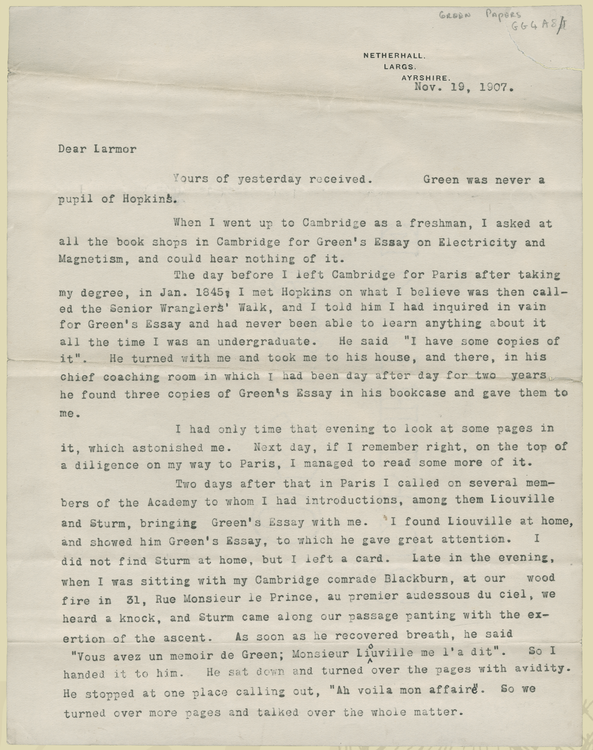
Letter from Lord Kelvin to Sir Joseph Larmor, 1907. From GG 4A 8



Green Papers
GG 4A 8

NETHERHALL.
LARGS.
AYRSHIRE.
Nov. 19, 1907.

Dear Larmor

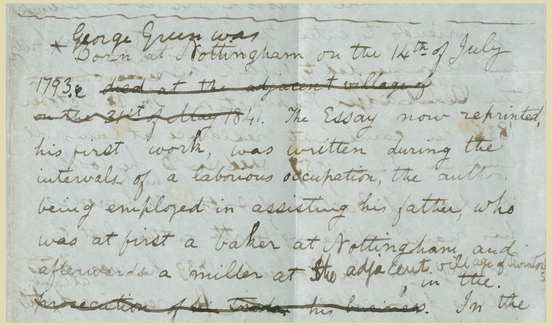
Yours of yesterday received. Green was never a pupil of Hopkins.

When I went up to Cambridge as a freshman, I asked at all the book shops in Cambridge for Green's Essay on Electricity and Magnetism, and could hear nothing of it.

The day before I left Cambridge for Paris after taking my degree, in Jan. 1845, I met Hopkins on what I believe was then called the Senior Wranglers' Walk, and I told him I had inquired in vain for Green's Essay and had never been able to learn anything about it all the time I was an undergraduate. He said "I have some copies of it". He turned with me and took me to his house, and there, in his chief coaching room in which I had been day after day for two years, he found three copies of Green's Essay in his bookcase and gave them to me.

I had only time that evening to look at some pages in it, which astonished me. Next day, if I remember right, on the top of a diligence on my way to Paris, I managed to read some more of it.

Two days after that in Paris I called on several members of the Academy to whom I had introductions, among them Liouville and Sturm, bringing Green's Essay with me. I found Liouville at home, and showed him Green's Essay, to which he gave great attention. I did not find Sturm at home, but I left a card. Late in the evening, when I was sitting with my Cambridge comrade Blackburn, at our wood fire in 31, Rue Monsieur le Prince, au premier audessous du ciel, we heard a knock, and Sturm came along our passage panting with the exertion of the ascent. As soon as he recovered breath, he said "Vous avez un memoir de Green; Monsieur Liouville me l'a dit". So I handed it to him. He sat down and turned over the pages with avidity. He stopped at one place calling out, "Ah voila mon affaire". So we turned over more pages and talked over the whole matter.

