ORIGINAL PAPERS

BY

JOHN HOPKINSON

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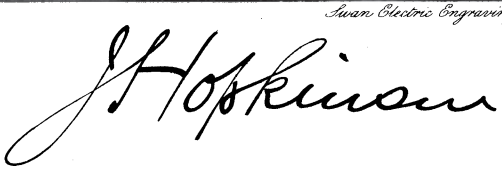

ORIGINAL PAPERS

BY THE LATE

JOHN HOPKINSON, D.Sc., F.R.S.

VOL. I.

TECHNICAL PAPERS

EDITED

WITH A MEMOIR

BY

B. HOPKINSON, B.Sc.

CAMBRIDGE:
AT THE UNIVERSITY PRESS.
1901

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107455986

First published 1901
First paperback edition 2014

A catalogue record for this publication is available from the British Library

ISBN 978-1-107-45598-6 Paperback

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* Now the Institution of Junior Engineers.

PORTRAITS.

EDITOR'S NOTE.

WITH the exception of the Memorandum on Engineering Education, the whole of the papers here reprinted have been published in various periodicals and books, and I have to thank the owners of the copyrights for permission to republish them. Dr Hopkinson issued a reprint of certain of his papers in 1893*, and intended to publish a complete collection. I have endeavoured in this reprint to carry out his intentions as to editing so far as they could be ascertained. In a few cases I have copies on which he noted certain omissions as desirable; in others I have had to use my own judgement as to what he would have done. The omissions on the whole, however, are few; and the papers for the most part are reprinted just as they appeared with obvious corrections. Vol. I., roughly speaking, contains the papers on technical subjects, and Vol. II. those of a more scientific character. The papers fall naturally into groups based on their subjects, and have been so arranged.

I have to thank Mr G. T. Walker, Fellow of Trinity College, Cambridge, for kindly reading the Mathematical papers at the end of Vol. II. for me.

* "Original Papers on Dynamo-Machinery and allied Subjects." Whittaker & Co.

MEMOIR.

THESE volumes contain all that John Hopkinson wrote of an original character on Engineering or Scientific subjects. They form a record of his career to which little can be added. His practical inventions, and certain parts of his constructive engineering, however, are not directly illustrated in them, and a short account of these may perhaps enhance the value of the book as a memorial. It is also desirable from this point of view, as well as interesting as a matter of history, to trace the influence of his work on the development of the Arts and Sciences with which it dealt. There have been few men in whose minds the spirit of scientific research has been so closely associated with the power of practical application as in Hopkinson's. His scientific work was always informed with a desire to satisfy practical needs, without being unduly cramped thereby. Thus, while in many cases it resulted in rapid Engineering advance, it also exercised a great influence on methods of research. It was conceived in sympathy with practical aims and practical men's ideas and yet it did not cease to be pure and disinterested seeking after knowledge. To those who know his work in only one of these aspects, a connected account of it showing something of the other may be acceptable; and finally, a little should be said of his education, which was in many ways remarkable.

To give much more than this in the way of biography is hardly possible. John Hopkinson's life had few features of interest for the general public: this is, perhaps, inevitable of one whose work dealt with natural and not with human forces.

In the relations with the world of a statesman or a soldier personality is all-important and feeling may be a very powerful factor. It is therefore of interest, after his death, to know the emotional as well as the rational side of his nature, and there is justification for revealing it by a detailed account of his private life. With an engineer it is different. If a man would command Nature, emotion is out of place; and the more he can efface himself and become a thinking machine, the more likely he is to succeed. Hopkinson had this power in an uncommon degree; once in his office, his reasoning faculty asserted itself to the exclusion of all others. It is true that he could command not only the respect, but the love, of those who served him, so that they worked for him as they would for few. But this power was accompanied by no feeling on his part, and, though it was doubtless due to a subtle influence which could not have been exercised by one of less perfect character, it may be said broadly that a very great part of his personality found no expression in his work and therefore does not concern the public. There seems, in his case, to be no excuse for revealing in its entirety after his death, what in life he did not reveal. He was the most reserved of men, and only his family knew him intimately.

Another cause would make it difficult—if it were desirable—to write an interesting life of John Hopkinson. It sometimes happens in a great man's career that the whole force of his nature is pitted in a struggle with adverse circumstances. Such occasions form the most valuable items in biography. But they depend for their interest on the sternness of the struggle no less than on the might of the combatants. It is something for the biographer to be able to say that his subject overcame such and such things: it is far more if it can be said that he only just overcame them. Of strife of this evenly-balanced kind there was none in John Hopkinson's life. He had his battles to fight like other men, and against odds that lesser minds could not have faced. But the issue never seemed in doubt; he always won with an unknown reserve in hand. From contemplation of what he did, one can infer no limitation to

