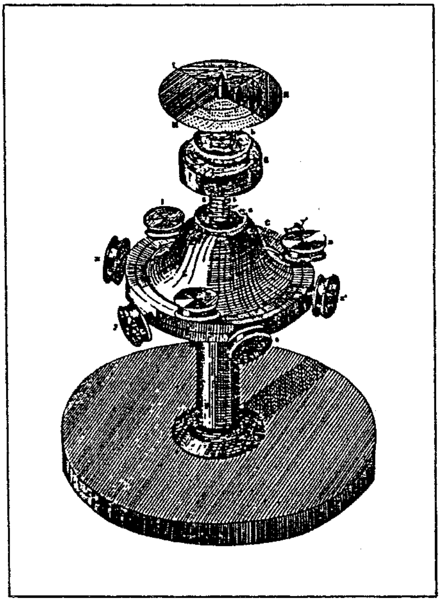
HISTORY OF PHYSICS GROUP



MAXWELL CONFERENCE EDINBURGH

MAXWELL'S DYNAMICAL TOP

NEWSLETTER

No. 7 SUMMER 1993

THE INSTITUTE OF PHYSICS

HISTORY OF PHYSICS GROUP NEWSLETTER NO. 7   SUMMER 1993

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ACKNOWLEDGEMENTS

Frontpiece :

Maxwell's Dynamical Top. Used for ' exhibiting the phenomena of the motion of a system of invariable form about a fixed point'.

Maxwell's Ether from The Scientific Papers of James Clerk Maxwell ed. W.D. Niven, Cambridge. 1890. From 'Energy, Force, and Matter' by P.M. Harman. C.U.P. 1982.

Bessemer's Converter. From Illustrated London News, 1856. In 'A History of Technology' ed. Sugar, Halmyard, Hall and Williams. Vol. 5 Late 19C. Oxford Clarendon 1958.

Maxwell's postcard from 'James Clerk Maxwell' by Ivan Tolstoy, Canongate, Edinburgh, 1981.

FIRST SCOTTISH MEETING OF THE HISTORY OF PHYSICS GROUP

By a happy coincidence, the committee member north of the border was seeking a suitable basis for a Group Meeting at exactly the time that a note appeared in *Physics World* about the aspirations of The James Clerk Maxwell Foundation. A telephone call to the author of the note, Professor David Ritchie, clinched not only a meeting theme - Maxwell - but also the ideal venue - Maxwell's birthplace. The date chosen turned out to be the pivotal date of the Edinburgh International Science Festival, who promptly offered financial support and inclusion in their published programme of events. Thus the meeting embarked on its course with significant initial momentum! Additional sponsorship was generously offered by the Scottish Branch of the Institute of Physics and also the Foundation's Legal Advisers: Bird Semple Fyfe Ireland W.S. To all these bodies we are most grateful.

The Meeting took its title from the slogan adopted by the Foundation: ***Scotland's Uncelebrated Genius: James Clerk Maxwell 1831-1879***, and within a few weeks a strong team of seven speakers had been assembled. Without exception they gave a positive and enthusiastic response, which was a great boost to the organiser's morale. And so, on Saturday 17th April 1993, under blue Edinburgh skies, eighty-odd participants converged on 14 India Street. Not only was this address Maxwell's birthplace but also currently the private home of Iain and Marion MacIvor. It is with unbounded gratitude that I here pay tribute to their enthusiastic support for the Meeting from inception to execution. I continue to marvel at the equanimity with which they faced the invasion of their privacy on 17th April, an invasion met moreover with overnight hospitality extended to two of the speakers, and consoling beverages provided for organisers and helpers at critical moments!

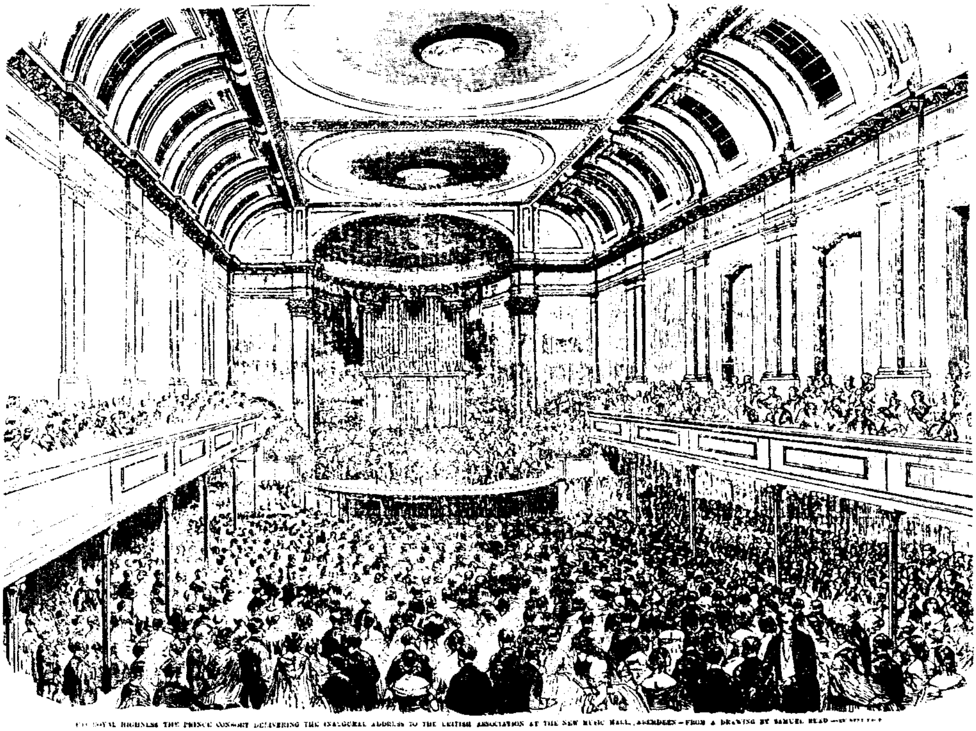
On the future of Maxwell's Birthplace David Ritchie has kindly supplied the following note:

> Following the one-day meeting on 17th April, arranged jointly by the IoP History of Physics Group and the James Clerk Maxwell Foundation, a drive is now in hand to implement the final stages of the plans for the house. The outstanding sum to be raised to make the future secure is £150,000. A number of those who attended the meeting contributed generously, some with covenants.
>
> The fine public rooms in the house are suitable for meetings, seminars and exhibitions. It is hoped that the Institute of Physics will continue to make use of these facilities for future events. The top floor will be occupied as mathematical laboratories by the International Centre for Mathematical Sciences (ICMS). The ICMS was founded by Edinburgh and Heriot-Watt Universities and the membership is open to other institutions.
>
> Please send enquiries and contributions to:-

James Clerk Maxwell Foundation
c/o Bird Semple Fyfe Ireland W.S.
Orchard Brae House
30 Queensferry Road
Edinburgh EH4 2HG (Tel.031 343 2500)

To return to the Meeting, the morning and afternoon sessions were chaired, respectively, by Professors Brian Pippard and David Ritchie. Summaries of the seven talks now follow, in order of presentation.

Stuart Leadstone
Meeting Organiser



The Prince Consort opens the British Association meeting at Aberdeen in 1859, where the 'Maxwell Distribution Law' of molecular velocities was first announced. (Courtesy Dr. J.S.Reid)

David Forfar : The Origins of the Clerk Maxwell Genius*

As David Forfar showed in a wide-ranging paper, though Clerk Maxwell may have been exceptionally talented, when his family background is considered, his talents seem pre-ordained.

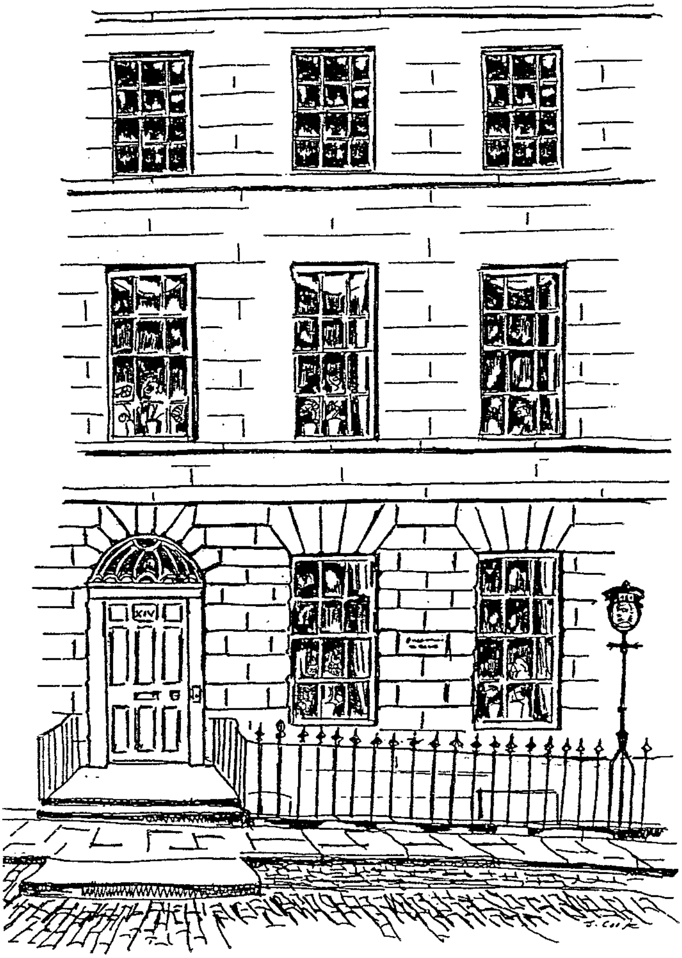
On his father's side Clerk Maxwell was descended from the Clerks of Penicuik, a family who had been prominent in Scottish intellectual and political circles from the 17th century. For example, his great great grandfather was Sir John Clerk (1676-1755). This Clerk had the benefit of studying law at Leiden where he met Hermann Boerhaave, who was to have such an influence on medical teaching in Edinburgh. Clerk was an accomplished musician who studied with Corelli and indeed Boerhaave wrote the words for a composition of Clerk's, "Scotland's Lament". Some things never change.