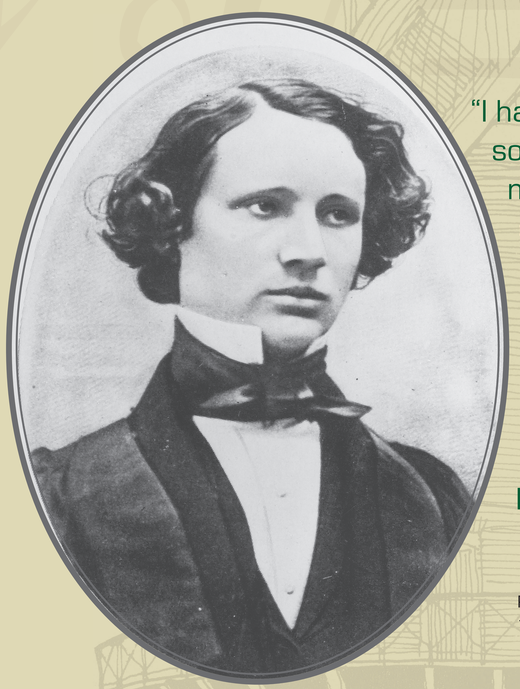


* George Green was
Born at Nottingham on the 14th of July
1793. He ~~died at the adjacent village of~~
~~on the 31st of October~~ 1841. The Essay now reprinted,
his first work, was written during the
intervals of a laborious occupation, the sale
being employed in assisting his father, who
was at first a baker at Nottingham, and
afterwards a miller at the adjacent village of Sneinton,
~~Prosecution of the trade~~ his business. In the

Draft account of Green's life, by William Thomson, 1846. From GG 4A 3

"It is impossible to avoid noticing throughout all of Kelvin's work evidences of the deep impression which was made upon him by the writings of Green"

SIR EDMUND WHITTAKER
A History of the Theories of Aether and Electricity (1910)



"I had only time that evening to look at some pages in it, which astonished me. Next day, if I remember right, on the top of a diligence on my way to Paris, I managed to read some more of it. Two days after that in Paris I called on several members of the Academy to whom I had introduction... Green's Essay made a great impression on Sturm and Liouville and others in Paris."

WILLIAM THOMSON

Professor William Thomson, Lord Kelvin, pictured left in 1846. From GG 4E 4/8

George Green.

HIS WORK REDISCOVERED

Green's 1828 essay lay forgotten for 17 years until it was read by William Thomson (1824-1907), later Lord Kelvin.

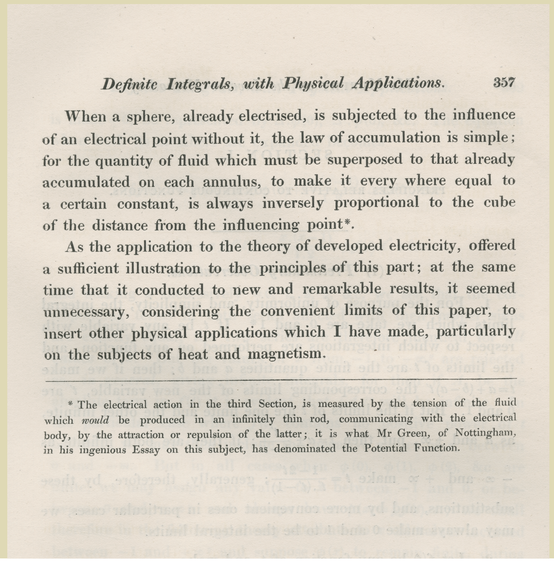
In January 1845 Thomson had just graduated from Peterhouse, Cambridge. He was interested in the mathematical theories of electricity. He noticed a footnote referring to Green's essay in a paper by the scientist Robert Murphy (1806-1843). Murphy had advised Green during his time in Cambridge, and been the referee for his 1833 essay on ellipsoids.

Green's essay could not be found in the bookshops. However, on the eve of his departure to study in France, Thomson mentioned it to his tutor William Hopkins (1793-1866), who gave him two of the three copies gathering dust on his bookshelves.

Thomson's French colleagues were excited to find that Green's work addressed the problems they had been tackling. Thomson wrote in his diary: "In 1828 [Green] had given almost all the general theorems in attraction which have since occupied Chasles, Gauss, etc". Jacques Sturm was surprised to find that what he considered his own discoveries had actually been made by Green.

The German mathematician August Crelle asked to publish the essay in his *Journal für die Reine und Angewandte Mathematik*. It appeared in three parts in 1850-1854 with a biographical preface by Thomson. Green's work became known in Europe, but Thomson regretted that he had not published it in a British journal to make it better known here. He used Green's work in his own studies into electromagnetism, and George Gabriel Stokes built on Green's research into hydrodynamics.

In 1862, Carl Neumann's paper on the stationary temperature of a homogenous body contained the first reference to "Green's Function" in scientific literature.

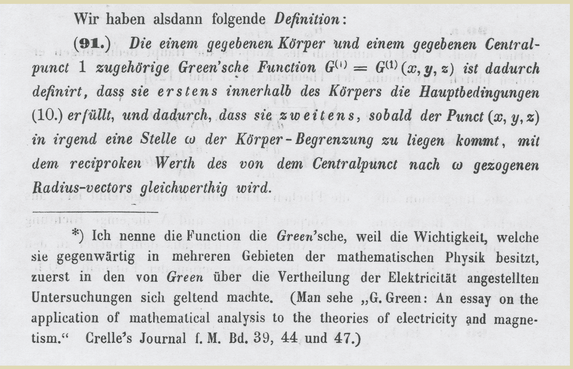


Definite Integrals, with Physical Applications. 357

When a sphere, already electrised, is subjected to the influence of an electrical point without it, the law of accumulation is simple; for the quantity of fluid which must be superposed to that already accumulated on each annulus, to make it every where equal to a certain constant, is always inversely proportional to the cube of the distance from the influencing point*.

