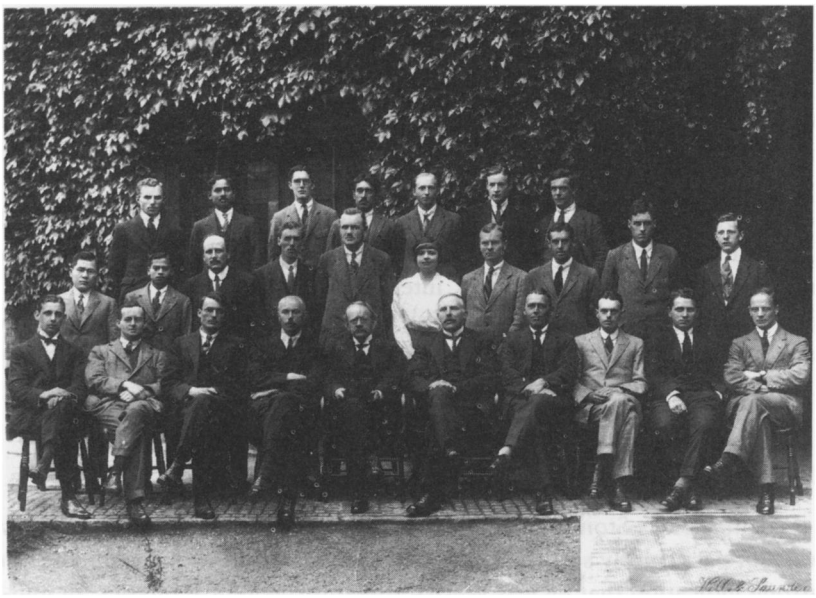
Stoner's conflict with his apparatus directly affected his relationship with Rutherford. In November 1922 he recorded that the 'great Rutherford came round on Tuesday, & talked, but he is not really very helpful. Although quite genial, he is very much the Professor'. Rutherford's irksome parting shot on that occasion was – 'You're getting on with the war. Of course you can't have [a] schol[arship] for gaining experience... but I'm not grumbling!'[32]

In the middle of February 1923, when Stoner's apparatus was least cooperative, Rutherford arrived with a distinguished visitor. Discovering how little had been achieved he commented disparagingly, indicating that if Stoner did not speed up his work, 'it will take you a lifetime before you get anything done'.[33] Although many Cavendish students appear to have coped with Rutherford's outbursts, such comments cut Stoner deeply. However, as he noted in a letter to his parents, Rutherford returned next day 'in quite an amiable mood. – He is a strange man.'[34] Shortly after this contretemps Stoner reviewed his career, expressing concern about his lack of progress and the uninspiring nature of his research. In that diary entry he raised, for the first time, the possibility of pursuing 'some successful theoretical work'. But, he added nonchalantly, 'I seem devoid of ideas.'[35] Some two weeks later Stoner was again depressed by another confrontation. Having reported the incident in his diary he assessed Rutherford as a

> blustering whirlwind, & unsympathetic, with a glaze of geniality. No doubt alright to really vigorous people, but good heavens...! Undoubtedly one of the great experimental physicists, & with wonderful insight, but a man one can hardly respect, & certainly cannot love.[36]

When writing this assessment Stoner lacked both physical and mental vigour. Always rather introverted and sensitive he found the winter of 1922–23 particularly trying, afflicted

28 ECS to his parents, 23 July 1922: MS333/101.
29 Diary, 10 October 1922: MS333/32.
30 Diary, 22 September 1922: MS333/32.
31 Diary, 17 February 1923: MS333/32.
32 ECS to his parents, 26 November 1922: MS333/101; Diary, 21 November 1922: MS333/32.
33 ECS to his parents, 15 February 1922: MS333/102; Diary, 15 February 1923: MS333/32.
34 ECS to his parents, 18 February 1923: MS333/102.
35 Diary, 21 February 1923: MS333/32.
36 Diary, 5 March 1923: MS333/32.



F.Madgwick. B.N.Banerji. H.D.Smyth. N.Ahmad. W.T.Gibson. L.L.Whyte. P.Kapitza.
Y.Nishina. A.C.Chakravarti. P.Mercier. J.Crackston. H.Robinson. Miss Taylor. E.S.Bieler. J.K.Roberts. P.M.S.Blackett. E.C.Stoner.
M.H.Belz. G.Henderson. D.A.Keys. F.W.Aston. Prof.Sir J.J.Thomson. Prof.Sir E.Rutherford. J.A.Crowther. G.Stead. E.V.Appleton. A.Muller.