Another John Clerk (1728-1812), son of the above, was a successful merchant, geologist (friend of James Hutton) and naval tactician whose ideas were used by Nelson at Trafalgar. And so it continued from one generation to the next.

On his mother's side Clerk Maxwell was descendent of the Cays of Northumberland, a family known for their legal careers, interest in antiquities, and knowledge of science.

Brought up in close contact with members of these families, Clerk Maxwell encountered a wide range of intellectual stimuli. Undoubtedly, Clerk Maxwell had great advantages in terms of both nature and nurture which Forfar did much to illuminate.
Alan Morton
*This paper has been published in the Bulletin of Mathematics and its Applications, **28**(1992),4-16.

Alan Morton



Maxwell's birthplace, 13 June 1831.
14 India Street, Edinburgh.

ROB FAIRLEY: DAFTY, BIRN AND THE WHITE HORSE

In our age of electronic cameras and easy travel it is not difficult to produce a detailed record of one's doings with which to bore one's friends. By contrast, during the years from 1837 to 1901, using her skill with pen and watercolour, Jemima Blackburn (nee Wedderburn) diligently recorded not only family and local events, but also produced a detailed and scientifically accurate record of wild life subjects. The quality and quantity of Jemima's output merits study for its own sake - her artistic talent was admired by Ruskin, Landseer, Millais, Thackeray and others. To the physicist there is an additional fascination to this artistic corpus - Jemima was a cousin of James Clerk Maxwell. She, James and Hugh Blackburn (whom she married in 1849) were close friends in childhood and adolescence, and James continued to visit the Blackburn family throughout his life. Not surprisingly therefore, James figures in about 30 drawings and paintings by Jemima. A selection of these were among the illustrations upon which Rob Fairley built his lively presentation on "Dafty, Birn and the White Horse". Most of us were already initiated into the first of these code words. In retrospect it is a joke of cosmic proportions that James's nickname at school was "Dafty"! In the course of Mr Fairley's lecture we were enlightened regarding "Birn" (Jemima) and "The White Horse" (31 Heriot Row), so named for the plaster model above the front door. This was the home of the Wedderburn family, of which Jemima was the seventh and youngest child, and also where James lived during much of his time as a pupil at Edinburgh Academy.

Against this background, and with a real blend of skill, wit and charm, Mr Fairley disclosed the intelligence, reserve, humour and curiosity which were evident from the first in the character of James. A particularly evocative series of pictures figured James in the company of his father John Clerk Maxwell; at Leith; in Heriot Row; shooting rabbits; gralloching a deer; out with Toby the dog; riding; building with bricks; running from the rain. Clearly the close and affectionate ties between father and son were a crucial and wholesome factor in James's development.

A major source of pastimes for the young cousins and acquaintances was a four-volume set of Hutton's "Mathematical Recreations", owned by Hugh Blackburn. Amongst the projects inspired by this was a series of hot-air balloons, each one bigger and better than the last. Picture James's father at the top of the stair-well of Killearn House, supporting the top of the fabric of a balloon, whilst down below four boys - three Blackburn brothers plus James - kneel, stretch, check and tend the "business-end". Picture also the disappearance over a hill of another fine specimen, with the creators in hot pursuit, scenes captured, as ever, by Jemima.

It is impossible in words to do justice to the illustrative material in Rob Fairley's talk. However, the atmosphere he created, and the insight he gave us into the formative years of this genius-to-be, will not be easily forgotten.

Stuart Leadstone

JEMIMA ON TOUR

The first major showing of the work of Jemima Blackburn (nee Wedderburn) 1823-1909 is currently touring Scotland and Northern England. The itinerary is as follows:

Hamilton District Museum	June-July 1993
Smith Art Gallery and Museum, Stirling	July-Aug 1993
Hawick Museum and the Scott Gallery	Sept-Oct 1993
Barrack Street Museum, Dundee	Feb-April 1994
Mercer Gallery, Harrogate	April-May 1994
Brantwood, Coniston	May-June 1994
Inverness Museum and Art Gallery	July-Aug 1994
The West Highland Museum, Fort William	Aug-Sept 1994

Jemima Blackburn was one of Scotland's leading watercolourists and illustrators in her day. As well as a prodigious output of natural history studies she painted intimate scenes of family life, some of which include her cousin James Clerk Maxwell. For further background see the summary of Rob Fairley's talk in this Newsletter.

Woodcut by Jemima Blackburn. (Courtesy Rob Fairley)

See advertisement on the back cover.

PROFESSOR IVAN TOLSTOY: MAXWELL'S PHILOSOPHICAL POSITION

The term genius has been debased by overuse by pseudoscholars and therefore ought to be defined before being applied to Maxwell. A prime criterion of genius is someone whose work affects and permanently changes the world. But a further criterion is essential: there have to be intellectual and psychological aspects involved. An outstanding example is Mozart, with his amazing fertility and incomprehensible well-springs of musical ideas. In natural science, genius can be applied to Newton, Gauss, Einstein, Faraday and - certainly - to Maxwell, who profoundly changed the worlds of science and technology. His electromagnetic theory is a milestone, unifying electricity and magnetism - the first great unified theory. It not only gave order to known realms of science, it foretold others involving as yet undiscovered regions of the electromagnetic spectrum. Feynman has asserted that the most significant event of the 19th century was Maxwell's discovery of the laws of electrodynamics, compared with which such events as the American Civil War pale into insignificance. The range of Maxwell's creativity includes colour vision, optics, statistical mechanics and electromagnetism.

Any attempts to analyse and account for such acts of genius are inevitably coloured by hindsight, and it is exceedingly difficult to get back to motives and causes, to give simple cause and effect accounts of how it all came about. Human society and the human mind are both complex systems (like that which gives us our weather), whose operations are not susceptible to either detailed prediction or to precise back-tracing. It is no wonder there are so many competing schools of thought in the history and philosophy of science. Harman, editor of Maxwell's letters, feels that Maxwell's philosophical bent played an important role. Segal asserts that Maxwell's models did not break away from the 19th century concept of a mechanical aether. Buchwald concludes from Maxwell's Treatise that he thought of charge and current in non-real, abstract terms, as aether displacements. Maxwell has to be regarded as the first modern theoretical physicist.

The history of Maxwell's electromagnetic equations is well documented. He regarded Faraday's work as seminal for his own. Maxwell's early papers (1855-6) are based on Faraday's concept of lines of force and provide the first systematic development of the field concept, using analogy with incompressible fluids. In his 1861-2 papers the physical aspect of lines of force is developed in terms of vortices and idle-wheels. Maxwell was prepared to put trust in analogical reasoning, a notion he probably derived from Edinburgh student days in Sir William Hamilton's philosophy class. Maxwell was quite explicit that the aether model was analogy, not fact. Charge displacement in a dielectric was compared with elastic strain, having a linear relationship with the applied "stress". The analogical explanation of electric displacements in a dielectric could lead to a theory of the propagation of light in solid dielectrics. But fluids, too, can transmit light, yet cannot maintain stress. Likewise vacuum. An aether was therefore necessary to account for electrical properties, including the storage of energy, despite there being no basis for it from independent experimental evidence. In his 1864 paper **The dynamical theory of electromagnetic fields**, Maxwell assumes the aether to have "small but real density", but distinguishes it from ordinary "gross matter". In the final sentence of his **Treatise** he acknowledges aether to be an hypothesis. His adoption of it had no rational basis. Attempts to reconstruct his thought processes in this matter are rather futile, and have by now probably gone as far as is possible. Some aspects of Maxwell's development of his theory transcended reason: it was essentially an act of genius. The notion of aether was purely metaphysical - irrelevant to any logical positivist. But the model succeeded pragmatically; all Maxwell's electromagnetic equations are correct.

As a student in philosophy classes at Edinburgh University Maxwell would have been influenced by the Kantian belief that "relations" rather than "things" influence events. The mind imposes its own structures on the world, and seeks principles embodied in phenomena. Maxwell was profoundly influenced by metaphysical aspects of philosophy. Kuhn's "normal science" does not need philosophy, but it is essential for revolutions in science. Such revolutions demand genius, and the workings of genius transcend logic. In Maxwell's own words, "what is done by what is called 'myself' is, I feel, done by something greater than myself in me".

In subsequent discussion the chairman, Sir Brian Pippard, commented that Einstein, Heisenberg and Schrodinger also had started their great theoretical revolutions with strong philosophical inputs, even though they abandoned them later, having outgrown them. A further comment compared concepts of vacuum in modern theories with the 19th century concept of aether. But we have nothing more to show for either than the equations they are invoked to model.

Bernard Spurgin

DR JOHN REID: MAXWELL'S SCOTTISH CHAIR - MARISCHAL COLLEGE, ABERDEEN

James Clerk Maxwell spent only a small part of his professorial career at Marischal College, and his fame lies mainly in his achievements elsewhere but his stay there was not without importance. The college had a tradition of providing good, accessible and forward-looking education and the young Maxwell was appointed to the Chair of Natural Philosophy in 1856 on a salary of a little less than £400.

At the time, there was heated debate about a possible merger with the neighbouring King's College Aberdeen and this was to dominate college life throughout Maxwell's tenure. He, however, took little part in political life, and indeed made no recorded contribution to any of the ninety meetings of the Senate he could have attended.