As the application to the theory of developed electricity, offered a sufficient illustration to the principles of this part; at the same time that it conducted to new and remarkable results, it seemed unnecessary, considering the convenient limits of this paper, to insert other physical applications which I have made, particularly on the subjects of heat and magnetism.

* The electrical action in the third Section, is measured by the tension of the fluid which *would* be produced in an infinitely thin rod, communicating with the electrical body, by the attraction or repulsion of the latter; it is what Mr Green, of Nottingham, in his ingenious Essay on this subject, has denominated the Potential Function.



Wir haben alsdann folgende *Definition*:

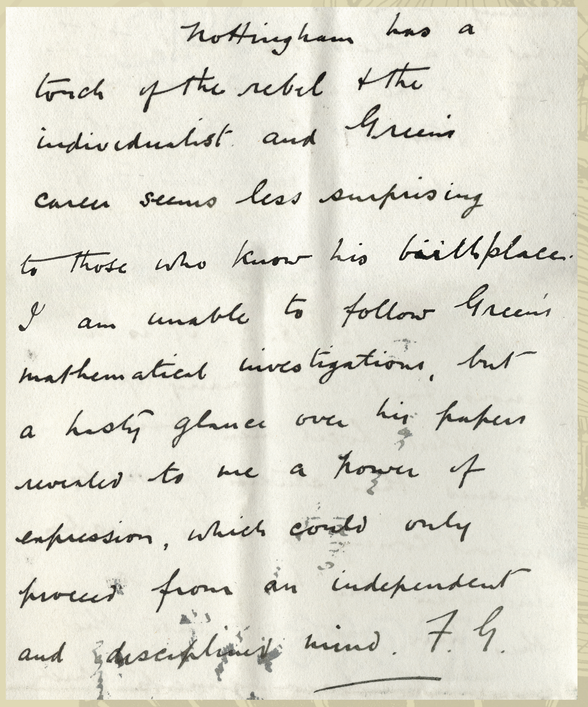
(**91.**) *Die einem gegebenen Körper und einem gegebenen Centralpunct 1 zugehörige Green'sche Function* $G^{(1)} = G^{(1)}(x, y, z)$ *ist dadurch definirt, dass sie erstens innerhalb des Körpers die Hauptbedingungen* (10.) *erfüllt, und dadurch, dass sie zweitens, sobald der Punct* (x, y, z) *in irgend eine Stelle* ω *der Körper-Begrenzung zu liegen kommt, mit dem reciproken Werth des von dem Centralpunct nach* ω *gezogenen Radius-vectors gleichwerthig wird.*

*) Ich nenne die Function die *Green'*sche, weil die Wichtigkeit, welche sie gegenwärtig in mehreren Gebieten der mathematischen Physik besitzt, zuerst in den von *Green* über die Vertheilung der Elektricität angestellten Untersuchungen sich geltend machte. (Man sehe „G. Green: An essay on the application of mathematical analysis to the theories of electricity and magnetism." Crelle's Journal f. M. Bd. 39, 44 und 47.)

LEFT: Footnote in Robert Murphy, *On the Inverse Method of Definite Integrals, with Physical Applications, Transactions of the Cambridge Philosophical Society IV* (1833). From GG 6A 6/3/1

ABOVE: Reference to Green's Function in Carl Neumann's *Allgemeine Lösung des Problemes über den stationären Temperaturzustand eines homogen Körpers* (Halle, 1862). From GG 6A 9

ABOVE: Edith M Becket, c.1928. From UMP/2/4/50 H Gwynedd Green, c.1928. From UMP/2/4/77
LEFT: Letter from Professor Frank Granger to Joseph Larmor, 1907. From GG 4A 10



Nottingham has a touch of the rebel & the individualist and Green's career seems less surprising to those who know his birthplace. I am unable to follow Green's mathematical investigations, but a hasty glance over his papers revealed to me a power of expression, which could only proceed from an independent and disciplined mind. F. G.

ABOVE: Covers of biographies of George Green, published 1976-2001. From the East Midlands Collection

George Green.

GREEN'S BIOGRAPHERS

The most authoritative biographies of George Green have all been produced by Nottingham writers.

In the early 20th century it was still possible to contact people who remembered Green's family. The mathematician Joseph Larmor (1857-1942) was intrigued by Green. In 1907 he wrote to Frank Granger, Professor of Classics and Philosophy at University College Nottingham. Granger replied giving details of Green's descendants and speculating about his education.