Figure 1. Staff and research students at the Cavendish, June 1922. Reproduced with the kind permission of the Cavendish Laboratory, Cambridge.

by problems with his apparatus, his supervisor, and the debilitating effects of diabetes. He is certainly to be admired for his determination to lead a near-normal life at Cambridge while trying to control his disability. On almost every page of his diary he noted his blood-sugar level. An unsatisfactory result frequently correlated with depression and an inability to cope with external events. This correlation was strikingly evident in early 1923 when his troubles at the Cavendish were at their height. After several weeks of lethargy he contacted two Cambridge scientists working on insulin. Since insulin treatment was in its infancy and available only in hospital, he admitted himself for a course of treatment at Addenbrooke's Hospital in early March, thus providing a respite from Rutherford and his indomitable apparatus.

Although he later described his stay in hospital as 'frustrating and disappointing' and of only limited benefit in controlling his diabetes,[37] Stoner left Addenbrooke's at the end of June with a far more positive attitude towards both his research and his supervisor. His changed assessment was also partly due to Rutherford's increased interest in him, his work and his financial situation. As he wrote to his parents from hospital on 22 May: 'This

37 'Autobiographical sketch', op. cit. (13), 19.

afternoon – great event – Rutherford appeared. He was most affable, & talked on many topics, scientific & otherwise. Also he is going to send in an application for a grant for me for next year... So something has got a move on, & I feel rather pleased about that.'[38] Not only was Stoner impressed by Rutherford's kindness but his intervention with the DSIR ensured the continuation of funds. At that time his father was often out of work and his financial worries frequently intruded into his diary and correspondence with his parents. The situation was further exacerbated in the summer of 1923 because the DSIR had stopped his grant since his stay in hospital had exceeded the three-month statutory limit. Rutherford had, however, generously intervened by returning 4 guineas – Stoner's supervision fees for the previous two terms. 'I hope', wrote Rutherford in the covering note, 'that you are well enough to come back to work. Please let me know when you expect to come.'[39] A week later he was back at the Cavendish.

A CAREER IN THEORETICAL PHYSICS?

While in Addenbrooke's Stoner had again examined his future. Although acknowledging that he was not particularly skilled as an experimentalist, one of his meditations contains the first strong indication that he was veering towards theoretical physics. In mid-April he wrote: 'May achieve something ("physical" theory) if not too impatient, & think I could direct practical workers into fruitful channels.'[40] Soon after leaving hospital he began thinking about 'some Q.T. (momentum) considerations – Quite enjoyable'. On the facing page of his diary is further indication of a change in his agenda through increasing involvement in theoretical physics, which he saw as offering a potential career. After stating that his interests were so broad that he doubted whether he could accomplish anything, he added:

> The[se] interests are largely theoretical... I do not care much for making mechanical devices, for devising. So if I am ever to be successful in experimental research I must have some vigorous theoretical background to urge me on to the less welcome tasks involved... I think in Physics is my chief hope & aspiration; I can narrow down to Modern Atomic Physics, Radiation... but no more. In that domain I long to do some original theoretical work which I myself think important... to clear up the quantum-classical hopeless dilemma. I am convinced it can be cleared up... & I would like to do that.[41]

During his third year at the Cavendish Stoner read extensively in theoretical physics: diary entries refer to Sommerfeld, de Broglie, the controversy over Compton scattering, Kramers on X-ray absorption, Bohr on the periodic table, 'Pauli on free electron equilibrium' and many other key innovations in quantum theory. He attended a talk by Ralph Fowler, one of the few theoreticians at Cambridge, on spectra. He joined the select $\nabla^2 V$ club, where the speakers included Kapitza on quanta, and also the Kapitza club, a small group that formed round Peter Kapitza and met to discuss challenging problems in modern physics, especially theoretical issues.

38 ECS to his parents, 22 May 1923: MS333/102.
39 E. Rutherford to ECS, 2 October 1923: MS333/106; Diary, 3 October 1923: MS333/32.
40 Diary, 15 April 1923: MS333/32.
41 Diary, 13 July 1923: MS333/32. See also entry for 29 September 1923.