The College was very much to his liking. He had the freedom to teach what he wished, and was stimulated by the contrasts of Aberdeen city life and that on his country estate, between teaching and research, experiment and Mathematics. His marriage to Katherine Mary Dewar, a daughter of the Prinicpal, lent a spiritual dimension to his life.

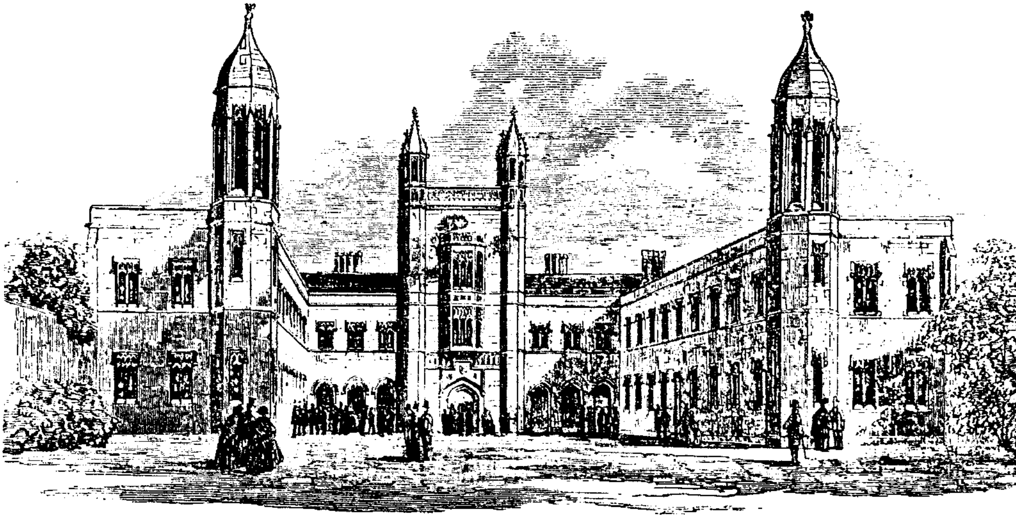
Maxwell's students were drawn mainly from the North of Scotland, typically the sons of tradesmen, with no previous experience of Physics. Only one became a recognised scientist, David Gill, a leading observational astronomer of the century.

Mathematics featured significantly in Maxwell's course, experiment less so, despite a legacy of excellent demonstration equipment from a predecessor - Professor Copland. One experiment, though, involved a rotating drop of liquid which could model one theory of the formation of the rings of Saturn, as discussed by Maxwell in one of the eight papers he produced whilst at Marischal College.

It was at the 1859 meeting of the British Association in Aberdeen, opened by Prince Albert, that he announced the distribution law for molecular velocities.

The merger of Aberdeen's two universities finally took place in 1860 and it was David Thomson, not Maxwell, who was appointed as Professor of Natural Philosophy at the new University of Aberdeen; this, despite the opinions of influential friends and colleagues of Maxwell, not to mention his family connections. There was not one scientist amongst the commissioners who made the controversial choice and, apparently, no formal evidence was collected concerning the suitability of any of the candidates for the job. Six months later, Maxwell was appointed Professor of Natural Philosophy at King's College London.

Peter Tyson



MEETINGS OF THE BRITISH ASSOCIATION.—MARISCHAL COLLEGE, ABERDEEN.—FROM A DRAWING BY SAMUEL READ.—SEE PAGE 320

Marischal College, Aberdeen, where meetings of the British Association were held in 1859.
It celebrates its 400th anniversary this year. (Courtesy Dr. J.S.Reid)

DR. PETER HARMAN : MAXWELL AND FARADAY *

After the earlier speakers had illustrated the world of Maxwell's ancestors and his childhood experiences, after his philosophical influences and early professional life had been surveyed, it fell to Dr. Harman to recreate in the house of Maxwell's birth his thoughts, words and conceptual changes.

Maxwell claimed in his treatise on Electro-Magnetism in 1873 that he had translated what he considered to be Faraday's ideas into a mathematical form. Dr. Harman's paper revealed that 'considered' meant much more and he proceeded to discuss the significance of the statement using facsimilies of two letters that Maxwell had written to Faraday.

Faraday had developed the concepts of curved lines of force and a state of strain or tension in a medium to explain e-m effects. The geometrical nature of this representation of nature appealed to Maxwell who saw that it was intrinsically mathematical and therefore capable of analytical development. In this enthusiasm for Faraday's intuitive ideas he was partly influenced by the Scottish tradition of establishing intelligible geometrical foundations as a precursor to mathematical manipulation.

He was guided in this development by ideas Faraday had evolved since the 1830's. Faraday considered that the particles in the core of the electro-magnet were in a state of electric tension: the electrotonic state. In electro-static induction he suggested that the particles of the dielectric transmitted forces between themselves which caused them to be thrown into a state of polarity or tension. Being unhappy with the Newtonian view of inpenetrable atoms surrounded by forces of attraction and repulsion, Faraday had proposed the concept of matter not being solid but produced by the lines of force themselves: the so-called 'collocation of forces' and that they therefore could penetrate each other.

He further suggested that transmission of forces could be explained by vibrations in the lines of force. He produced an image to illustrate the relation between electricity and magnetism: that of of the two linked rings. A current of electricity in the one ring generated magnetic lines of force in the other ring.

Maxwell responded to these geometrical concepts and tried to develop a system of geometrical propositions about the lines of force. Using Kelvin's potential theory and by analogy with the flow of heat he proposed a model of lines of force as a flow of an incompressible fluid. Using the collocation of force and linked ring images he proposed that the quantity of lines of force that go through a given area was a measure of the electrotonic intensity. Also he suggested that the magnetic intensity round the boundary of a surface measures the quantity of electric current through that surface.

Maxwell had thus transformed and enlarged Faraday's ideas in developing a physical geometry of fields. Later he was to apply Stokes' Theorem and elements of Hamiltons Quaternions to produce the mature analytical expressions of e-m quantities found in his treatise.

Faraday had extended his lines of force idea to propose that lines of gravitational force were sent out from the Sun. However he found difficulties in this as he felt that this would involve the creation and annihilation of force as he understood it. Maxwell wrote to Faraday discussing this problem. Maxwell was attracted by the geometrical images again and was also trying to link it with the developing theories of energy and the conservation of energy of the 1850's.

* This paper will be published in a forthcoming issue of the European Journal of Physics.

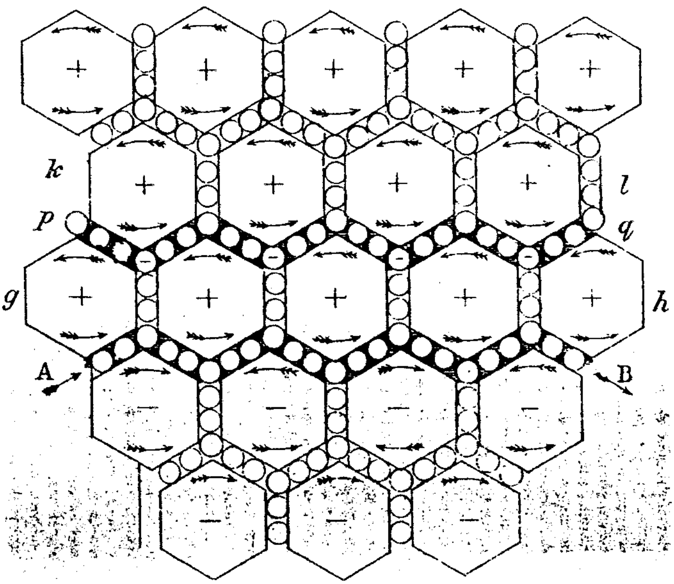
He explained them to Faraday but subsequent correspondence revealed that Faraday's idea of force was different to both conservation of energy and the equality of action and reaction. Maxwell eventually found these ideas and therefore Faraday's collocation of force model of matter unacceptable. It was Faraday's model of the field involving curved lines of force in different directions through space that was geometrically and hence mathematically satisfying to Maxwell.

It was Kelvin's concept of vortical motions in an ether, introduced to explain the Faraday Effect, that enabled Maxwell to develop his mechanical model of the ether in 1861 with its molecular vortices and idle wheel particles. He was able to show how forces were mediated through the medium. The model gave a mechanical explanation for electomagnetic analytical quantities such as field intensity, electric current and the electrotonic state. He felt, though, that this model was awkward and temporary but successful in demonstrating that a mechanical model was conceivable; he considered the mathematical expressions and relations of physical quantities developed by the theory to be correct whatever the physical substratum.

Maxwell had been successful in illustrating Faraday's concept of the electrotonic state and proceeded to see how the 'polarised state' of matter could be described mechanically, using his extended ether model of an elastic solid substance which could be distorted by electric particles. He found that polarisation could be represented by a 'displacement' or distortion of the solid. This model allowed for the supposition of shear waves and from this it was but a step to considering light as undulations in the medium. Optics and electro-magnetism could thus be unified.

Maxwell acknowledged his debt to Faraday in enabling him to develop these theories. From the paper we were better able to judge the degree of transformation and mathematical translation that Maxwell had produced and why he qualified for the title of genius.

Bob Joyce



Maxwell's physical model of molecular vortices and electric particles.

