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Notes on the life of Maxwell:
Beyond the Classification of Physical Sciences*

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James Clerk Maxwell

- birth: 13 June 1831 (Edinburgh)
- death: 5 November 1879 (Cambridge)
- father: John Clerk Maxwell (died: 3 April 1856)
- mother: Frances Cay (died: 6 December 1839)
  - married: 4 October 1826
    father: 38y. mother: 34y.

1. Edinburgh : 1847(16y.)-1850(19y.)

Maxwell entered University of Edinburgh, 1847 Autumn.

William Hamilton's class in Logic, Maxwell had taken detailed notes of his lecture, and he considered it the most substantial of the lectures he had attended.

Maxwell also attended Hamilton's class on Metaphysics. Hamilton formed a high estimate of Maxwell's abilities, and these lectures left a lasting impression, encouraging his abiding concern to establish the conceptual rationale of his physics by appeal to philosophical argument.

Later, Hamilton wrote testimonial, dated 26 February 1856, for Maxwell's candidature for the Professorship of Natural Philosophy at Marschal College, Aberdeen.

Draft on the interpretation of Lagrange's and Hamilton's equations of motion. By J. Clerk Maxwell, Prof. of Experimental Physics, Cambridge, July 1872.

'The following statement has nothing original in it, but I think that our attention cannot be too often directed to the most important theorem in physical

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*From the title of Maxwell's article on 'Physical Sciences', in *Encyclopaedia Britanica* (9th edn) **19** (Edinburgh, 1885) p.1-3.
The original title of manuscript read 'The classification of the physical sciences'.

science – that which deduces, from the given motion of a connected system, the forces which act on it.'

W. R. Hamilton's publications :
'On a general method in dynamics', Phil. Trans. 1834,
'Second Essay on a general method in dynamics', Phil. Trans. 1835.

In his post card to Tait at 13 July 1871, Maxwell confessed his total ignorance of Hamilton's 4 papers:
'Theory of systems of rays', Transactions of the Royal Irish Academy, **15** (1827), **16** part 1 (1830), **16** part 2 (1831), **17** (1832).

George Boole (1815-1864)
Maxwell was strongly attracted by Professor Boole's course on Mathematical Analysis of Logic.
Boole's publications:
'Mathematical Analysis and Logic', 1847,
'An investigation of the laws of thought',1854.

Edinburgh → Cambridge

During the third session at Edinburgh University (in 1849-50) he began preparation to go up to Cambridge, settling on Peterhouse after much discussion.
In July and early August of 1850 he attended the meeting of British Association for Advancement of Science in Edinburgh.
Being stimulated by Sir David Brewster and Professor Stokes, he published a paper 'On experiment on the cause of Haidingers Brushes' on 5 August 1850 during the above meeting held at Edinburgh in July and August 1850.

'As the structure of the human eye has been minutely studied by many anatomists and optitians, the unexpected discovery of a polarizing apparatus in the living eye would lead us to think that some important part of the eye had escaped the observation of the oculists.'

2. Cambridge : 1850(19y.)-1855(24y.)

1850 Autumn, Maxwell arrived at Cambridge.
His mentor Forbes wrote a strong recommendation letter to William Whewell, Master of Trinity College.

December 1850 he migrated to Trinity.

The course of study at Cambridge was exacting for the competitive examinations.
The first academic hurdle to be surmounted was the Previous Examination, which Maxwell sat in March 1852.

In that year candidates were requested to display familiarity with the Gospel of St. Matthew (in the original Greek).

According to P. M. Harman, editor of the scientific letters and papers of James Clerk Maxwell, Cambridge University Press, 1990 and 1995, after the freedom and vitality of his Edinburgh years, Maxwell was not totally enamoured of Cambridge life.

In the Tripos examination in January 1854 Maxwell graduated second wrangler to E.J.Routh, but was bracketed equal Smith's Prizeman with Routh in the examination for Smith's Prizes which followed.