In his X-ray researches he was joined by Leslie Martin, who brought companionship but manifested an all-too-casual attitude towards work. Moreover, the apparatus again proved unreliable as the following diary entries (dating from between late October and early December 1923) indicate: 'The tube fil[ament] curr[ent] collapsed!' 'A dreadful day. Elec[trometer] ceased to work properly; batteries run down; general collapse. Tested. S[ugar] found!' 'Needle put on in lab. – but elec[trometer] still unsens[itive]. Why, heaven knows!' 'Later filament broke... What a life! Seldom have I known such a run of bad luck, & when it is accentuated by R[utherford]'s rudeness'.[42] By mid-November he had become convinced that 'Much of my time in the lab is sheer waste of time.'[43] Yet, despite these frequent set-backs and swings of mood he was generally in better spirits than during the previous winter, and his determination to complete the project rarely wavered. Yet he felt disinclined to continue with experimental physics after completing his research at Cambridge and often wondered what else he might do. He considered the possibility of writing about science for the general public, even writing the history of science, but seemed uncertain whether he could turn these interests into a remunerative career.

Being in a more stable frame of mind, he also found Rutherford less aggravating and on only two occasions did he briefly note Rutherford's displeasure at the slow rate of progress. Moreover, several diary entries indicate that Stoner now often found Rutherford's presence less threatening and even congenial: 'most genial... commented on my appearance – that I was looking well'; 'fairly hopeful report'; 'Ruth[erford] still affable.' When Stoner gave a talk on his work at the Cavendish he was complimented by Rutherford who also invited him to tea.[44] Even in the middle of his battle with the recalcitrant electrometer Stoner could write to his parents that 'Rutherford this term, has, I must say, so far, been very good, tho' progress has not been such as to inspire him at all to benignity.'[45] This was praise indeed.

Stoner's final two terms at Cambridge were particularly productive. Although problems continued to plague his experimental work, it progressed considerably as he raced to complete on time. Moreover, his relationship with Rutherford remained cordial and, towards the end of his final term, he commented: 'Reasonable talks with Rutherford even'.[46] On one issue there had been some disagreement, but no hard feelings. This concerned the rule, laid down by Rutherford, that work at the Cavendish must cease at 6 p.m. to enable research students to devote their evenings to reading, writing and, particularly, thinking. Stoner, however, wanted to work evenings during his final hard-pressed months. Moreover, evening work fitted his diabetic regimen better. When first approached on this matter Rutherford – 'like a bear' – refused, but he subsequently gave Stoner permission to work evenings.[47] This is an indication of growing self-confidence since Stoner could now stand up to Rutherford.

Returning to Cambridge for his final term Stoner expressed the hope that his health would improve so as to enable him to pursue active research in both experimental and

42 Diary, 31 October 1923; 13 November 1923; 17 November 1923; 3 December 1923: MS333/32.
43 Diary, 17 November 1923: MS333/32.
44 ECS to his parents, 28 October 1923: MS333/102; Diary, 9 and 22 November 1923: MS333/32.
45 ECS to his parents, 25 November 1923: MS333/102.
46 Diary, 20 June 1924: MS333/33.
47 Diary, 3 and 4 March 1924: MS333/33; ECS to his parents, 4 May 1924: MS333/103.

theoretical physics. Over the next few weeks his research on X-rays continued with a mixture of failure and success, but rather more of the latter. His reading also became more focused on the problems raised by the quantum theory of the atom. On 1 May he noted 'read Somm[erfeld]. on multipletts etc'.[48] Six days later he reported a useless interview at the Appointments Board and also a 'Talk to [C.T.R.] Wilson on Bohr's latest' paper.[49]

Then, on Saturday 10 May, a short period of intense creativity commenced. In a state of great excitement he wrote: 'Had no sleep until 6 a.m.!! Wild thoughts of atomic electronic structure, quantum numbers, intensities of lines... & thought whole business solved! Very excited... Tired... at lab. little done'. His flight into atomic theory continued into the following day: 'A day of great theoretical excitement – almost too great, but most excellent. Class[ification]. of at[omic]. levels, Zeeman effects etc. etc. To bed late'. By contrast with these two days' excitement and inspiration, Stoner's next diary entry – for 12 May – was a laconic 'Usual'.[50] In just one weekend's frantic theorizing Stoner had engaged some of the major issues of contemporary theoretical physics. As he noted on the following Saturday, 'This week I really have had quite [*sic*] an exciting time scientifically, & tho' I have found most of my new ideas anticipated, yet one is on the right lines... Ideas on Zeeman effect take form; distrib[ution]. among levels etc. I must carry on!'[51]