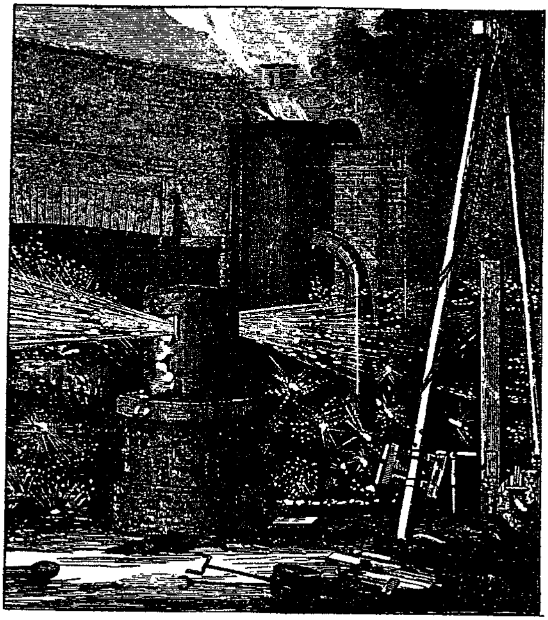
MR RICHARD SILLITTO: MAXWELL'S ELECTROMAGNETISM AND ITS BEARING ON MODERN OPTICS

In this lucid talk the impact of special relativity and of quantum theory on Maxwell's electromagnetic theory was examined. Special relativity, launched by Einstein in 1905, was classical, deterministic and a science of the continuum. Quantum theory, once described as incomparably more difficult by Professor John Gunn of the University of Glasgow, dates from 1900, is fundamentally probabilistic and is a science of the discontinuous. The postulates of special relativity allowed Einstein to extend Maxwell's theory to the electromagnetism of moving bodies and therefore enlarged its scope. The interpretation of the magnetic field as a relativistic effect engendered a new unified approach to the understanding and teaching of electromagnetism. The effect of special relativity on Maxwell's theory, therefore, was to enlarge its scope, give it a deeper and more coherent meaning, but basically to leave it unscathed.

The effects of quantum theory on Maxwell's theory have not been so simple and may still be evolving. Maxwell's theory of the electromagnetic radiation from a furnace or a 'black body radiator' failed so drastically to predict the observed distribution of radiant energy that its predictions are often called the 'ultraviolet catastrophe'. Max Planck in 1900 provided an equation through a combination of theoretical reasoning and 'fudging' which predicted exactly the correct energy distribution. To achieve this he had to surrender the classical theory according to which energy is equally distributed over all possible modes of the radiation field.

A statistical theory of optical radiation from incoherent sources, based on Maxwell's classical electromagnetism but assuming a gaussian distribution of amplitudes, was developed from the 1930's onwards by Emil Wolf and others. This was highly successful in explaining macroscopic optical phenomena such as interference and polarisation until the 1950's when circuitry developed during the War for other purposes was rapid enough to follow source fluctuations which were averaged in the Wolf theory. This produced results which to many optical physicists were unexpected, unwelcome and very controversial. It required the development of a quantum theory of optical coherence, chiefly by R G Glauber from 1963, to explain these phenomena. This theory also began with Maxwell's electromagnetism as a starting point but translated the classical mathematical expressions into the quantum formulation according to well established rules. The new formulation naturally incorporated the quantum description of emission and absorption processes and showed how to determine the appropriate distribution function. This allowed it to explain the new subtle observations and also the differences between laser and ordinary light, to predict unexpected phenomena and to open up a new field of research. But the new theory implied that Maxwell's theory was valid for all of the optical instruments and experiments known before the new observations. As a result, Maxwell's theory will continue to be useful in much of optical and most of radioscience in the future. This allowed Mr Sillitto to conclude his most interesting talk by suggesting that an alternative title might have been 'The durability of Maxwell's electromagnetic theory'.

John Roche



Bessemer's Fixed Converter and Black body radiation.

Sir Brian Pippard: The Origins of Statistical Physics

In the closing talk, Sir Brian Pippard drew attention to one of Maxwell's major contributions outside electromagnetic theory: the introduction of statistical physics to explain the behaviour of gases. Here Clausius's 1857 paper on kinetic theory had paved the way. Maxwell later paid tribute to Clausius, saying that he had opened up a new field of mathematical physics: the study of moving systems of innumerable molecules. The kinetic theory of gases, though having ancient roots, was in a precarious state in 1857. It was not popular with the chemists, and the important principle of Avogadro, that equal volumes of different gases under the same conditions contained the same number of molecules, though first stated in 1811, was not accepted until 1860.

As early as 1738 Daniel Bernoulli, using nonstatistical Newtonian mechanics, had derived a formula in which the pressure exerted by a gas was equal to two thirds the total number of molecules times their average energy density. Others, such as Herapath, Waterston and Kronig had made important contributions to the theory, but often used inadequate mathematics. Clausius's first paper put all this work on a more rigorous footing and showed how Avogadro's law followed as a reasonable consequence. Two years later, however, following criticism that the molecules of a gas diffusing from a bottle should all reach a given point at the same time, he introduced the idea of molecular collisions and found that the probability of a molecule travelling a length x followed an exponential curve $e^{-x/\lambda}$ where λ was a constant known as the mean free path.

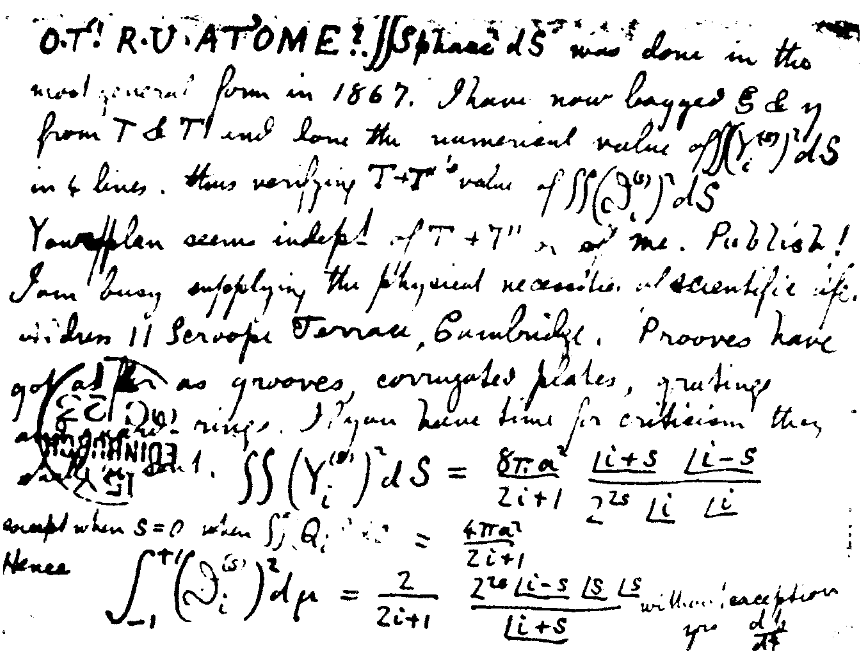
This led to Maxwell's introduction of statistical ideas. Clausius had assumed that molecules were all hard spheres travelling at the same speed, but Maxwell asked what chance there was of finding a given molecule with a given velocity, and he did something strange in the process. Wholly sold on statistics, he argued that the chance of finding a molecule moving in one direction did not depend in any way on the motions in other directions, and so came upon his famous distribution function. Jeans said in 1931 that Maxwell had reached a formula which, according to all known rules, should be hopelessly wrong, but Maxwell derived it more rigorously subsequently in a more complicated manner, showing that, if a distribution was to remain unchanged, it must have that form. This extremely important result was the beginning of statistical physics.

One application of Maxwell's theory concerned viscosity, arising from the shearing force necessary to maintain equilibrium between layers of molecules in relative motion. He set himself to show by experiment that halving the pressure would double the mean free path; and that momentum transfer and viscosity were both independent of pressure. A tradition in the Cavendish Laboratory asserted that Maxwell measured the viscosities and pressures while his wife stoked up the boilers to maintain a constant temperature. This might have been possible at 51°F but was extremely unlikely when the operating temperature was increased to 185 degrees!

The experiments showed a viscosity change of about 1.24 or 1.26, comparable to a ratio of absolute temperatures at 1.2605. The simplicity of the known gas laws then suggested that viscosity really was proportional to temperature. Unfortunately, this is not true, for the ratio is only 1.20 and viscosity is proportional to the square root of temperature for hard spheres. Maxwell explained this by introducing a force of repulsion between molecules inversely proportional to the fifth power of their separation. The effective size of the molecules was found to depend on velocity and therefore on temperature. The calculations were extremely complex and led Ludwig Boltzmann to call Maxwell a magician.

The simple mean free path argument of Clausius had, through Maxwell, effected a bloodless revolution in physics; statistical theory became inextricably mingled with the subject. Apart from such elaborately beautiful calculations as those involved in explaining the Crookes radiometer, Maxwell's remaining contributions included the consideration of systems identical in all respects except for their initial conditions of motion. This was the microcanonical ensemble, which, in the hands of Willard Gibbs, produced a powerful formulation of statistical physics. The speaker concluded an entertaining lecture with the verdict that, despite the pioneering contribution of Clausius, Maxwell was the true genius of statistical mechanics.