his powers. And in such limitation centres no little of the interest of biography, for upon it depends in large measure the sympathy which the reader may feel for the subject. In consequence, too, of his freedom from disappointment, Hopkinson changed remarkably little after early manhood. In most lives adversity comes in plenty and leaves its mark—good or bad—upon character: none came to John Hopkinson. For twenty-five years the only change in him was a gradual and unresisted expansion. As he came to feel his strength his power of expression grew, and with happy family life his sympathies widened: in other ways he altered little. Reading the letters which he wrote long ago from Cambridge and Birmingham, on the threshold of his career, one seems to see the same man in all essentials whom one knew quite recently. I feel, therefore, that it will suffice for the non-technical part of this introduction if I can give a short account of him as he was then, and of how he came to be so. This course is possible because biographical material is fairly plentiful during the first thirty years of his life. His letters reveal far more of himself then than later, when they came to be mere records of passing events, given without comment and affording but little clue to the state of mind of the writer.

John Hopkinson was by birth and breeding a North-countryman. His mother—born Alice Dewhurst of Skipton—was of a family which has occupied a leading position in that town for several generations. Her father was the founder, and her brothers for long the heads, of the successful cotton-spinning factory which bears their name. Mr Dewhurst, John's grandfather, was in many ways an ancestor to be proud of. In early life he suffered much trouble in the death of his wife and all his family; but he married again, and had many children. One can infer that he possessed much of the immense vitality and energy which distinguished his grandson. As John knew him, he was a fine old Yorkshireman, impetuous, even fiery, but possessed of the kindest of hearts. He was much troubled with rheumatism, but he fought his malady with the most indomitable courage and tenacity. His grandson had a vivid

recollection of his hobbling round his garden, determined not to give in to his infirmity. He had strong religious views, and brought up his children on nonconformist principles which they taught with undiminished vigour in their own families. The spirit, if not the form, of his fine puritanical creed lives in many of his descendants to-day, and in none is it more apparent than it was in John Hopkinson. It was the expression of a sturdy independence of character, and it taught an almost stern devotion to truth and duty. These were the qualities which Alice Hopkinson learnt from her father and passed on to her son. Of the narrowness which sometimes marred the nonconformist faith in those days there was none in her teaching. Thus it was, that though John Hopkinson in part rejected the form of her creed, he was able to keep its essence, and this slight divergence never affected the sympathy between him and his mother. To the end of his life it remained, a perpetual joy to both of them.

John Hopkinson's father, now Alderman Hopkinson of Manchester, was born in Lancashire and began life as an apprentice in the firm of Wren and Bennett, manufacturing engineers. In this concern he became a partner, held that position until 1881, and then devoted himself exclusively to consulting work. He was interested in several coal and iron enterprises and has been for many years Chairman of the Carnforth Iron Works. He has made himself an honoured name in connection with the affairs of his native city; his membership of the Council dates from 1861 and he was Mayor in 1882. As an engineer, he was brought up in a school in which practical experience was regarded as the one essential to success: but though in the first place practical, he had a remarkable sympathy with scientific development. His training made him attach much importance to precedent; but if conservative, he was by no means conventional in his ideas. He had much of the independence which so distinguished his eldest son. Especially was this the case in matters relating to the education of his children. In sending John to Cambridge while intending him to be an engineer, he went contrary to all

the traditions as to technical training in which he had been brought up.

It is inevitable that in the first few years of childhood the mother's influence should be the more potent; and this was doubtless the case with John Hopkinson, though less so than usual: Mr Hopkinson, more than most fathers, made companions of his children, and John, the eldest, was constantly with him from a very early age. He was a teacher of exceptional ability, and during the long rambles in the Lake District and Wales and the visits to the Works when he accompanied his father, John must have learnt something of his powers of observation and have acquired some of his bent towards engineering and scientific pursuits. A singularly complete education rather effaced the surface effects of these early years, and it is perhaps difficult to find indications of their importance for those who have only known John Hopkinson as a man and have never known his parents. Others more fortunate, who have seen Mr Hopkinson with children even in his old age, will be able to form some idea of his relations with John at a time when the father was full of youthful vigour and the son a bright and healthy boy, eager for information on all going on around him. Though the first-born was naturally the most favoured one, all the family shared in the advantage of having such a father. Of the five sons, three, including John, became engineers of distinction. A fourth, Albert, is a doctor of medicine in large practice in Manchester. Alfred, who was second in order of age, became Principal of Owens College in 1898 after a successful career at the Bar and in Parliament. Such diverse successes in one family must be largely due to home influences; to the father is to be ascribed the aptitude for scientific and practical pursuits which has been so apparent in four of his sons and most of all in the eldest.