Unable to contact Rutherford immediately, Stoner left a note for him outlining his new scheme for electron orbits. Presumably realizing that comments from a theoretical physicist were required, Rutherford subsequently passed the note to Fowler. During the following week Stoner discussed his ideas at length with Fowler, who encouraged him to publish them. Given Stoner's reticence it is perhaps not surprising that in his letters to his parents he made only passing reference to this burst of theoretical activity in mid-May, referring to it as 'some rather amusing, if slight, theoretical speculations'.[52] Only in a letter dated 25 July – that is, after he had been offered the position at Leeds – did he inform them in a mock-humorous manner: 'I have been having a most hectic time trying to write up an epoch-making (!??) paper, of which you will have the benefit in the effect it has produced on me – but it has been quite amusing.'[53]

The paper that was published in the October issue of *Philosophical Magazine* under the title 'The distribution of electrons among atomic levels', tackled a problem central to Bohr's atomic theory[54] and proved almost epoch-making.[55] Bohr had postulated that in the atom the elliptical paths of electrons are to be described by two integer quantum numbers: n, indicating the length of the major axis of the ellipse, and k, signifying its eccentricity.

48 Diary, 1 May 1924: MS333/33.

49 Diary, 7 May 1924: MS333/33. The paper referred to was probably N. Bohr, H. A. Kramers and J. C. Slater, 'The quantum theory of radiation', *Philosophical Magazine* (1924), **47**, 785–802.

50 Diary, 11 and 12 May 1924: MS333/33.

51 Diary, 17 May 1924: MS333/33.

52 ECS to his parents, 11 and 14 May 1924: MS333/103.

53 ECS to his parents, 25 July 1924: MS333/103.

54 For Bohr's theory of the early 1920s see the documents included in *Niels Bohr Collected Works: Volume 4, The Periodic System (1920–1923)* (ed. J. Rud Nielsen), Amsterdam, 1977, especially N. Bohr, 'The theory of spectra and atomic constitution', ibid., 257–328, which is fairly close to the lectures Bohr delivered in Cambridge in March 1922 (MS333/27).

55 E. C. Stoner, 'The distribution of electrons among atomic levels', *Philosophical Magazine* (1924), **48**, 719–36. See also Heilbron, op. cit. (10).

TABLE II.—Suggested Distribution of Electrons.

[The distribution of electrons in the atoms is given by the part of the table above and to the left of the thick lines]

Element.	Atomic Number.	Level (n).	Sub-Level. (k, j.) I 1,1	II 2,1	III 2,2	IV 3,2	V 3,3	VI 4,3	VII 4,4
He	2	K (1)	2						
Ne	10	L (2)	2	2	4				
A	18	M (3)	2	2	4	(4	6)		
Kr	36	N (4)	2	2	4	(4	6)	(6	8)
Xe	54	O (5)	2	2	4	(4	6)		
Nt	86	P (6)	2	2	4				

Figure 2. Distribution of electrons proposed by Stoner in 1924. Source: E. C. Stoner, 'The distribution of electrons among atomic levels', *Philosophical Magazine* (1924), **48**, 722.

Moreover, k could take any value between 1 and n. Stoner criticized Bohr's theory for its incompleteness and its 'somewhat arbitrary' symmetry postulates. Also highly problematic was the third (inner) quantum number j, which Sommerfeld had introduced to classify multiplet spectra. However, as Stoner noted near the beginning of his paper, no consistent interpretation existed for relativistic doublets in X-ray spectra. The work of De Broglie and Dauvillier[56] had challenged part of Bohr's scheme but it seemed to Stoner that these authors had introduced an arbitrary assumption about the number of sub-levels. Moreover, their scheme wrongly predicted the number of X-ray absorption edges. Stoner also engaged the anomalous Zeeman effect, which he considered to be of magnetic origin and dependent upon the inner quantum numbers.