Peter Rowlands


O.T.! R.U. ATOME? ∬ Sphaac dS was done in the most general form in 1867. I have now bagged ξ & η from T & T' and done the numerical value of $\iint (Y_i^{(s)})^2 dS$ in 4 lines. thus verifying T+T' value of $\iint (\Theta_i^{(s)})^2 dS$

Your plan seem indep! of T+T'' & of me. Publish! I am busy supplying the physical necessities of scientific life [illegible] 11 Scroope Terrace, Cambridge. Prooves have got as far as grooves, corrugated plates, gratings [illegible] rings. If you have time for criticism they [illegible]

$$\iint \left(Y_i^{(s)}\right)^2 dS = \frac{8\pi a^2}{2i+1} \frac{\lfloor i+s \ \lfloor i-s}{2^{2s} \lfloor i \ \lfloor i}$$

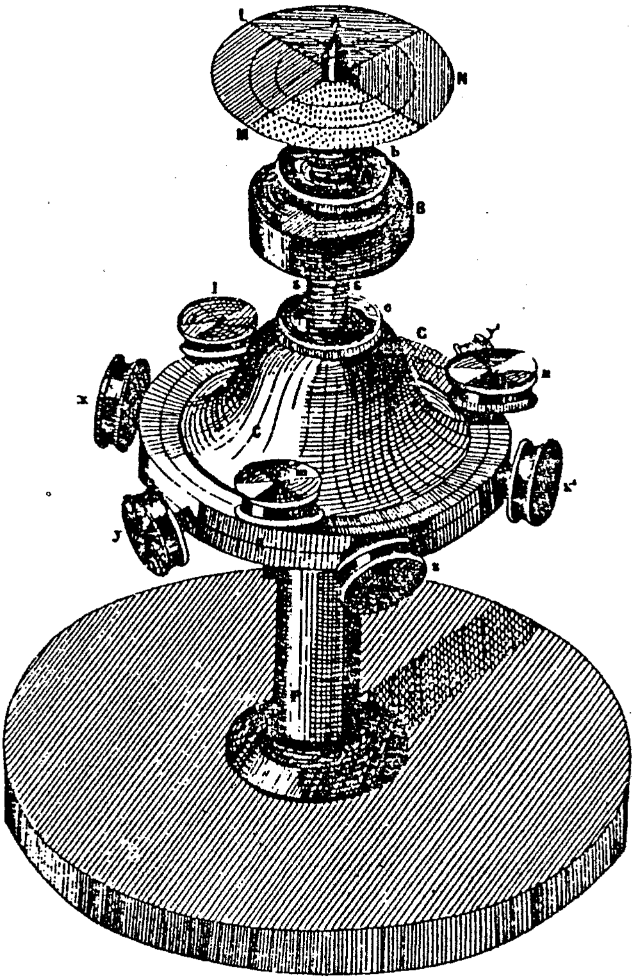
except when s = 0 when $\iint Q_i$ [illegible] $= \frac{4\pi a^2}{2i+1}$

Hence

$$\int_{-1}^{+1} \left(\Theta_i^{(s)}\right)^2 d\mu = \frac{2}{2i+1} \frac{2^{2s} \lfloor i-s \ \lfloor s \ \lfloor s}{\lfloor i+s}$$ without exception

yrs $\frac{dp}{dt}$

 Postcard from James Clerk Maxwell to P. G. Tait. *Cambridge University Library*



Maxwell's Dynamical Top. Used for 'exhibiting the phenomena of the motion of a system of invariable form about a fixed point'.

The Scientific Letters and Papers of James Clerk Maxwell Volume 1: 1846-1862

Editor

P.M. Harman, Lancaster University

This work is the first volume of a comprehensive edition of the scientific letters and manuscript papers of James Clerk Maxwell, covering the period from 1846 to 1862. It is edited and annotated with a full historical commentary by P.M. Harman. Based almost entirely on Maxwell's autograph manuscripts, many printed for the first time, it illuminates the development of his scientific work.

Maxwell's contributions to many fields of physics rank with those of Newton and Einstein and are fundamental to much of modern physics and technology. In this volume, documents are reproduced which describe Maxwell's greatest period of scientific innovation. Early works on field theory, including his announcement of the electromagnetic theory of light, as well as work in geometry, Saturn's rings, color vision and the statistical theory of gases are among the most notable writings.

This is an important book for physicists, mathematicians and historians of science. A fundamental source of reference for the study of Maxwell and his work, it will be especially relevant to university and physics departmental libraries.

1990 c. 750 pp. 11 halftones/200 line diagrams
25625-9 Hardcover

EDITORIAL

What makes a good meeting or conference? A varied selection of interesting papers, contrasting personalities, a stimulating venue, good food and smooth organisation. Stuart Leadstone, with typical care and adroitness supplied all these elements in Edinburgh, and he richly deserved the warm thanks extended to him by the participants for bringing about such an enjoyable and stimulating day.

What makes a good newsletter? Interesting articles, conference reports, notices of meetings and lectures, illustrations and layout. I would like to thank David Hooper, the previous editor, for all the time and effort that he expended on the earlier issues and the guidance that he gave me over the composition and layout of future issues.

I would also like to take this opportunity of thanking Peter Tyson for the skill with which he coped with the difficult task of taping the talks at the conference and for the advice and suggestions that he has given concerning the newsletter. Its form owes a lot to his ideas. The hard work is mine!

HISTORY OF PHYSICS GROUP COMMITTEE MEMBERS

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Newsletter Editor; Mr. R.R. Joyce, 163 Dudley Rd. Upper Gornal, Dudley, W. Midlands, DY3 1TD.

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Dr. J. J. Roche	Mrs. R. Williamson

DISCLAIMER

The I.O.P. History of Physics Group Newsletter expresses the views of the Editor or of the named contributors, and not necessarily those of the Group nor of the Institute of Physics as a whole. While every effort is made to ensure accuracy, information must be checked before use is made of it which could involve financial or other loss. The Editor would like to be told of any errors as soon as they are noted please.

LECTURES AND MEETINGS

This information has kindly been supplied by the BSHS and the BSHM and is their copyright. We have included an information leaflet concerning the activities of our sister organisation the BSHS, that our readers may find of interest. We hope to include one from the BSHM in a later issue.

XIXth International Congress of History of Science
at Zaragoza
on 22-29 August 1993
As usual the Congress will consist of Symposia which will address themes of special interest and Scientific Sessions devoted to various branches of the history of science and technology. The second circular is now available and may be requested from Mariano Hormigon, Facultad de Ciencias (Mathematicas), Ciudad Universitaria, E-50009, Zaragoza, Spain.

British Association, History of Science Section

Annual Meeting
at Keele University
on 30 August to 3 September 1993
Sessions organised by the History of Science Section are science and literature (speakers David Knight, D.G. King-Hele and Gillian Beer), the two cultures (speakers Arthur Miller, Lewis Wolpert and John Fowles) and the industrial revolution (a visit to Ironbridge (speakers Hugh Torrens and Lord Morris). Further details about the programme from Dr Frank A J L James, RICHST, Royal Institution, 21 Albemarle Street, London, W1X 4BS. Details of registration from the British Association, Fortress House, 23 Savile Row, London, W1X 1AB.

International Congress on the History of Medicine

• 34th Congress
at Glasgow
on 4-9 September 1994
The Congress is organised by the Scottish Society of the History of Medicine on behalf of the British Society for the History of Medicine. Further details from 34th International Congress on the History of Medicine, Conference Secretariat, Meeting Makers, 50 George Street, Glasgow, G1 1QE, Scotland.

Technological Change
at Rhodes House, Oxford
on 8-11 September 1993
This conference will be held in collaboration with the University of Oxford, the University of Bologna and the Science Museum. It will provide an opportunity for a fundamental re-examination of the state of the discipline of history of technology in its widest sense. Sessions on the following themes are being planned: Technology and the ancient world; Medieval technology and social change; skills and technologies in early modern Europe; technology, science and industry; technology transfer: Europe, America and the East; systems and networks, creativity and achievement in technology; images and perceptions of technology; design and technology; historiographical perspectives; work in progress (in particular students' work). Further details from Prof Robert Fox, Modern History Faculty, University of Oxford, Broad Street, Oxford, OX1 3BD.

The International Tyndall School's National Environmental Week and Festival
10 - 19 Sept 1993,
Carlow, Eire.
Contact I.T.S. Office, Carlow Festivals Centre, Tullow St, Carlow. 010 353 503 40635.

British Society for the History of Mathematics

• The History of Computing
at Rewley House, Oxford
on 18-19 September 1993
Speakers will include Bill Aspray, Martin Campbell-Kelly, Mary Croarken, Robin Gandy, Willem Hackmann, Eduardo Ortiz and Steve Russ. Further details from Raymond Flood, Rewley House, 1 Wellington Square, Oxford, OX2 7QE.

Society for the History of Natural History

• Natural History and Literature (1650-1850)
at Bishop Otter College, Chichester
on 23-25 September 1993
The papers in this conference will be grouped into three major themes, The Antediluvians, The Ancients and Antiquarians, and The Moderns. In addition, there will be dramatic monologues at the Minerva Theatre, a conference dinner, and visits to local sites of historical interest. Further details from Dr Paul Foster, Bishop Otter College, College Lane, Chichester, West Sussex, PO19 4PE.

Royal Institution Centre for the History of Science and Technology

• Research Seminars
at the Royal Institution
on 28 June and 27 September 1993 at 4.30
These will be respectively Dr Alison Winter (The Public Construction of Expertise in Victorian Britain: Airy, Scoresby and Navigation in Iron Ships) and Dr Gloria Clifton (The Computerisation of History: The Project SIMON Database of Scientific Instrument Makers) Further details from Dr Frank A J L James, RICHST, Royal Institution, 21 Albemarle Street, London, W1X 4BS.

• Science Lecturing in the Eighteenth Century
at the Science Museum London
on 13 November 1993
This meeting will be held in conjunction with opening of an exhibition at the Science Museum entitled "Science in the eighteenth century: The King George III Collection". The speakers will be Pat Fara, Alan Morton, Roy Porter, Steve Pumfrey, Simon Schaffer, Larry Stewart, Hugh Torrens and Jane Wess. Further details from Dr Alan Morton, Science Museum, Exhibition Road, South Kensington, London, SW7 2DD.