The next step was to be elected to a Fellowship in Trinity, but he was unsuccessful at his first attempt in October 1854. Forbes wrote to Whewell of Maxwell's 'disappointment of a fellowship', and in reply Whewell observed that;

I am sorry that Maxwell is in anxiety. I consider his chance of a Fellowship here next to certain, though it would be well that he should attend to his classics more than he has done, and give some neatness and finish to his mathematics: but I should like to know that he would be willing to labour in College as a mathematical lecturer for some years when he is elected. ... if you should happen to know Maxwell's intentions and plan of life, I should be obliged if you would tell me. '

In the event he was elected a Fellow of Trinity in October 1855, and immediately found himself engaged in college lecturing.

During his years as undergraduate Maxwell had attempted to reformulate mathematically Faraday's extraordinary series of experimental discoveries, of electromagnetic induction, the laws of electrochemistry, and magneto-optical rotation.

Thanks to William Thomson he could see 'Disquisition generals circa superficies curves', by M. C. F. Gauss (1827).

13 March 1854 'On the transformation of surfaces by bending.'
10 December 1855 'On Faraday's lines of Force (Part I)'
11 February 1856 (Part II)
13 February 1856 Letter from Forbes

Professorship of Natural Philosophy at Marschal College, Aberdeen was vacant.
Maxwell decided to apply the post to please his father.
Maxwell's father suddenly died 3 April 1856 at his house, Glenair.

Letter of 30 April 1856 from Forbes;

My Dear Sir,

I have just seen in the newspaper that you have been appointed to the Chair in Marschal College, on which I beg sincerely to congratulate you.
I regret much that it should at the same time be my lot to express my sympathy on the occasion of the recent death of your father.
Such a loss occurs but once in a lifetime. In your case I am sure that it has the greatest alleviation which it admits of – I mean the consciousness that you have been an affectionate and dutiful son, and that your excellent conduct relieved your father's mind from every shade of anxiety regarding you.
Believe me always, your very sincerely,

James D. Forbes.

3. Marschall College : 1856(25y.)-1860(29y.)

Inaugural lecture at Marschal College, Aberdeen, 3 November 1856.

Maxwell completed Adams Prize essay on Saturn's ring in December 1856. The paper was published in 1859.

June 1858, Maxwell married Katherine Mary Dewar, daughter of Principal Dewar of Marschal College.

In 1857 Maxwell was appointed Commissioners to administer the Act of Parliament which enacted the union of King's and Marschal Colleges to form the University of Aberdeen.

The Commissioners had to decide whether to recommend either the union of the colleges (with the retention of existing classes) or their 'fusion', which would leave a single class and professor in each subject and would have the consequence that redundant professorships would be abolished. Maxwell was at first strongly in favour of fusion; but when the Commissioners reported early in 1860, recommending fusion they proposed that the Professorship of Natural Philosophy in the University of Aberdeen should be held by David Thomson, the King's College professor. Writing to Monro in 24 January 1860, Maxwell announced that "As to Nat Phil I am to be turned out by the Commissioners (that is if their ordinances are to be carried)."

In his letter of 22 December 1857 to Campbell, Maxwell stated as follows:

"College Fusion is holding up its head again under the fostering care of Dr.David Brown (father to Alexander of Queen's). Know all men I am a Fusionist, and thereby an enemy of all the respectable citizens who are Unionists (that is, unite the three learned faculties, and leave double chairs in Arts). But there is no use writing out their theory to you. They want inferior men for professors – men who will find it their interest to teach what will pay to small classes, and who will be more under the influence of parents and the local press than more learned or better paid men would be in a larger college."

1859

'On the mean length of the paths described by the separate molecules of gaseous bodies in the occurrence of molecular motion: together with some other remarks upon mechanical theory of heat' by Rudolf Clausius, trans. Phil. Mag.**17**(1859) p.81-91, original: Ann. Phys.**105**(1858) p.239-58

Letter to Stokes 30 May 1859.

Reading the Phil. Mag. Feb. Issue, Maxwell wrote a paper to be submitted to the 29th Meeting of the British Association for the Advancement of Science,held at Aberdeen in September 1859.