In his paper Stoner concentrated on the significance of j, and classified each electron orbit by n and the sub-levels by both k and j. He also proposed that the number of possible orbits for n_{ij} electrons is $2j$ (i.e. twice the inner quantum number). Figure 2 shows the resulting distribution of electrons – being above and to the left of the thick lines for the

56 L. de Broglie and A. Dauvillier, 'Le système spectral des rayons Röntgen et structure de l'atome', *Journale de Physique* (1924), **5**, 1–19.

elements listed. The maximum number of electrons associated with a given n can then readily be calculated (viz. $2\Sigma_{k=1}^{n}(2k-1) = 2n^2$), as can the total number of electrons required to fill the orbits 1 to n. For example, with helium two electrons fill the K level ($n = 1$); the remaining eight of neon's ten electrons fill the L level ($n = 2$; $2n^2 = 8$). When $n = 3$, $2n^2 = 18$: of these eighteen, eight complete the third period in Mendeleev's table (as with argon), the remaining ten contributing to the transition metals of the fourth period. Stoner also suggested how this scheme could account for the intensities of X-ray lines and X-ray absorption, as well as magnetic, chemical and optical properties.

Stoner's theory for the distribution of electrons was rapidly hailed as a major innovation. Sommerfeld praised it in a letter to Fowler and incorporated Stoner's views in the fourth edition of his *Atombau und Spektrallinien* (1924). Soon letters and reprints began to arrive at Leeds from leading scientists throughout Europe.[57] Stoner was now a player in the international league of quantum theorists. However, his glory was short-lived. With characteristic brashness and incisiveness Wolfgang Pauli transformed Stoner's innovative scheme by omitting his hard-won inner quantum number, j. Stoner's theory thus came to be eclipsed by the neatly-formulated Exclusion Principle bearing Pauli's name.[58]

EPILOGUE

The preceding interpretation of Stoner's transition from an undergraduate in the Cambridge mould to a theoretician pursuing independent research in Leeds stresses the importance of financial pressures and career motives, together with his physical and personal difficulties. But there is a further and parallel aspect of his biography that requires attention since during the period 1921–24 Stoner also undertook an emotional odyssey fraught with danger, hope, frustration and torment. During his three-year apprenticeship at the Cavendish not only did he construct apparatus, imbibe contemporary physical theory and expand his knowledge of the physical universe, but he was also forced to confront himself. This was a profound and often searing emotional experience for Stoner. Even as the year 1924 ended he characterized his *annus mirabilis* as 'all ups & downs. Optimism & gloom'.[59] In adopting what Thomas Söderqvist calls 'an existential approach' to biography, I shall briefly draw attention to some aspects of Stoner's self-understanding as recorded in his diary during his time at the Cavendish.[60] These aspects can also be seen mirrored in his evolving relationships with both Rutherford and physics.

57 ECS to his parents, 19 October 1924: MS333/117; ECS to A. Lande, 24 October 1924: Archive for History of Quantum Physics; A. Sommerfeld, 24 February 1925: MS333/126; L. de Broglie to ECS, 1 May 1925: MS333/126. See also D. Coster to N. Bohr, 7 December 1924; N. Bohr to D. Coster, 10 December 1924: *Niels Bohr Collected Works*, op. cit. (54), 679–81.

58 Heilbron, op. cit. (10).

59 Diary, late December 1924: MS333/33.

60 T. Söderqvist, 'Should scientific biography be an edifying genre? Towards an existential approach to science biography', in *Telling Scientific Lives. Studies of Scientific Biography* (ed. M. Shortland and R. Yeo), Cambridge, forthcoming. A version of this paper was delivered at the Anglo-American Joint Meeting held in Toronto, July 1992.

One key to understanding Stoner's inner self is to be found in the following diary entry: 'Read Barb. diary & amazed how accurately he describes some of my own (everybody's) experiences.'[61] The 'diary' he had been reading was an autobiographical novel entitled *The Journal of a Disappointed Man* by W. N. P. Barbellion, a pseudonym for Bruce Frederick Cummings, a naturalist who died in 1919 at the early age of thirty-one.[62] Stoner identified with the central character – a poor, struggling naturalist, trying unsuccessfully to come to terms with himself, with illness and with others, while attempting to make his way in the world. The story engrossed Stoner, who read Barbellion's unhappiness and insecurity into his own situation. He even planned an 'Idea for a story. The escape of the introvert (Barb[ellion], myself) as a result of a pos[itive]: phil[osophy]'.[63] Many of Stoner's diary entries dealing with career failure and the unfulfilled promise of youth read like passages from *A Disappointed Man*. Like Barbellion, Stoner perceived himself as an introvert who was physically ill, enfeebled, frequently uninspired and lacking energy. Moreover, he often worried about his psychological condition: 'I find I am in a continuous state of tension – nerves – as though no time for anything.'[64] He was, moreover, troubled by his inability to settle down and concentrate on any single topic. With this self-diagnosis, his life at the Cavendish must often have proved a torment.