After a short time at a day-school near his home, John was sent to Lindow Grove in Cheshire. This school was then in the hands of a Mr Satterthwaite; but, in the summer of 1861, it passed into those of Charles Willmore, who, for some years after this, had charge of John's education and undoubtedly

exercised great influence upon him. His views on the training of boys were remarkable and are worth quoting here, as they furnish the key to much in John Hopkinson's early training. In a letter written to him in December 1866, Willmore says:—"I greatly object to long hours of study for boys. I have a great belief in the physical development being the main thing till the time a boy leaves school; that is—for what I have just said might be misinterpreted—that any intellectual advance at the expense of health is very dearly bought." These doctrines he practised consistently without much regard for what the world thought of them. The school was situated in fine country and the boys were encouraged to spend much of their time out of doors. Thus the taste for open-air pursuits which Mr Hopkinson had given to John was further strengthened by his school-life, and this was beyond question the most important feature of that part of his education: its effects never left him. Throughout his life he rejoiced in exercise and fresh air beyond all things. As he himself put it, Willmore taught him the "self-regarding virtues," and that, in his case, put all the other teaching in the shade, good though it was. But for his healthy tastes, his rather delicate body could hardly have carried "that most fiery spirit." Of course he might have acquired them at one of the Public Schools—though there were not so many of them in country districts then as there are now. But it must be remembered that John Hopkinson did not belong to the class from which Public School boys are drawn. His father intended him to be an engineer; he had neither the inclination nor the means to let his son spend five years in enjoying himself and learning Latin verse at Harrow or Rugby. It was necessary that he should get as much knowledge of a useful kind as possible in the short time available before taking to business. Willmore was almost alone among schoolmasters in seeing that, even for boys of such a class, health and healthy tastes were more necessary still; and in acting on his belief. Unfortunately, parents did not all show such wisdom as Mr Hopkinson did, and realise the soundness of these views. Willmore's firm stand against all manner of cramming and excessive study for

examinations, perhaps cost him many pupils; but he never wavered from it and it has set an honourable and distinctive stamp upon his work.

So it happened that John Hopkinson had a thoroughly good time at school. Without being precocious, he had more than common intelligence and was able, without great difficulty, to hold his own with his schoolfellows at their lessons. The atmosphere of his home gave him a tendency to hard work; but he was by no means a book-worm, and had much time and energy to spare for enjoying life. One letter, written from Lindow Grove, may perhaps be quoted here: it gives an idea of what he was like—shows that he already had a sturdy, independent character:—"There was a row yesterday about jumping over the farmer's bank; after all, though, we have paid very cheap for the fun. The farmer, when he caught them, used all sorts of imprecations at them; he said if he ever caught them again he would take them to Macclesfield. I was not in the party that he met. I do not believe that he would have told if it had not been that when he shouted most of the boys of our party ran. I did not. I think if we had walked away quietly, he would have been satisfied, but as they ran he thought that we meant it to annoy him. We had a very great deal of fun, and we only got stopped going walks."

In 1864 Mr Willmore left Lindow Grove and became headmaster of Queenwood in Hampshire. John and some other boys accompanied him thither. The school was situated in wild and beautiful country on the confines of the New Forest. No better place could be found for carrying out Willmore's ideas of education. Unfortunately, discipline had been rather slack under his predecessor, and he had at first to be rather strict. John's letters were mournful for the first few weeks because he could not go for long walks in the surrounding country; he evidently felt this restriction deeply; but it was soon relaxed and then for a year his life was more enjoyable even than at Lindow Grove. Mr Willmore says that he developed greatly at this time both in body and in mind. He was great at bird-nesting and would go about it with much energy and daring, climbing the highest forest trees

in search of eggs. Then in summer there were hornets' nests to be taken and butterflies to be caught. He used to tell a story of how he once caught some hornets for one of the masters. The insects were duly presented, shut up in a bottle: the master expressed a hope that "the cat's paw wasn't burnt." "No," said John, "and I hope the monkey's mouth won't be"; a retort of which he was always very proud. Similar touches of humour abound in his letters. He seems to have shown a decided bent for mathematics while at Queenwood. He was, in fact, rather beyond the teaching provided in this subject; though it was probably much better than could be found in most schools of the same class. He also received a fair grounding in Chemistry. In its teaching of Science, though it was rudimentary compared with what one finds now, Queenwood was almost unique at that time. Among its masters, it had counted Tyndall, Frankland, and Debus.

One may fittingly close this sketch of John's time with Willmore by giving his own views of it. They are recorded in a speech delivered at a dinner given by old Queenwood boys in honour of their schoolmaster. He says, referring in half-serious spirit to the virtues which they owed to Mr Willmore:—"I will confine myself to one virtue, yielding in importance to none, one which I suppose moralists would class as a self-regarding one, one which has not received a place in systems of ethics—I mean that of obtaining through life such enjoyment as it is capable of affording. As far as I can remember, Mr Willmore did not inculcate this virtue upon us, but I am bound to say that he gave us every opportunity of practising it, and he was never better pleased than when he saw us practising it with reasonable discretion.... I am sure that if it were possible for one of us to do a thing that was mean or shabby, one of the greatest deterrents to his being guilty of it would be to remember the burning scorn with which Mr Willmore would have regarded anything of the kind when he was at school."