In the paper entitled "On the Dynamical Theory of Gases" he clearly stated as:

"The author has established the following results:

1. *The velocities of the particles are not uniform, but vary so that they deviate from the mean value by a law well known in the 'method of least squares'.*
2. *Two different sets of particles will distribute their velocities, so that their vires vivæ will be equal, and this leads to the chemical law, that*

the equivalents of gases are proportional to their specific gravities. From Prof. Stoke's experiments on friction in air, it appears that the distance travelled by particle between consecutive collisions is about 1/477,000 of an inch, the mean velocity being a bout 1505 feet per second.

3. *The laws of the diffusion of gases, as established by the Master of the Mint, are deduced from this theory, and the absolute rate of diffusion through an opening can be calculated. The author intends to apply his mathematical methods to the explanation on this hypothesis of the propagation of sound, and expects some light on the mysterious question of the absolute number of such particles in a given mass."* (under line by T.T.)

Maxwell was always deeply concerned with experimental works. This can be seen in the following paper.

J.C. Maxwell, 'On Loschmidt's experiments or diffusion in relation to the kinetic theory of gases', Nature, **8** (1873) p.298-300

Maxwell failed to retain his post in Aberdeen and to be appointed at Edinburgh as a successor of his mentor Forbes. Instead his old schoolfellow P. G. Tait was appointed.

4. King's College : 1860(29y.)-1865(34y.)

In July 1860, appointed Professor of Natural Philosophy at King's College, London.

Inaugural Lecture at King's College, London, October 1860.

During his stay at chair of King's College in London, Maxwell was co-opted as a member of the British Association Committee on standards of electrical resistance in 1862. One of his classmates at University of Edinburgh, Fleeming Jenkin joined the committee, who had invented the centrifugal governor to control the speed of revolving coil for the experiments on electrical standards. Recalling his early work on the stability of the motion of Saturn's rings in 1856, Maxwell formulated mathematically the stability of governors. The paper entitled 'On Governors' appeared in Proceedings of the Royal Society of London, Vol. **16** (1868) p.270-283.

On physical lines of force Phil. Mag.
March, April and May 1861, Parts I and II ,
January and February 1862, Parts III and IV.

Clausius ~1862: Disgregation
~1865: Verwandlungsinhalt (entropy ε γ τ ρ π η)
Maxwell resigned from King's College 10 February 1865.

The reason was to pursue research unrestricted by academic duties.

During Term 3 mornings a week one-hour long lecture to each of these 2 classes; in addition the requirement to teach a separate course on experimental physics, an evening class once a week.
Duties of teaching were too heavy for one person properly to discharge.

After resigned from King's College, Maxwell devoted himself to accomplish his life work.

Treatis on Electricity and Magnetism

Part I	Electrostatics
Part II	Electrokinematics
Part III	Magnetism
Part IV	Electromagnetism

A new professorship for teaching.

Experimental Physics advertized 14 February 1871 and the follwing 3 names were argued;
William Thomson (1824-1907),
Hermann Helmholtz (1821-1894),
Maxwell (1831-1879).

Thomson was critical to the education milieu of Cambridge, and declined to stand for election. Helmholtz was just to be appointed Prof. Physics, Berlin (1871).

Maxwell's position was regarded as third choice. In addition, his resignation from King's College, London may have led his Cambridge colleagues to surmise his likely disinterest in an academic post.

5. Cambridge University : 1871(40y.)-1879(48y.)

Inaugural lecture at Cambridge, 25 October 1871.

This lecture dawned the new era of physics:

XLIV. Introductory Lecture on Experimental Physics.

The University of Cambridge, in accordance with that law of its evolution, by which, while maintaining the strictest continuity between the successive phases of its history, it adapts itself with more or less promptness to the requirements of the times, has lately instituted a course of Experimental Physics. This course of study, while it requires us to maintain in action all those powers of attention and analysis which have been so long cultivated in the University, calls on us to exercise our senses in observation, and our hands in manipulation. The familiar apparatus of pen, ink, and paper will no longer be sufficient for us, and we shall require more room than that afforded by a seat at a desk, and a wider area than that of the black board. We owe it to the munificence of our Chancellor, that, whatever be the character in order respects of the experiments which we hope hereafter to conduct, the material facilities for their full development will be upon a scale which has not hitherto been surpassed.