When his research was progressing well Stoner could claim that he was 'thrilled' with physics. Frequently, however, such positive thoughts deserted him. Yet amidst his gloom he could often summon great determination – what he called his 'positive philosophy' – to overcome his physical illness and his lack of vigour. The will to succeed was considerable. 'Wish I was thoroughly well & vigorous... but I will triumph eventually'; 'Feel that I ought to be able to do something, that I *can*, yet somehow don't. Perseverance & persistence are necessary.'[65] Impelled by an exaggerated puritan ethic, which was not shared by his co-workers Stead and Martin, Stoner believed he could overcome his difficulties by hard work. While the possibility of failure evoked the deepest terror, success in physics was his oft-stated goal.

Yet physics also imposed great constraints on life and, at one level, threatened his being. On a loose sheet he copied the following passage from *A Disappointed Man*, which exemplified his own existential condition: 'Surrounded by all the stimulating environment of scientific research, I am cold and disdainful. I keep up the old appearances but underneath it is quite different. I am an *hypocrite*... finding the part more difficult to bear... My career! Gadzooks'.[66] Like Barbellion he perceived that the single-minded prosecution of research in quest of a career was blocking the development of his own personality. Moreover, he recognized that science was in conflict with his aspirations for meeting and developing relationships with women. Even while an undergraduate he symbolized this conflict in a sketch for a novel entitled 'The Scientist', in which the leading character is torn between science and his love for a woman ('B'). However, another

61 Diary, 10 January 1924: MS333/33.

62 W. N. P. Barbellion [B. F. Cummings], *The Journal of a Disappointed Man*, London, 1919. H. G. Wells wrote the Introduction. See also R. H. Hellyar, *W. N. P. Barbellion*, London, 1926.

63 Diary, 10 January 1924: MS333/33.

64 Diary, 4 November 1923: MS333/32.

65 Diary, 5 December 1923; end December 1922: MS333/32.

66 Barbellion, op. cit. (62), 73. Copied on a loose sheet of paper: MS333/32.

man captivates 'B', who subsequently dies, presumably leaving the scientist free to return to his true love.[67]

A further recurrent tension manifested in Stoner's diary was between the narrow specialism of physics and the numerous other possibilities that life had to offer, but could not be realized while he resolutely pursued scientific research:

> I have a longing to write... I want to write not only about science & physics... but also about life... in essays, novels & plays. Then I want to live... to experience all the rich possibilities... [Can I] be a specialist, & escape the specialist shell; a universalist & avoid 'evaporation'; a scientist... & an artist? Practically should I give up literary hankerings entirely & devote all energy to Physics?[68]

Despite such meditations, the practical option triumphed. Yet his single-minded pursuit of science was the source of a deep existential frustration that was only partly resolved through his voracious appetite for books, particularly novels.

Not only financial insecurity but – more importantly – Stoner's inner drive kept him at the laboratory bench every day, determinedly fighting electrometer fibres and the numerous other problems posed by his experimental research. While such work was often joyless and boring, physical theory increasingly provided a stimulating alternative. Through the study of quantum theory Stoner transcended the mundane realm of severed electrometer fibres and instead engaged the delights of pure thought. For, despite his avowed insistence that the theoretician should pay close attention to experimental results, he derived considerably more emotional satisfaction from theoretical physics than from experimental investigations. Moreover, the freer but lonelier life of a theoretician suited him temperamentally far better than the experimentalist's life in a laboratory. By the time he published his 1924 paper he was no longer a marginal man in the Cavendish, but could pursue his investigations in seclusion while maintaining contact with Fowler and a few others mainly through correspondence.

Most importantly, the new life he had carved out for himself freed him not only from the Cavendish but also from Rutherford. He had never felt comfortable in Rutherford's company; indeed, he had often found Rutherford's presence threatening, even destructive. He had never been one of Rutherford's 'boys'. However, by the close of 1924 he was no longer dependent on Rutherford, nor did he have to live in Rutherford's shadow. Instead he had secured his freedom by becoming a theoretical physicist at the University of Leeds.

67 Diary, entry facing 13 April 1921: MS333/30. Two other entries for 1921 are also relevant: one is an attack on single-sex schools (like Bolton Grammar School) which prevent young men and women forming friendships; the other deals with the fulfilment of the individual through marriage. In 1951 Stoner married Heather Crawford, secretary in the Department of Physics at Leeds University.

68 Diary, 29 September 1923: MS333/32.