Scientific Instrument Society

• First Invitation Lecture
at The Society of Antiquaries, Burlington House, Piccadilly, London, W1
on 17 November 1993, 6.30 - 8.30 pm
The Society's first Invitation Lecture will be given by Dr R G W Anderson, Director of the British Museum, on "People and Museums: Expectations and Responses". This is a public lecture and admission is free. Details from Trevor Waterman, Meetings Secretary, 75a Jermyn Street, London SW1Y 6NP.

The Problems of Replication
in March 1994
at Nuffield Curriculum Centre
This meeting will include papers, demonstrations and discussion on the value of replicating historic experiments, both for historians and for educators. Further details from the BSHS Programme Secretary, Dr Stephen Pumfrey, Dept of History, University of Lancaster, Lancaster, LA1 4YG.

Making Space: Territorial Themes in the History of Science
at University of Kent at Canterbury
on 28-30 March 1994
The conference aims to focus on themes such as the construction of boundaries around or between academic disciplines, privileged sites for science, spatiality and representations (cartography, stereography, etc), spatiality of technologies such as telegraphy, transport, radio, the politics of space, imperial and colonial science, space in social theory, the historiography of space. A call for papers is circulated with this *Newsletter*. Further details from Dr Crosbie Smith, History of Science Unit, Physics Laboratory, University of Kent, Canterbury, Kent, CT2 7NR.

The Outsider in Science
in London
in May 1994
The theme of the meeting is to consider the life and work of figures who made and published notable contributions to science which were only partly recognised (or not at all) in their lifetimes and who never gained proper professional recognition. Prospective speakers are invited to submit, by 1 September 1993, a title and 100 word abstract to I Grattan-Guinness, 43 St Leonard's Road, Bengeo, Hertfordshire, SG14 3JW (for physics, mathematics and engineering) or Roy Porter, Wellcome Institute for the History of Medicine, London, NW1 2BN (for chemistry, geology, life sciences and medicine).

Science and British Culture in the 1830s
at Trinity College Cambridge
on 6-8 July 1994
This meeting, which is being held on the occasion of the bicentenary of the birth of William Whewell, is in the early stages of planning. Offers of papers to and further details from either Dr Geoffrey Cantor, Department of Philosophy, University of Leeds, Leeds, LS2 9JT or Dr Simon Schaffer, Department of History and Philosophy of Science, University of Cambridge, Free School Lane, Cambridge, CB2 3RH.

ICOHTEC

Annual Meeting
at Bath
in July / August 1994
Further details from Prof R.A. Buchanan, Centre for History of Technology, University of Bath, Claverton Down, Bath, Avon, BA2 7AY.

The British Society for the History of Mathematics. NEWSLETTER

18-19 September 1993

THE HISTORY OF COMPUTATION

Speakers at the BSHM autumn residential meeting, at Rewley House, University of Oxford, include Bill Aspray—*von Neumann* • Martin Campbell-Kelly—*Victorian data-processing* • Mary Croarken—*L.J. Comrie: a centenary talk* • Robin Gandy—*after-dinner talk* • Willem Hackmann—*computational instruments in the Museum of the History of Science* • Eduardo Ortiz—*from tables to algorithms* • Steve Russ—*the history of algorithms* • Ian Stewart—*the unfolding of chaos* • Doron Swade—*Charles Babbage* • Glan Thomas—*Boole and AI* • John Tucker—*on the history of software* • Sister Benedicta Ward—*Bede and the computus*

16 October 1993

WILLIAM ROWAN HAMILTON AND THE DISCOVERY OF QUATERNIONS

This meeting will be held at Imperial College, London, on the 150th anniversary of Hamilton's discovery of quaternions. Further details of the programme in the next newsletter.

18 December 1993

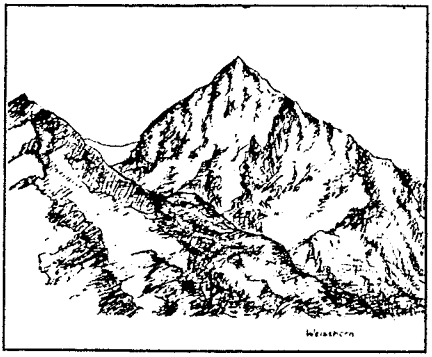
BSHM CHRISTMAS MEETING AND AGM

The speakers at this meeting include BSHM former president The Very Revd Columba Graham Flegg, who will give a talk to commemorate the fiftieth anniversary of the death of the Russian mathematician and theologian St Pavel Florensky.

26 February 1994

RESEARCH IN PROGRESS

The third in the annual series of research days, to be held at Imperial College London.



Weisshorn, first ascent by John Tyndall F.R.S. in 1861.

JOHN TYNDALL F.R.S. (1820-1893)

Tyndall was born in Leighlinbridge on the border of Carlow-Kilkenny and was a man of humble origins but great determination. He conducted pioneering work to perform the first quantitative researches into meteorology, atmospheric and water pollution, studies of floating matter in the air (to found with Pasteur the science of bacteriology), discovered the greenhouse effect, identified the chemical nature of ozone via spectroscopic analysis and made an immense contribution to scientific education. All of these achievements are to be celebrated in the *ITS National Environmental Week and Festival.*

On par with his intellectual achievements his legendary physical daring that helped to found the modern sport of mountaineering will also be celebrated in *The Tyndall Challenge* and *Tyndall Mountaineering Forum* during 1993.

THE I.T.S. NATIONAL ENVIRONMENTAL WEEK AND FESTIVAL: A NEW DEPARTURE IN THE HISTORY OF PHYSICS

The *International Tyndall School's* National Environmental Week and Festival taking place from 10-19 September 1993 is intended to establish in Carlow an Environmental Event of considerable and lasting importance on a national and international level.

July and the *Tyndall Challenge* will see the launch of the event by the Tyndall Mountain Club who will attempt in a strenuous two weeks to repeat Tyndall's most famous first ascent of the Weisshorn (1861) and traverse of the Matterhorn (1867) to Pic Tyndall.

This event is probably the first of its kind to be established in the British Isles as the ITS aims to annually celebrate a major historical figure who was one of the first scientists to define himself a "physicist" as opposed to the less professional natural philosopher.

The NEW Festival will comprise the following Events:-

The International Ecological Forum
11-19 September

Agrifood and the Environment Conference
13-14 September

Monitoring the Environment - Future Trends Conference
15-16 September

The Public Health and Safety Programme
16 September

Institute of Physics Radon School
15-16 September

Assessing the Environmental Impact of Food Production Conference
16-17 September

The Tyndall Mountaineering Conference and Exploration Programme
13-19 September

The event will be launched by the Institute of Physics ITS Lecture entitled *Sounds of Music* to be delivered by Professor Charles Taylor at the Royal Institution of Great Britain at 8 p.m. on 10th September and will be transmitted live to Tyndall's birthplace of Carlow and on to the Universities of Columbia and Pennsylvania via a satellite link. It is hoped that in Carlow for this launch will be Ireland's Taoiseach Albert Reynolds who will open the evening before handing over to Professor Peter Day, Director RI to introduce the lecturer. We also hope to produce a launch video for sale.

These American universities by receiving this lecture will be honouring Tyndall's contribution to the development of their first research facilities monies for which he raised on his Grand Lecture Tour of the States in 1872. Also he donated all his lecture fees to found Tyndall Scholarships in these universities for poor American students to study in Europe and which are running to this day. The proceedings of the conferences will be published in hardback by ASAE(American Society of Agricultural Engineers) and available to libraries around the world.

There are numerous other IOP events and activities with Brian Davies' Inaugural Dargan Lecture on "Science and Art", The Beauty of Physics Exhibition which will be a central element in the Festival Centre Exhibition Centre and lectures contributed by the IOP's Environmental Group at the *Monbitoring the Environment - Future Trends* Conference.

I will be giving a paper on "Tyndall and Materialism" in the Philosophical School which will be debating the philosophy of environmentalism. Also presenting papers will be two major international figures - Professor Richard Kearney on "Enlightenment and Counter-enlightenment - Philosophy in Ireland" and Richard Douthwaite on "The Growth Illusion".

The whole environmental event will be supported by a continuous week of public environmental, cultural and social events that comprise Carlow Feile an Fhomhair (Autumn Festival). There will be exhibitions of art, crafts, history, photography and science. There will be environmental quizzes, lectures on history, science and famous Irishmen of the region and an International Students Environmental Meeting. During the day there will be sports aplenty and guided trips taking in some of the history and sights of the South-East and Ireland's finest gardens and castles. At night the town will be alive with traditional Irish dance, music, theatre, poetry, and drama of all kinds to entertain all visitors to the region.

The last wolf in the British Isles was killed by the wolfhounds of John Watson of Ballydarton in Carlow in 1786.

From September 5th to early December of 1860 Tyndall was working eight to ten hours a day on the absorption of radiant heat by gases and vapours, where he had a virgin field of discovery as suggested to him by his earlier work on glaciers. It was in these pioneering studies that Tyndall laid the groundwork for the new sciences of environmental monitoring and which he developed over the next decade with his quantitative researches in atmospheric monitoring, light scattering and pollution monitoring of water and air. Continuing from this work his collaboration with Pasteur to establish the science of bacteriology opened up another major field of scientific endeavour. This historical research is collected in his "Contributions to Molecular Physics" (1872) and "Floating Matter of the Air" (1881).

President Mary Robinson is patron of the event and has provided a piece for the General Brochure(there are 7 brochures for each of the events) and it is also of significance that this is the first summer school to be held in the Republic for a man who was an avowed Unionist.