Several of Granger's colleagues became keenly interested in Green. In 1921 Edith M Becket, Lecturer in the Department of Education, published an article in the *Transactions of the Thoroton Society*. A paragraph on Green's mathematical significance was written by Professor Henry Piaggio of the Mathematics Department.

In 1945 a longer essay was published by H Gwynedd Green, Reader in Geometry. Through Professor F Stratton of Gonville and Caius College, Cambridge, he had acquired Lord Kelvin's and Sir Joseph Larmor's papers relating to Green. These important documents are now part of the George Green Collection at The University of Nottingham.

An exhibition about Green was organised by the Department of Physics and Nottingham Castle Museum in 1974. The occasion led to the publication of the booklet *George Green, Miller, Sneinton (1976)*. For the first time the people of Nottingham could easily resolve their curiosity about Green and his mill, and local interest grew.

Mary Cannell, 1993. From GG 8/5/1/2

Doris Mary Cannell (1913-2000), was a painstaking and utterly committed researcher, uncovering connections and significances that others had missed.

Mary Cannell, former Acting Principal of Nottingham College of Education, became Honorary Secretary of the George Green Memorial Fund in 1977. She published two booklets about Green in 1988, and a full-length biography in 1993 (2nd edition 2001). She placed Green in the broad social and educational context of Nottingham and Cambridge, and explained Green's influence on subsequent mathematical physicists.

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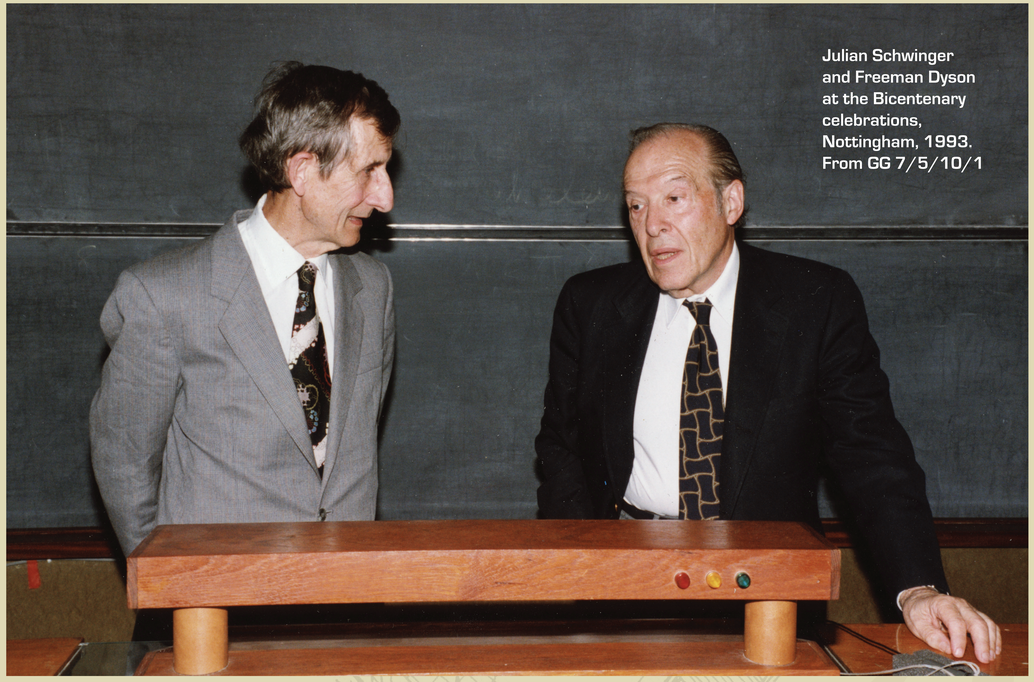
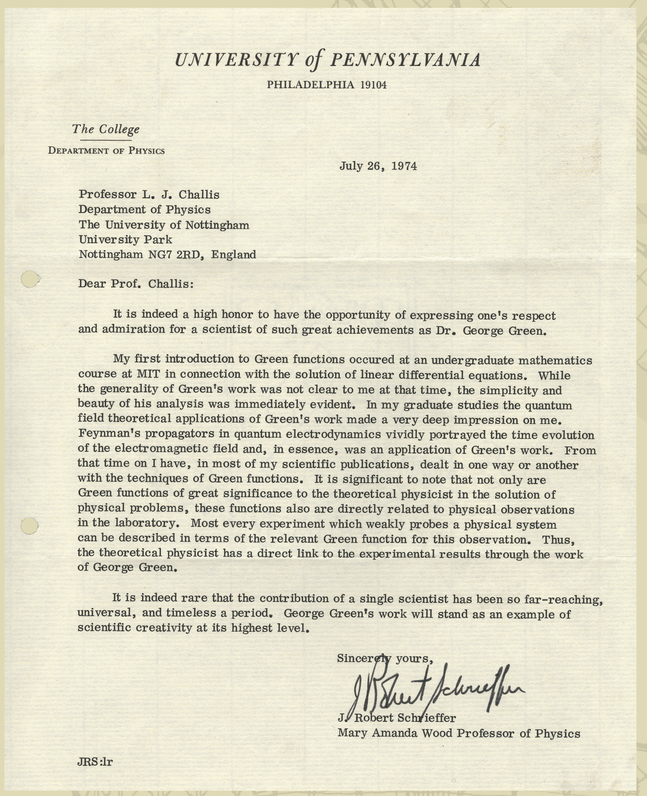