Early in 1865, when he was 15½ years of age, John Hopkinson began his student days at Owens College. At that time the education furnished by Owens was the nearest approach there was to what is now considered the proper training for an Engineer.

Cambridge had not yet awakened to her responsibilities in this respect and the more old-fashioned engineers thought that their sons should go into the shops at fourteen. Owens aimed at replacing the first three years of an engineer's "time" with a more liberal and wider education than could be found in the workshops. The spirit of the place was much the same as it is now, though the appliances for teaching were far less elaborate. If the great laboratories which are now the pride of the College were not yet made there was plenty of experimenting for lecture purposes within its walls. There (and at that time only there) the best of teaching in experimental science and in engineering subjects was combined with pure mathematics and other studies of an academic character. Sandeman, the purest of pure mathematicians, of whom it is said that Hopkinson was the only man who ever understood his lectures, Barker, more practical but still a typical senior wrangler, taught under the same roof with Roscoe and Schorlemmer the chemists and Clifton the physicist. These were the men who were Hopkinson's teachers just at the time when his studies were becoming important. He soon began to impress them with his ability. He showed up ahead of his fellow students in the College competitions from the first; even in German he got a certificate—evidence of general power, but not, I fear, of lasting proficiency. It was his mathematics which won his successes; he did not care for and could not remember the long string of facts, which then formed so large a part of chemistry; but he could do *sums*—a power rare among chemistry students, and therefore liberally rewarded with marks.

Hopkinson's examinations and his success therein were a somewhat remarkable feature of his life. They began with the Dalton scholarships in 1867, in which year also he matriculated at London University (coming out ninth in the Honours Division), and continued almost without intermission until he took his fellowship at Trinity in 1871. His first attempt was for a small exhibition at Owens in 1865 and it failed because he worked too hard in preparing for it. This little disaster, taken very seriously at the time, gave him a horror of cramming which never left him. In certain subjects, such as Botany, which were out of his line, but

of which regulations required that he should show some knowledge, he would occasionally condescend to it, but in Mathematics and Physics he regarded it as quite useless even for the immediate purpose of impressing an examiner. Thus his academic successes were a real index of his remarkable quickness of mind and not, as is so often the case, merely evidence of a good memory and of great industry. He hardly ever missed being first in a competition in which he was seriously interested. Few men have made so large a sum as he did in this way: none have repaid it more fully to the world.

While at Owens, Hopkinson lived at home. His brothers were then, as they always remained, his principal companions; and he had few other intimate friends. John Hopkinson took a high view of his responsibilities as eldest son and at quite an early age he began to assist in teaching the younger members of the family. When they grew older they followed in his footsteps. Everything that he did, and especially new departures, such as going to Cambridge, had far-reaching effects as an example to his brothers. His brilliant success in all that he undertook gave them confidence in following him. Later still, when he came to occupy an influential position, he helped them in every possible way. He had very strong clan feeling, based no doubt partly on sentiment, but largely also upon knowledge of the power of a united and able family. In recent years this appeared even more in his relations with his own children. That which made him an ideal elder brother made him also a perfect father.

This is perhaps the place to say something of Hopkinson's life in the mountains, for it was there that his friendship with his brothers, and later with his children, found its most perfect expression. Reference has already been made to his tree-climbing proclivities while at school. During the vacations at Owens he began to find more magnificent game in the hills. The expeditions in North Wales and the Lake District were probably not so sensational as they afterwards became, but in the course of their long tramps the brothers must have come across many pieces of scrambling which would test steadiness of head and sureness of foot. Rock-climbing is probably the finest of all

exercises in the variety of its demands upon bodily activity; and his apprenticeship in the art did much to consolidate Hopkinson's frame. He was of a very spare and wiry build with a long reach. When at the height of his powers few men were his equal upon difficult rock. It was not till comparatively late in life that he took to mountaineering as a sport, but when once he had tasted its joys he cared for no other recreation. His first visit to the Alps was in the Autumn of 1871 just after he left Cambridge, but the fascination of the snows apparently did not seize upon him then, and it was not until some years later that he began to spend his summer vacation there regularly. He reached the zenith of his strength and activity when he was about forty years of age. At that time he was a truly magnificent sight upon a mountain. I have seen him ploughing through soft snow up to his waist on the slopes of the Aletschhorn and tiring out men ten years his junior who had but to follow in his tracks. On other occasions he would lead, carrying the day's provisions, over rocks where his companions could scarcely follow him unloaded. He seemed to need no sleep, he would do two long ascents in consecutive days, and enjoy both thoroughly. He and his brothers soon got beyond the powers of the average Swiss guide. I remember several occasions in which we took one to make up our party, but it was always a failure; the poor man was too slow and generally had reason to regret his job, for my father was exceedingly impatient of being kept back. He took pleasure, but to no inordinate degree, in making new ascents; his sentiment in the matter was much the same as in scientific discovery. In the one case as in the other, he cared quite as much for his own feeling that he stood where no man had been before, as for public knowledge of that fact, and despised all squabbling for priority. The fascination of the sport for him perhaps needs no explanation; nothing else within his reach could seize his attention and require the exercise of all his bodily and mental faculties. If he rode on horseback, his active mind was always occupied with some point in his work. Golf, shooting, fishing had no attractions for him. Nothing seemed to serve him as a holiday and set him up for the next year's labours except a month in the