The National Environmental Week will build considerably on the IOP Tyndall Lecture Series which I established in 1977 with the help of the RI and which was graced in its first year by Charles Taylor's marvellous lecture on *Sounds of Music*. Today the Tyndall Schools Lecture is the major lecture event in the Irish school's calendar. The central role played by the Irish in general and Tyndall in particular in establishing the profession of physics has been documented in a paper in Physics Education(1). It is clear that Tyndall as the first examiner in physics for the Department of Arts and Science and the man who wrote all of the most influential first generation school texts books is someone whom the IOP should justifiably honour by leading the celebrations in this his centenary year.

The ITS National Environmental Week and Festival with its ambitious scope is a *unique* opportunity to internationalize Ireland's 'green and clean' reputation for the future development of agriculture, industry and tourism while preserving a healthy environment for our future generations. It will be a week of real Irish culture and "craic"(a word from the Irish which has to be experienced rather than explained but has a little to do with a certain dark fluid!).

Next year we hope that there will be an added Tyndall History of Physics Conference so please get in touch if you have any ideas.

Make sure and book your place for this ITS National Environmental Week and Festival and bring the family who will find the entire region alive with activities for young and old alike. Contact The ITS Office, Carlow Festivals Centre, Tullow Street, Carlow 010 353 503 40635 FAX 41053.

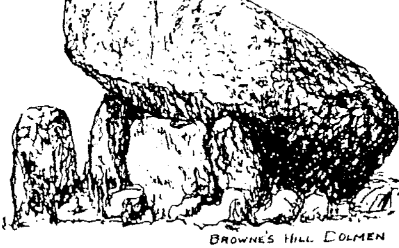
Dr N D McMillan
Director ITS

REFERENCE

McMIllan N.D., British physics-the Irish role in the origin, differentiation and organisation of a profession, Phys. Educ.23,272-278,1988.

Organisers

The Institute of Physics (Irish Branch), SPIE — The International Optical Engineering Society, The Institute of Physics, Teagasc, The Institute of Biology of Ireland, The Institution of Engineers of Ireland, Institute of Electrical Engineers (Irish Centre), The Institute of Chemistry of Ireland, Royal Society of Chemistry (Irish Centre), Federation of Irish Chemical Industries, Radiological Protection Institute of Ireland, Irish Congress of Trade Unions, MSF, Irish Science Teachers Association, FÁS, ASH Ireland, Irish Heart Foundation, An Taisce, Amnesty International, Earthwatch, Self Help Development International, Concern, Irish Wildbird Conservancy, Irish Wildlife Federation, Irish Organic Farmers & Growers Association, RSPB (Northern Ireland), Irish Peatland Conservation Council, Sonairte, Teachers Union of Ireland, Greenpeace, Coillte Teoranta, Navan at Armagh, Burren Action Group, Friends of the Earth, Vegetarian Society, Compassion in World Farming, Energy Conservation Association of Ireland, Cork Environmental Alliance, Tyndall Mountain Club, Carlow County Council, Carlow Urgan District Council, Carlow Regional Technical College, Carlow Chamber of Commerce, South East Regional Tourist Organisation.



BROWNE'S HILL COLMEN

MADAME ERMITRUDE BIBLIOPHILE'S CABINET OF WONDERS

The following are extracts from Victorian and Edwardian books. They are included for interest and also to exhibit the richer quality of prose and illustration compared to our modern journals and textbooks. Various reasons of cost, labour, society and education can be cited as reasons but it remains that a Victorian book with its engravings and text has a charm and pleasure that is missing in today's publications. If readers know of examples that generate this, please write in with a photostat and reference and we will publish some in a future issue.

From 'Curiosities of Science' by John Timbs F.S.A. 1858 London, Kent and Co.

LIFTING HEAVY PERSONS.

One of the most extraordinary pages in Sir David Brewster's *Letters on Natural Magic* is the experiment in which a heavy man is raised with the greatest facility when he is lifted up the instant that his own lungs, and those of the persons who raise him, are inflated with air. Thus the heaviest person in the party lies down upon two chairs, his legs being supported by the one and his back by the other. Four persons, one at each leg, and one at each shoulder, then try to raise him—the person to be raised giving two signals, by clapping his hands. At the first signal, he himself and the four lifters begin to draw a long and full breath; and when the inhalation is completed, or the lungs filled, the second signal is given for raising the person from the chair. To his own surprise, and that of his bearers, he rises with the greatest facility, as if he were no heavier than a feather. Sir David Brewster states that he has seen this inexplicable experiment performed more than once; and he appealed for testimony to Sir Walter Scott, who had repeatedly seen the experiment, and performed the part both of the load and of the bearer. It was first shown in England by Major H., who saw it performed in a large party at Venice, under the direction of an officer of the American navy.*

Sir David Brewster (in a letter to *Notes and Queries*, No. 143) further remarks, that "the inhalation of the lifters the moment the effort is made is doubtless essential, and for this reason: when we make a great effort, either in pulling or lifting, we always fill the chest with air previous to the effort; and when the inhalation is completed, we close the *rima glottidis* to keep the air in the lungs. The chest being thus kept expanded, the pulling or lifting muscles have received as it were a fulcrum round which their power is exerted; and we can thus lift the greatest weight which the muscles are capable of doing. When the chest collapses by the escape of the air, the lifters lose their muscular power; reinhalation of air by the liftee can certainly add nothing to the power of the lifters, or diminish his own weight, which is only increased by the weight of the air which he inhales."

* This curious fact was first recorded by Pepys, in his *Diary*, under the date 31st of July 1665.

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We remind readers that such activities should not be performed by except by trained athletes.
It is pointed out in the HOP's Health and Safety Guidelines that a team of paramedics and academics together with resuscitation equipment must be on hand before the attempt. In the case of female practitioners a gynaecological and perhaps maternity unit would also be recommend

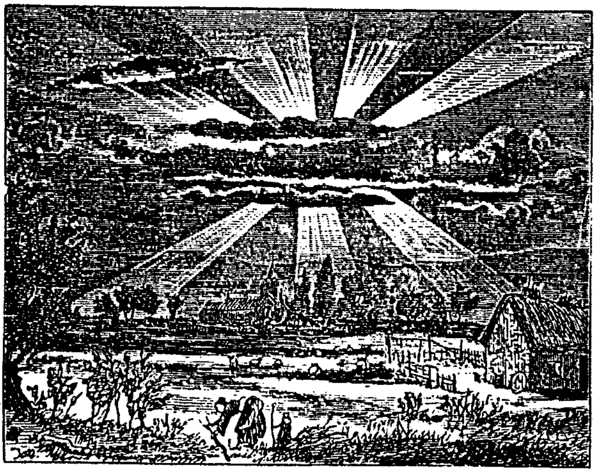
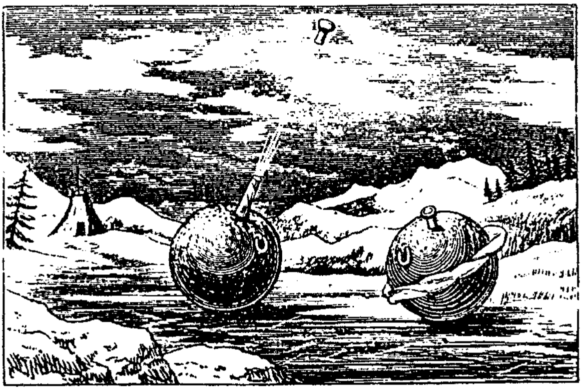
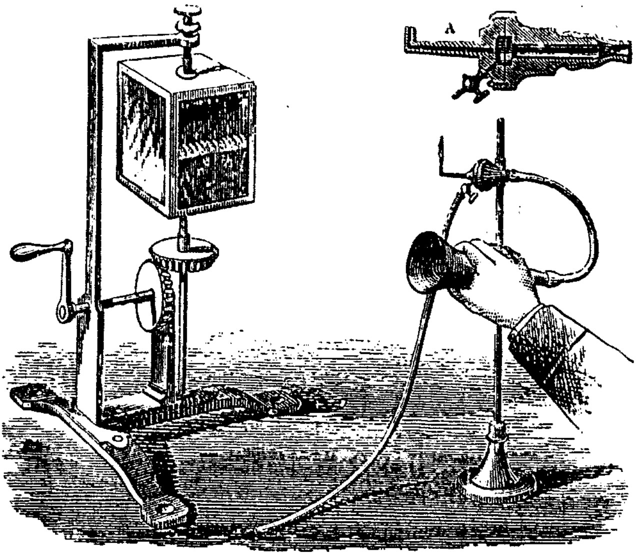


Fig. 48. - LIGHT PROCEEDS IN STRAIGHT LINES. Reference to be published in the next issue.

MR. PHACTPHINDERS PARAPHERNALIA

The following illustrations are published without any explanation. We hope that they stimulate readers' curiosity and imaginations as to the purpose for which they were used. If you think that you know or have an ingenious or amusing idea then please write in and we will publish the best entries along with the true purpose.





Maxwell's Dynamical Top

Dr Roger C Clark, Department of Mathematical Sciences, Aberdeen University.

Maxwell designed his dynamical top (Fig. 1) specifically *'for exhibiting the phenomena of the motion of a system of invariable form about a fixed point'* [1]. As the motion is exhibited by means of a coloured disc, there can be and has been confusion between his dynamical top and the colour top or teetotum which Maxwell used in his experiments on colour mixing. This is the device he is seen holding in the portrait painted when he was at Trinity College, Cambridge in 1855. A full description of this teetotum (Fig. 2) is given in the manuscript *"On the comparison of colours using a spinning top"* [2]. By contrast, the dynamical top is carefully designed with sufficient adjustments to enable the centre of mass to be positioned precisely at the point of support, the axle to be made a principal axis of inertia and for each of the principal moments to be varied relative to one another. It is first referred to in a letter Maxwell wrote from Trinity to his father in February 1856 [3] where he says *'I took my great top there and spun it with coloured discs attached to it. I have been planning a form of top, which will have more variety of motion, but I am working out the theory so I will wait till I know the necessary dimensions before I settle the plan.'* The 'great top' mentioned here is perhaps the simple top (Fig. 3) (which has no adjustments) that is now in the Cavendish Laboratory, Cambridge along with Maxwell's own dynamical top. [4]

A version of the top was demonstrated to the British Association meeting in Cheltenham in August 1856 [5]. The body of that version was made of wood but it had an iron axle with a steel point. On the axle was an iron nut which served the same purpose as the brass bob on the tops made in Aberdeen. It only had four horizontal bolts for adjusting the centre of mass, instead of six, but, where the later version has three vertical screws, the earlier version had four.