Julian Schwinger and Freeman Dyson at the Bicentenary celebrations, Nottingham, 1993. From GG 7/5/10/1



UNIVERSITY of PENNSYLVANIA
PHILADELPHIA 19104

The College
DEPARTMENT OF PHYSICS

July 26, 1974

Professor L. J. Challis
Department of Physics
The University of Nottingham
University Park
Nottingham NG7 2RD, England

Dear Prof. Challis:

It is indeed a high honor to have the opportunity of expressing one's respect and admiration for a scientist of such great achievements as Dr. George Green.

My first introduction to Green functions occured at an undergraduate mathematics course at MIT in connection with the solution of linear differential equations. While the generality of Green's work was not clear to me at that time, the simplicity and beauty of his analysis was immediately evident. In my graduate studies the quantum field theoretical applications of Green's work made a very deep impression on me. Feynman's propagators in quantum electrodynamics vividly portrayed the time evolution of the electromagnetic field and, in essence, was an application of Green's work. From that time on I have, in most of my scientific publications, dealt in one way or another with the techniques of Green functions. It is significant to note that not only are Green functions of great significance to the theoretical physicist in the solution of physical problems, these functions also are directly related to physical observations in the laboratory. Most every experiment which weakly probes a physical system can be described in terms of the relevant Green function for this observation. Thus, the theoretical physicist has a direct link to the experimental results through the work of George Green.

It is indeed rare that the contribution of a single scientist has been so far-reaching, universal, and timeless a period. George Green's work will stand as an example of scientific creativity at its highest level.

Sincerely yours,

J Robert Schrieffer
Mary Amanda Wood Professor of Physics

JRS:lr

Letter from Professor J Robert Schrieffer, Nobel Laureate, to Professor L J Challis, 1974. From GG 4C 1

"Sixty years ago... the laws describing the way things moved were found to be totally untrue when they were studied on an atomic scale and new laws called quantum mechanics had to be introduced. Remarkably though Green's techniques not only survived this revolution but if anything proved to be even more important in the new world than in the old."

LAWRIE CHALLIS, St Stephen's Church, Sneinton, 13 July 1993.
From GG 7/4/13

George Green.

THE CONTINUING RELEVANCE OF HIS MATHEMATICS

George Green is remembered nowadays for inventing Green's Theorem and Green's Functions.

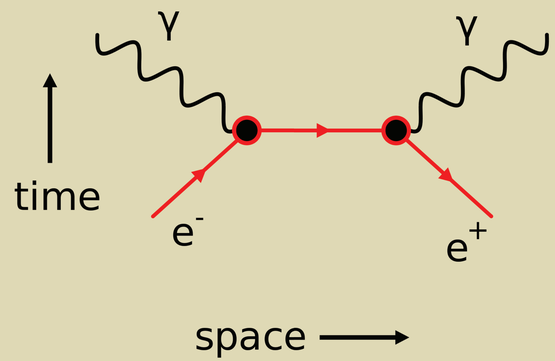
Green's Functions enable the calculation of the response of a system somewhere to a sudden kick elsewhere. For example, pressing a button on the remote control causes the TV channel to change a few feet away.

Green's Functions can describe movement such as electricity, waves, flowing liquids, or gases. They have therefore been applied to work in classical physics and engineering. However, Green's work has a general application which has supported discoveries in disciplines which would have been quite unthinkable in his own lifetime.

In the 1940s, during the Second World War, Professor Julian Schwinger was working on radar. He discovered that the best way of designing metal guides to direct radio waves was by using Green's Functions.

In 1945 Schwinger was appointed Associate Professor at Harvard University and realised that Green's Functions could also be used in quantum field theory, looking at the movement of atoms and electrons.

Green's Functions have since been used in areas such as nuclear physics, quantum electrodynamics and superconductivity. In 1965 Schwinger was awarded the Nobel Prize for Physics, jointly with Sin-Itiro Tomonaga and Richard Feynman, for their independent work in creating the modern theory of quantum electrodynamics.