Alps. Though it was the immediate cause of his death I cannot regret that he was a mountaineer, for it was in the Alps that one came to know him best. There alone the enthusiasm and poetry in his nature would blaze forth unrestrained.

Mr Hopkinson intended that his eldest son should join him in his own works and to that end would probably have put him to practical work in the shops on his leaving Owens: he certainly had no thought of sending him to Cambridge. In those days a Cambridge education was considered to be waste of time for an engineer. The successful members of the profession had had no such education themselves; many of them had started as common workmen. The consequence was that most engineers, including John Hopkinson's father, did not even number College men among their acquaintance, much less thought of sending their sons to a University. The initiative in Hopkinson's case came from the boy himself. Young though he was, he had remarked that the engineers of the time suffered from the narrowness of their training. They began with practical experience, and if they kept pace at all with the developments in their Art following in the wake of science, they had to learn that science late in life. John determined that he would reverse the process and devote some time to the study of science before beginning to practise. Mr Willmore seems to have been the first to hint to him and to his father that he might score academic successes in a wider field than Owens. It was, however, principally due to Professor Barker that the idea of seeking at Cambridge his engineering education took definite shape in his mind. It was Barker's advice and encouragement which led him in the spring of 1867 to enter for a Mathematical Scholarship at Trinity College. He was first among some thirty competitors. His success settled any doubts which his father might have felt and in October of the same year he began his University life.

The Trinity Scholarship examination was the first in which Hopkinson met men other than his fellow-students at Owens. Among his competitors were of course some of the best of his year at Cambridge. His success in it therefore established his reputation for ability in a wider circle than Owens College,

and he added to it by his performance in the First B.Sc. Examination, at London University. Then as now, this competition, owing to its high standard and the emoluments associated with it, attracted the best Cambridge mathematicians in their first and second years. Among those who were in the honours division about this time were Moulton and Harding—senior wranglers—and W. K. Clifford, who was second in the Tripos. Hopkinson was beaten for the Mathematical Exhibition by Pendlebury, who was a year senior to him at Cambridge and was subsequently senior wrangler, but he obtained sufficient marks to qualify for it and won the exhibition for Natural Philosophy and Chemistry. It is therefore not surprising that when he went to Cambridge he was already regarded as the probable senior wrangler of his year. For private tuition, he went to Routh, who had for some years held the first place as mathematical coach. His academic career was much like that of other men destined to be senior wrangler, though it was more than usually free from failures. He took in succession the Sheepshanks Exhibition, the Scholarship in Mathematics at London, and all the other honours and emoluments which fall to the lot of the first mathematician of his year at Cambridge. It is unnecessary to catalogue them here; they can be found in the University Calendars of the time. Perhaps, however, the Whitworth Scholarship deserves more particular mention. These scholarships were founded with a view "to the promotion of engineering and mechanical industry in this country." The examination was largely of a practical character and Hopkinson's success in it is a reminder that in his academic surroundings he did not forget what he had learnt in his father's works. Indeed he was in the habit of spending a large part of his vacations there, an excellent corrective to the Cambridge of those days with its horror of all things technical.

To one who is not specially interested in his Engineering work, Hopkinson's time at Cambridge and a few years after is probably the most interesting part of his life. At school and at Owens he was but a clever boy with few distinctive features except such as appear in his class-lists. Having regard to what he became, the process of his education is of interest; but his

personality is undefined. On the other hand, from a few years after leaving Cambridge the uniformity of his success and the freedom from strife make his life of little interest to any but his intimates. But at Cambridge it is different: there is constant development, there is sometimes trouble and difficulty, which, if it appears slight to older men, was of vast importance to the youth who suffered it and no doubt had as great an effect upon him as the sharpest struggle with adverse fate on one more hardened. His letters from Cambridge, too, reveal far more of his inner self than at any other time of his life, and with their aid it is possible to form a fairly vivid picture of what he was like.