The final brass version was built in Aberdeen by Charles Ramage of the instrument makers Smith and Ramage and was demonstrated to the Royal Society of Edinburgh in April 1857. [1] By December of that year, Ramage was making four tops *'for various seats of learning'* [6]. It is clear from Maxwell's letters that among these were Durham [7] (to R.B. Hayward), Edinburgh [8] (to J.D. Forbes) and Cambridge [9] (to lecturers at Trinity). Maxwell's own version of the top went with him when he moved to Kings College, London [10] and from there to Cambridge. In 1859, a letter accompanying a top sent to P.G. Tait mentions that the Trinity lecturers had *'broke the cup of theirs by bumping it down inconsiderately'.* [9] It also describes a short handle enabling the user *'to spin it and prevent drilling of the finger'*. This was needed because the upper end of the axle is as pointed as the lower end. Maxwell had at one time visualised mounting the top like a gyroscope with the upper end guided by 'a separately balanced swing-frame'. [11]

When he demonstrated the top in Edinburgh in 1857 Maxwell was particularly proud of two innovations. The first was the use of the coloured disc to show the movement of the 'invariable axis' - the angular momentum vector - relative to the axle of the top. The second was his simplification of the mathematics describing this motion by use of the conservation of angular momentum and energy. In his paper he wrote '*The optical contrivance for rendering visible the nature of the rapid motion of the top, and the practical methods of applying the theory of rotation to such an instrument as the one before us, are the grounds on which I bring my instrument and experiments before the Society as my own*'. [12] The following month in a letter to Stokes [13] he wrote '*I have had a dynamical top of brass made at Aberdeen and have been simplifying the theory of the motion of the "invariable axis" (normal to the invariable plane) in the body. The extremity of this axis describes spherical ellipses about the greatest or least principal axes.....*'

Maxwell's method of deriving this motion is still used by modern textbooks on classical mechanics to describe force-free rotation of a rigid body. [14] He showed that the theory can be deduced '*as briefly as possible from two considerations only, - the permanence of the original angular momentum in direction and magnitude and the permanence of the original vis viva.* [15] In modern notation this implies that both

$$L^2 = L_x^{\ 2} + L_y^{\ 2} + L_y^{\ 2}$$

and

$$T = \frac{L_x^{\ 2}}{2I_x} + \frac{L_y^{\ 2}}{2I_y} + \frac{L_z^{\ 2}}{2I_z}$$

are constant where L_x, L_y and L_z are the components of the angular momentum vector L in the axes of the body and I_x, I_y, I_z are the principal moments of inertia. Hence, Maxwell concluded, the angular momentum vector sweeps out a cone that passes through the intersection of these two surfaces. He goes on to calculate the rate at which L describes this path by observing that '*Since the invariable axis is fixed in space its motion relative to the body must be equal and opposite to that of the portion of the body through which it passes*'. [16]

Maxwell describes how to use the coloured disc to set up the axle as one of principal axes of inertia. This is done by watching the changing colour of the centre of motion when the top is spun initially about its axle. '*If the axis about which the top is really revolving, falls within this disc, its position may be ascertained by the colour of the spot at the centre of motion. If the central spot appears red, we know the invariable axis at that instant passes through the red part of the disc*'. [17] Adjustment of the vertical screw nearest the red part of the disc can then be made to reduce the wandering of the axis of rotation from the axle.

After being set up the spinning top must be given a sharp knock to set it spinning about an arbitrary axis. Its behaviour is then determined by the relative values of the principal moments of inertia. Maxwell describes each possible case. If the axle is the axis of the greatest principal moment of inertia the colours are seen in the same order as they appear on the disc in the direction of spin of the top. If the axle corresponds to the least moment of inertia the colours are seen in the opposite order. The greater the ratio of these two moments, the faster the colours change while the angular momentum vector describes a small ellipse. Finally, as Maxwell points out, '*If the axle be made the mean axis, the path of the invariable axis will be no longer a closed curve, but an hyperbola, so that it will depart altogether from the neighbourhood of the axle*'.[18]

He concludes his paper by postulating that the same type of precession might be seen in the earth's motion, while admitting that it could be heavily damped. He predicted the period of this precession to be 325.6 solar days. [19] There is a wobble of the earth's axis with a period of about 420 days, the Chandler wobble, that is believed to be due to the force-free precession Maxwell described. However the correspondence between Maxwell's prediction and the Chandler wobble is not simple. [20]

The top spun in the video demonstration was sold in 1885 by Harvey and Peak the instrument makers of Beak Street, London. It was purchased at that time for six guineas by Professor Charles Niven for Aberdeen University. [21]

Acknowledgements

I am grateful to Mr Stuart Leadstone for suggesting that a video of Maxwell's Dynamical Top should be made, to Mr John Sangster for his able assistance in producing the video and to Dr John S. Reid and the staff of the Physics Unit of Aberdeen University for their help.

References

Most of the references can be found either in '*The Scientific Papers of James Clerk Maxwell*', edited by W.D. Niven; Vol. 1; Cambridge University Press 1890, (hereafter referred to as 'Scientific Papers', 1) or in '*The Scientific Letters and Papers of James Clerk Maxwell*'; edited by P.M. Harman; Vol. 1, 1846-1862; Cambridge University Press 1990 (hereafter referred to as 'Scientific Letters, 1).

1. *'On a Dynamical Top, for exhibiting the phenomenon of the motion of a system of invariable form about a fixed point, with some suggestions as to the Earth's motion'*. Trans. Roy. Soc. Edin. 21, (1857), 559-70. (Scientific Papers, 1, 248-62).

2. Manuscript on the Comparison of Colours using a Spinning Top. *'Description of the Chromatic Teetotum as constructed by Mr J.M. Bryson, Optician Edinburgh'*. 1855. (Scientific Letters, 1, 284-6); see also *'Experiments on Colour, as perceived by the Eye, with remarks on Colour Blindness'*. Trans. Roy. Soc. Edin. 21, (1855), 275-98. (Scientific Papers, 1, 126-54).

3. Letter to John Clerk Maxwell, 14 February 1856, (Scientific Letters, 1, 384).

4. I am grateful to Dr Peter M. Harman and to the Cavendish Laboratory (private communications) for clarifying this point.

5. *'On an Instrument to illustrate Poinsôt's Theory of Rotation'*. Report of the twenty-sixth meeting of the British Association for the Advancement of Science; held at Cheltenham in August 1856. (Scientific Papers, 1, 246-7).

6. Letter to Lewis Campbell 22 December 1857 (Scientific Letters, 1, 576).

7. Letter to Peter G. Tait 21 November 1857 (Scientific Letters, 1, 558).

8. Letter to James D. Forbes 26 November 1857 (Scientific Letters, 1, 568).

9. Letter to Peter G. Tait 9 March 1859 (Scientific Letters, 1, 604).

10. Letter to Michael Faraday 21 May 1861 (Scientific Letters, 1, 681).

11. Letter to James D. Forbes 30 March 1857 (Scientific Letters, 1, 497).

12. Reference 1 page 249.

13. Letter to George G. Stokes 8 May 1857 (Scientific Letters, 1, 502-4).

14. Herbert Goldstein, '*Classical Mechanics*', 2nd Edition. 1980 Addison-Wesley. pp 208-9

15. Reference 1 page 250.

16. Reference 1 page 253.

17. Reference 1 page 257.

18. Reference 1 page 258.

19. Reference 1 page 260.

20. Reference 14 page 212.

21. Revised Catalogue of Scientific Apparatus; Harvey and Peak, Beak Street, Regent Street, London W; 1885. Entry 696 '*Maxwell's Dynamical Top, for illustrating phenomena of rotation. The top is made with all parts and adjustments correctly to size and weight as described by the late Professor Maxwell; packed in mahogany case...£6 6 0.*' (I am grateful to Dr John S. Reid for bringing this to my attention).

Fig. 3

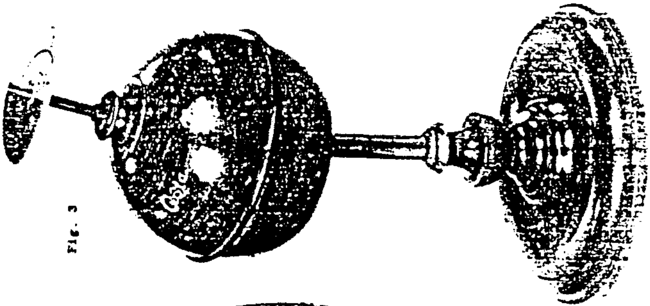


Fig. 2

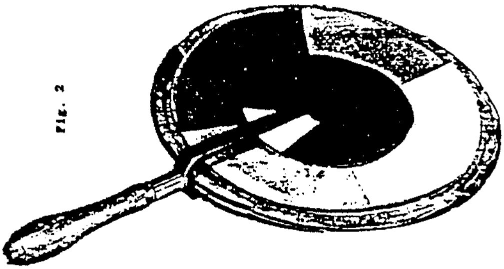


Fig. 1