Feynman diagram showing space-time vectors of electron-positron annihilation, drawn by 'Bitwise', 2010.
http://en.wikipedia.org/wiki/File:Feynman_EP_Annihilation.svg

Feynman introduced diagrammatic techniques to aid the calculation of Green's Functions. Feynman Diagrams are essentially Green's mathematics in graphic form.

Schwinger and Professor Freeman Dyson received honorary degrees from The University of Nottingham in 1993, as part of the George Green Bicentenary celebrations.

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Sir Peter Mansfield in front of an MRI scanner. Image courtesy of The University of Nottingham.

George Green.

GREEN'S FUNCTIONS AND THE DEVELOPMENT OF MRI

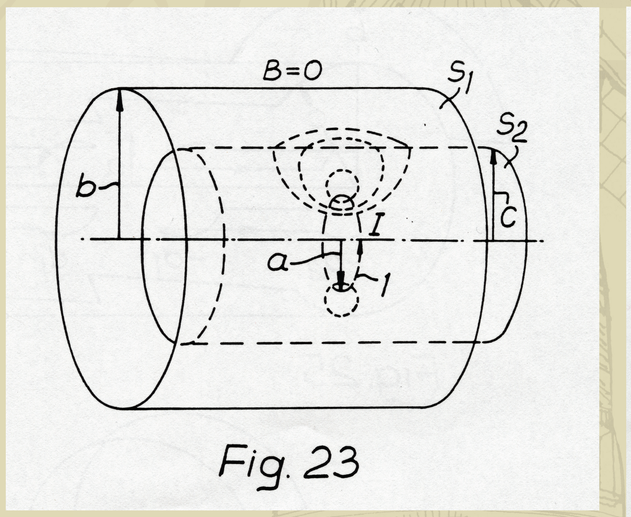
The University of Nottingham physicist Sir Peter Mansfield won the Nobel Prize for medicine in 2003 for his pioneering work into Magnetic Resonance Imaging (MRI).

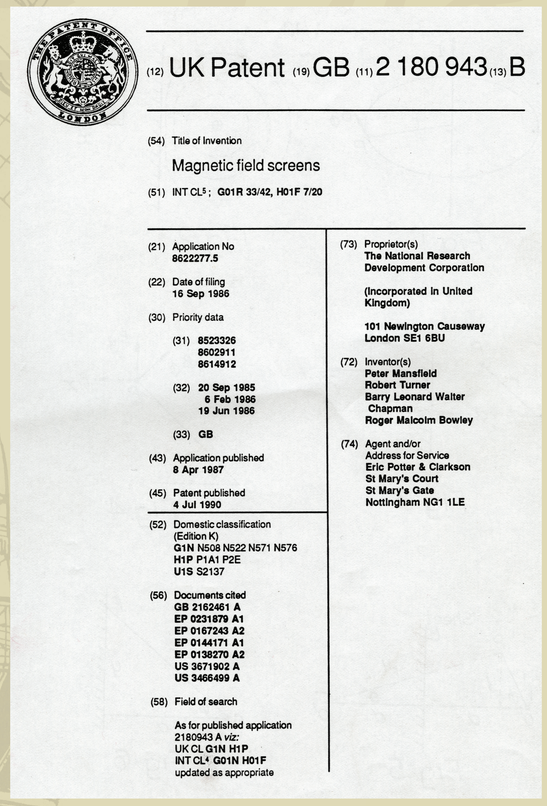
MRI scanners produce images of the inside of the human body using magnetic fields and radio waves. In the 1980s Mansfield worked on creating a scanner using a superconducting magnet and gradient coils. There was a problem: stray magnetic fields around the coils induce currents in the superconductor which would distort and blur the resulting image. In his autobiography, *Long Road to Stockholm* (2013), he recalls how he came up with a solution of introducing a magnetic screen between the gradient coil and the inner bore of the static magnet.

His colleagues in the School of Physics, Dr Robert Turner and Professor Roger Bowley, then worked on the precise design of the gradient coils. Bowley worked out how to screen a single circular coil using an analogy with a vortex ring in a cylinder. Turner extended the treatment to screen any gradient coil by using Green's Function in his mathematical calculations. The Green's Function allows you to calculate how the electrical current at one position affects the magnetic field elsewhere. Turner used Green's Function to ensure that there were no stray magnetic fields outside the screening coils, so the images were as clear as possible.

Turner and Bowley published a paper, *Passive Screening of Switched Magnetic-Field Gradients,* in 1986, and their work was incorporated into Mansfield's patent, 'Magnetic field screens', filed the same year, and published in 1990.

The method developed by the Nottingham scientists ensured that the images produced were as sharp as possible. All the major manufacturers began to use the technique, and MRI scanning took off as an important diagnostic tool in modern medicine.