His work filled the largest place in his life. It has been stated that he came up to Cambridge with a considerable reputation. One of his contemporaries (Rev. Arnold Thomas) remembers his being pointed out in October of 1867 as the prospective senior wrangler, "a keen, strong face, without however any of the peculiarities of expression which are usually supposed to characterise the child of genius." To some extent he shared the popular belief in himself. In his first term he writes to his father:—"As for competition, there is plenty in my own year; though I am probably the best man now, I don't think I shall be able to hold that position long, much less three years and a half." A rare faculty of his, and one very apparent even in these days, was an unbiassed judgment as to his own powers. Not only did he know what he could do, but he did not affect ignorance. It is interesting to read his letters from Cambridge and to see how, as data accumulate, showing him to be the best man of his year, he coldly draws his conclusions and frankly avows them. It was then the custom, as it is now, for the coach to set his pupils a weekly paper of problems to be done at leisure. For this marks were given, and all the best undergraduate mathematicians of the year met in these competitions. Hopkinson faithfully recorded the results; during his first year he was often second and even third among his contemporaries. But it troubled him not at all; he still went steadily on his way with a single eye to the greater competitions to come. The fierce excitement of the Tripos perhaps affected him a little in the usual way. In the midst of it

he writes:—"There is no doubt how the matter stands, viz.:—that if I had done up to my usual form, my place would have been safe, but as it is it is very likely I have lost it, and if one man beats me, two or three may." However, if he felt fear in that supreme moment he took no panic measures. "On the Monday evening," he writes, "for some reason—certainly not funk, for I have been cool as a cucumber the whole time—I did not get to sleep till about five in the morning, and as I was without chloral or spirits, I had no means of forcing it. However, I did not feel it on Tuesday. Last night I got some chloral and secured immediate sleep; having had one's brain in vigorous activity, it is rather hard to get the blood out of it." Even in such a crisis, he could regard himself as a physiological problem.

The result, in spite of his gloomy forebodings, was of course never in doubt. He turned out to have been first in fourteen out of sixteen papers. In the Smith's Prize he was again first. This examination was contrived to test originality of thought rather than the great speed which led to success in the Tripos. The papers were hard and the time for doing them was unlimited. Hopkinson's success in it therefore established his position beyond doubt as the first mathematician of his year. The year was thought by the examiners to be a fairly good one and judging from the subsequent careers of the men it was well up to the average, if not in the very first rank. That so eminent a mathematician as Dr Glaisher was second seems to imply that Hopkinson was much above the average of senior wranglers. His strong point of course lay in the physical application of mathematics. But the testimony of so high an authority as Professor Cayley, who was greatly impressed by Hopkinson's work in the Smith's Prize examination, shows that he was little inferior in pure mathematics. Hopkinson himself took little interest in that branch of the science; he used to compare it irreverently to chess-problems, the elegance of whose solution depends chiefly on the smallness of the number of moves. He had no appreciation of any originality or beauty in the problem itself. Still he looked upon the whole thing from a business-like point of view, and was not deterred from thorough study of a

subject by any doubts as to its ultimate value. His principal aim at Cambridge was *to come out top*. His subsequent career is a triumphant vindication of competitive examination, for surely few men have been so completely under its influence as he was for five years of his life.

This concentration of his energies on the one aim was one of several causes which prevented him from making many friends at Cambridge. He was one of a large family, with brothers near his own age, and there was therefore no great inducement to him to seek society away from home: his inclination was quite the other way. Probably too, on their side, his fellow-men did not fully understand him. They admired the tremendous energy with which he would row a hard race on the river and then, on the same day, go in and win a scholarship; but it was wonder, rather than sympathy, that they felt. One can well imagine too that in those days he would be at no pains to conceal his impatience when he came into contact with less vigorous minds. It was in no sense "side"—the greatest of all sins in undergraduate eyes—it was that he was driven forward faster than others could follow and it was positive pain to him to hold back. He writes in 1869:—"The meeting of the Ray Club I went to was awfully slow. I had some talk with Prof. Babington at the beginning of the evening which was interesting. I then did nothing but gaze about me for half-an-hour, and finished up by sitting down to a book till it was time to go...." His was not the easy-going temperament which is the right medium for College friendships. Later in the same letter he remarks:—"I have lots of work on now and plenty to think of, what with Mathematics, boating and other engagements; I like a certain amount of pressure," and he frequently says that the place would be intolerable without plenty to do. It is easy to understand that such a character would provoke the respect of undergraduates, but not their love.

That he stood somewhat apart from the majority of his fellows did not affect him greatly. Once in a moment of trouble he alludes to it and in a rare fit of introspection seeks for its cause in himself. But that one allusion shows that he felt the need of

sympathy in those around him, and though he cared nothing for general popularity he was by no means a recluse. Nor was the pursuit of his primary purpose at all inconsistent with the fullest enjoyment of every side of life at Cambridge. He made several intimate friends among the mathematicians, notably J. W. L. Glaisher, and Carver, who was fourth in the Tripos. Towards the end of his time, when his great powers commanded attention, he came to know such men as James Stuart, J. F. Moulton, W. K. Clifford, and he was made a member of the famous Apostles' Club. He was a good oarsman, and became captain of the Second Trinity Boat Club in 1869. On the running-path he won several races,—he was especially proud of a mile won shortly before his Tripos. His description of a walking race, in which he owed his success to his tactics as much as to his speed, is worth quoting:—"At the end of the first round—each round is one-third of a mile—Marriott led by about 10 yards. I did not see the fun of that, so I caught him and passed him as rapidly as I could, then he kept sprinting to catch me, to encourage which, I slackened at each corner and let him try to pass me. So for about eight corners he tried to pass me and walked on the outside in consequence. I found this manœuvre very useful: for the last two rounds he was content to walk just behind. About 150 yards from the end I put on the spurt and left him some 10 or 15 yards behind."

He had his full share of the high spirits which are supposed to be the glory of healthy British youth; and many were the escapades into which they led him. In one of them—perhaps remembered by his companion, who is now one of the great ones of the College,—"sulphuretted hydrogen, a horribly bad-smelling gas," was generated in the next man's rooms, wherefore porters and plumbers came to take up the drains, and the University Professor of Latin was driven from his quarters. His conflicts with the authorities were many and various; though, as a rule, they were wisely condoned. Against compulsory chapels, which were then more of an incubus than they are now, he waged unceasing war. To the end of his days he carefully preserved his correspondence with the Dean; who appears, however, to have

been a person of great discretion, and not much disposed to exact the letter of the law from a prospective Senior Wrangler. Hopkinson's attitude in such matters was no doubt largely that of the healthy undergraduate: but it was also based on a mental characteristic, which outlasted youth. To the end of his life he had a hatred of all conventions, unless one must so name the moral principles which were part of himself and of which he was hardly conscious. Any law or custom whose breach would not be inconsistent with these must be justified to his reason, or he would thrust it aside not only without compunction, but with keen pleasure. He took a simple delight in mildly shocking people, as all who have seen him in his lighter moments will remember. At Cambridge he greatly relished his position as a Nonconformist and Radical among the Tory Churchmen, and seized every opportunity of playing the Philistine. The same spirit often appears in a more serious form in his manner of dealing with scientific questions. It was not only that he was original; he took a positive pleasure in working away from traditional lines, because they were traditional. There is no doubt, for example, that he found additional zest in his magnetic researches, because they showed the elaborate mathematical hypotheses of the subject to be without any basis of fact. If he could ever be said to be affected by prejudice in such matters it was against accepted theories.

Hopkinson soon made up his mind that it would not suit him to spend his days as a Cambridge don; and in his last year he began to look about for a profession. He had some thoughts of taking a Mathematical Lectureship at Owens College, which was vacant about this time. The letter which he wrote to Principal Greenwood asking for information about the place, and stating his qualifications for it, is of much interest:—"My qualifications for the post are a thorough knowledge of pure and applied mathematics so far as examination can test such a knowledge; together with a better knowledge of science generally, especially general Physics and Chemistry, than is possessed by most men of equal Mathematical attainments. On the other hand I am not accustomed to the use

of instruments of physical research, have had no experience of teaching, and am much younger than is usually thought suitable for such positions. But all these objections are less serious when the head of the department is a man of such high standing as Professor Balfour Stewart, and the last is thus far an advantage that I shall have had no time to learn to be idle. Unless it is intended immediately to very greatly extend this department of the College, I imagine there will not be enough work completely to occupy the time of the second professor. This would give me two advantages in my candidature: first, if another man had the post it would probably be necessary to bring him to Manchester to do work which would not sufficiently occupy him; second, what surplus time I may have on leaving Cambridge, I intend to devote to acquiring such knowledge of engineering as will give a more practical turn to the studies I have been engaged in here, the being partially engaged in such work would, it seems to me, be valuable to a professor in Owens College." His principal motive in applying for the post was probably a desire for independence of means; he certainly thought that his career was to be found in engineering and did not regard this professorship as more than a temporary expedient. His father, however, with rare breadth of view, saw that even so it would unduly cramp his energies and advised him to give it up. As Dr Routh was of the same opinion he withdrew his application. His election to a Fellowship at Trinity in the autumn of 1871 gave him the independence he wanted; though the condition of celibacy, which was then attached to it, was destined to limit his tenure to some eighteen months only. It is interesting to note that the fellowships of 1871 were the first awarded without the imposition of a religious test.