(12) UK Patent (19) GB (11) 2 180 943 (13) B

(54) Title of Invention

Magnetic field screens

(51) INT CL[5]; G01R 33/42, H01F 7/20

(21) Application No
8622277.5

(22) Date of filing
16 Sep 1986

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U1S S2137

(56) Documents cited
GB 2162461 A
EP 0231879 A1
EP 0167243 A2
EP 0144171 A1
EP 0138270 A2
US 3671902 A
US 3466499 A

(58) Field of search

As for published application
2180943 A viz:
UK CL G1N H1P
INT CL[4] G01N H01F
updated as appropriate

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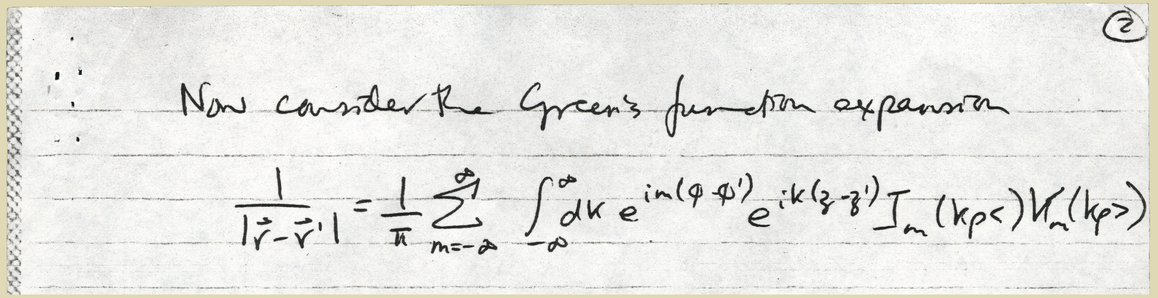
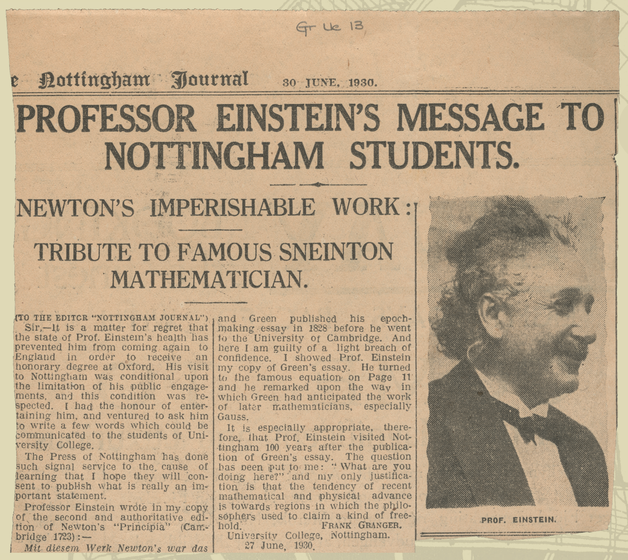
ABOVE: Figure 23 from the UK Patent GB 2 180 943 B 'Magnetic Field Screens', published 4 July 1990, showing the double screen around a primary core. From Acc 2490, by kind permission of Roger Bowley.
RIGHT: Detail from UK Patent GB 2 180 943 B 'Magnetic Field Screens', published 4 July 1990. From Acc 2490, by kind permission of Roger Bowley.



Dr Robert Turner's handwritten notes, 'Magnetic fields produced by current densities confined to a cylinder', 1985. From GG 6B/25

H Gwynedd Green, who had delivered a talk on Green's life, is shown standing next to the President of the British Association for the Advancement of Science, Dr GWC Kaye, as he lays a memorial wreath, 1937. From UR 1376/10



Gr Ue 13

e Nottingham Journal 30 JUNE, 1930.

PROFESSOR EINSTEIN'S MESSAGE TO NOTTINGHAM STUDENTS.

NEWTON'S IMPERISHABLE WORK:

TRIBUTE TO FAMOUS SNEINTON MATHEMATICIAN.

(TO THE EDITOR "NOTTINGHAM JOURNAL")

Sir,—It is a matter for regret that the state of Prof. Einstein's health has prevented him from coming again to England in order to receive an honorary degree at Oxford. His visit to Nottingham was conditional upon the limitation of his public engagements, and this condition was respected. I had the honour of entertaining him, and ventured to ask him to write a few words which could be communicated to the students of University College.

The Press of Nottingham has done such signal service to the cause of learning that I hope they will consent to publish what is really an important statement.

Professor Einstein wrote in my copy of the second and authoritative edition of Newton's "Principia" (Cambridge 1723):—

Mit diesem Werk Newton's war das

and Green published his epoch-making essay in 1828 before he went to the University of Cambridge. And here I am guilty of a light breach of confidence. I showed Prof. Einstein my copy of Green's essay. He turned to the famous equation on Page 11 and he remarked upon the way in which Green had anticipated the work of later mathematicians, especially Gauss.

It is especially appropriate, therefore, that Prof. Einstein visited Nottingham 100 years after the publication of Green's essay. The question has been put to me: "What are you doing here?" and my only justification is that the tendency of recent mathematical and physical advance is towards regions in which the philosophers used to claim a kind of freehold.

FRANK GRANGER.

University College, Nottingham.
27 June, 1930.

PROF. EINSTEIN.

Newscutting reporting Einstein's visit to Nottingham, 1930. From Gr Ue 13

George Green.

CELEBRATING GREEN

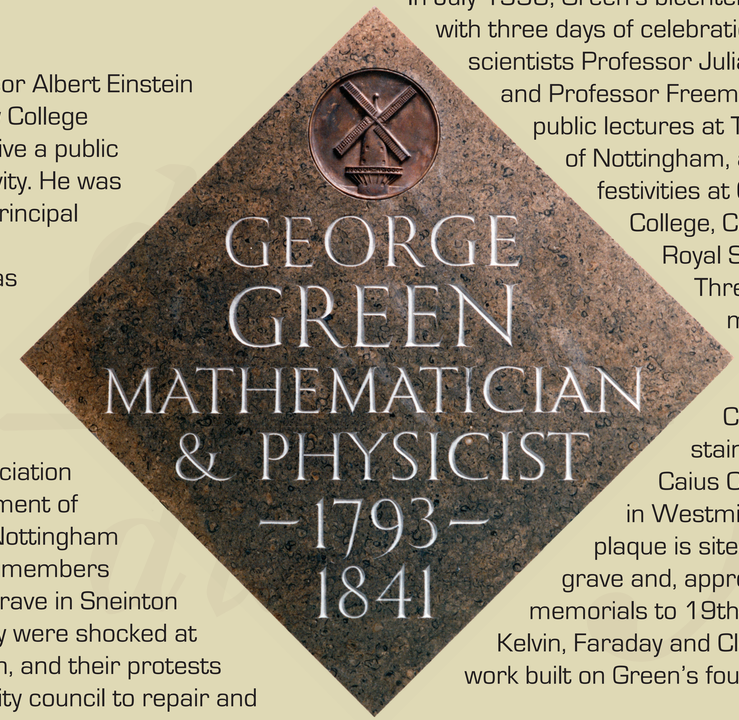
Green has been honoured in public at various times, culminating in 1993 with celebrations marking the bicentenary of his birth.

In 1930 Professor Albert Einstein visited University College Nottingham to give a public lecture on relativity. He was hosted by Vice-Principal Professor Frank Granger, who was keen to mention Nottingham's most famous mathematician.

The British Association for the Advancement of Science met in Nottingham in 1937, and its members visited Green's grave in Sneinton churchyard. They were shocked at its poor condition, and their protests persuaded the city council to repair and maintain it.

In 1974, an exhibition at the Castle Museum was timed to coincide with a major conference on magnetic resonance in Nottingham. In the same year, Professor Lawrie Challis spoke about Green at the International Physics Conference in Budapest. Challis and his colleagues, particularly Professor Tony Spencer, were engaged throughout the 1970s and 1980s in campaigning to save Green's Mill. They also continued to highlight his importance to science. A conference organised by the George Green Memorial Fund and the History of Physics Group of the Institute of Physics, was held at Nottingham in 1988.

In July 1993, Green's bicentenary was marked with three days of celebrations. The American scientists Professor Julian Schwinger and Professor Freeman Dyson gave public lectures at The University of Nottingham, and there were festivities at Green's Mill, Caius College, Cambridge, and the Royal Society in London. Three permanent memorials were dedicated: a plaque in St Stephen's Church, Sneinton; a stained glass window in Caius College; and a plaque in Westminster Abbey. The plaque is sited near Newton's grave and, appropriately, near the memorials to 19th-century scientists Kelvin, Faraday and Clerk Maxwell, whose work built on Green's foundations.



INSERT: Memorial plaque to George Green, 1993. From GG 7/5/44
ABOVE: Procession at the George Green memorial service at Westminster Abbey, 1993, by permission of Andrew Dunsmore/Picture Partnership. From GG 7/5/34/1

"I showed Professor Einstein my copy of Green's Essay. He turned to the famous paragraph on page one, and remarked on the way Green had anticipated the work of later mathematicians, especially Gauss."

UNIVERSITY COLLEGE NOTTINGHAM VICE-PRINCIPAL PROFESSOR FRANK GRANGER, in a letter to the *Nottingham Journal*.

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