On leaving Cambridge Hopkinson at once proceeded to carry out his own and his father's intention by starting work in Wren and Hopkinson's factory. It was not long, however, before another and better opening appeared. Many years before, the firm had made glass-grinding machinery for Messrs Chance Brothers and Co., Light-house Engineers, of Birmingham, to

Mr Hopkinson's design. Mr James Chance, the head of the firm, was himself a mathematician of much ability and had a distinguished academic career. From time to time he heard with interest of John's successes at Cambridge and when, in 1871, he wished to be relieved of the active superintendence of the Lighthouse Department, his thoughts turned to young Hopkinson as a likely man to take his place. He commissioned Mr Hopkinson to make an arrangement with John under which the latter was to become Engineer and Manager of the Optical Works for a year. It was arranged that he should spend a few months at his father's works in order to acquire some practical experience; and at the end of that time, in March 1872, he began his professional life in a position of much responsibility. It was no light undertaking that confronted him. He was not yet 23 years old and had had little engineering experience. He was put at the head of men many of whom had spent a much longer life than his at the work in which he was to supervise and command them. Yet within three years of his appointment he was not only acknowledged master, but he had largely increased the profits of his department by various changes in the methods of management. The rapidity with which he gained both the respect of his subordinates—from whom, as he said, he had everything to learn—and the confidence of his employers, was extraordinary. It was doubtless due in part to the fact that his position was one peculiarly fitted to his powers—in no other branch of engineering could one so favourable have been found. If, for example, he had begun in railway engineering, he would have had to spend much time in learning the accumulated experience on which the art is principally founded, and without which no man, whatever his genius, can attempt to practise it. Though his ability and energy must have brought ultimate success, it could hardly have come so quickly as it did. But the design of lighthouse apparatus rests, in the first place, upon mathematical deductions from experiment on the optical properties of glass. Experience, if useful, is not so essential for its accomplishment. To a man of Hopkinson's attainments the mathematics were a simple matter;

his training at Owens directly fitted him for the experiment. Thus in one important part of his work he had little to learn. It was of course by no means all, but his preeminence in it at once gave him a status with those above and below him and more than atoned for his lack of experience in other departments. Nor was the latter want by any means an unmixed evil. To one of his vigour of mind and character six months sufficed to supply it to a great extent; and then he was none the worse for having come to his work fresh and unhampered by tradition.

During the year 1872 he lived alone at an inn a few miles from the Glass-works. There is, in his correspondence for that year, an almost daily record of his doings. He was at first put in charge of the Lighthouse and Optical Glass Departments: the Coloured Glass Department was subsequently added. In addition to designing the lighthouse apparatus, he had to superintend its manufacture from beginning to end. Glass-making, the grinding and polishing of lenses, the design of iron towers—all these matters came under his management. In no one of them had he previous experience; but by the end of that first year not only did he know them soundly, but he had left his mark on each. As early as July 1872 he began experiments with the intention of improving the quality of the optical glass, which, as then manufactured, was of poor colour. Six months later he writes that their leading customer in this line is in high good humour with the glass they are supplying. So it was throughout his work. Even in this first year, when most men would have been content with learning the job and keeping the place going, he introduced change and improvement in every direction.

There is something very attractive in the picture of a young man in a position of great responsibility, presented in that series of letters. The responsibility one has to infer—it sits so lightly on him that it is rarely mentioned. But the youthfulness is very evident. Every new problem is hailed with delight and attacked without a trace of fear or anxiety. One sees, so to speak, only the overflow, and is left to imagine the further

depths of energy and power necessary for the routine work. The technical questions which came before him interested him most. The management of the men was less to his taste, and he found the settlement of wages rather a worry. Yet even here he inaugurated a new order of things, introducing a system of premiums on the work turned out in less than a specified time; and in due course he got piece-work in operation throughout his department. This was in some ways his most remarkable achievement in this year, as it was certainly the most valuable in its results both to the men and their employers. In many parts of his work he found his father's ripe experience of great assistance. During this year he constantly asked for Mr Hopkinson's advice, both on technical points and on his relations with his employers. He always had great confidence in his father's judgment in such matters, and to the end of his life would often refer to him for help.

The lonely year at Birmingham ended in March, 1873, when Hopkinson married Evelyn Oldenbourg, to whom he had become engaged a year previously. He had now a wife and home, a considerable income and an established position; and this at a time of life when most young men are occupied in struggling for one or more of these desiderata. He was free from all anxiety for the future. He had satisfied sufficient of his ambitions to give him confidence that the others would be in due course satisfied also; and meanwhile he had the joy which attends striving when success is almost certain. Such a frame of mind was the best possible for his work, and to it in no small measure must be ascribed his early productiveness. How far that extraordinary power of concentration which was the secret of his rapidity of work would have been proof against constant personal worries, how far it was due to their absence it is difficult to say. It would seem that freedom from anxiety was essential to his scientific work at any rate: at the time when he was contemplating removing to London for instance, he remarks in a letter:—"At present being unsettled I am doing nothing in science," and similar expressions occur on other occasions.

Hopkinson remained with Chance Bros. until the end of 1877.