The main feature, therefore, of Experimental Physics at Cambridge is the Devonshire Physical Laboratory, and I think it desirable that on the present occasion, before we enter on the details of any special study, we should consider by what means we, the University of Cambridge, may, as a living body, appropriate and vitalise this new organ, the outward shell of which we expect soon to rise before us. The course of study at this University has always included Natural Philosophy, as well as Pure Mathematics. To diffuse a sound knowledge of Physics, and to imbue the minds of our students with correct dynamical principles, have been long regarded as among our highest functions, and very few of us can now place ourselves in the mental condition in which even such philosophers as the great Descartes were involved in the days before Newton had announced the true laws of the motion of bodies.

....

The theory of atoms and void leads us to attach more importance to the doctrines of integral numbers and definite proportions; but, in applying dynamical principles to the motion of immense numbers of atoms, the limitation of our faculties forces us to abandon the attempt to express the exact history of *each atom, and to be content with estimating the average condition of a group of atoms large enough to be visible. This method of dealing with groups of atoms, which I may call the statistical method, and which in the present state of our knowledge is the only available method of studying the properties of real bodies, involves an abandonment of strict dynamical principles, and an adoption of the mathematical methods belonging to the theory of probability. It is probable that important results will be obtained by the application of this method, which is as yet little known and is not familiar to our minds. If the actual history of Science had been different, and if the scientific doctrines most familiar to us had been those which must be expressed in this way, it is possible that we might have considered the existence of a certain kind of contingency a self-evident truth, and treated the doctrine of philosophical necessity as a mere sophism.*

About the beginning of this century, the properties of bodies were investigated by several distinguished French mathematicians on the hypothesis that they are systems of molecules in equilibrium. The somewhat unsatisfactory nature of the results of these investigations produced, especially in this country, a reaction in favour of the opposite method of treating bodies as if they were, so far at least as our experiments are concerned, truly continuous. This method, in the hands of Green, Stokes, and others, has led to results, the value of which does not at all depend on what theory we adopt as to the ultimate constitution of bodies.

One very important result of the investigation of the properties of bodies on the hypothesis that they are truly continuous is that furnishes us with a test by which we can ascertain, by experiments on a real body, to what degree of tenuity it must be reduced before it begins to give evidence that its properties are no longer the same as those of the body in mass. Investigations of this kind, combined with a study of various phenomena of diffusion and of dissipation of energy have recently added greatly to the evidence in favour of the hypothesis that bodies are systems of molecules in motion.

I hope to be able to lay before you in the course of the term some of the evidence for the existence of molecules, considered as individual bodies having definite properties. The molecule, as it is presented to the scientific imagination is a very different body from any of those with which experience has hitherto made us acquainted.

In the first place its mass, and the other constants, which define its properties, is absolutely invariable; the individual molecule can neither grow nor decay, but remains unchanged amid all the changes of the bodies of which it may form a constituent.

In the second place it is not the only molecule of its kind, for there are innumerable other molecules, whose constants are not approximately, but absolutely identical with those of the first molecule, and this whether they are found on the earth, in the sun, or in the fixed stars.

By what process of evolution the philosophers of the future will attempt to account for this identity in the properties of such a multitude of bodies, each of them unchangeable in magnitude, and some of them separated from others by distances which Astronomy attempts in vain to measure, I cannot conjecture. My mind is limited in its power of speculation, and I am forced to believe that these molecules must have been made as they are from the beginning of their existence.

I also conclude that since none of the processes of nature, during their varied action on different individual molecules, have produced, in the course of ages, the slightest difference between the properties of one molecule and those of another, the history of whose combinations has been different, we cannot ascribe either their existence or the identity of their properties to the operation of any of those causes which we call natural.

Is it true then that our science speculations have really penetrated beneath the visible appearance of things, which seem to be subject to generation and corruption, and reached the entrance of that world of order and perfection, which continues this day as it was created, perfect in number and measure and weight?

We may be mistaken. No one has as yet seen or handled an individual molecule, and our molecular hypothesis may, in its turn, be supplanted by some new theory of the constitution of matter; but the idea of the existence of unnumbered individual things, all alike and all unchangeable, is one which cannot enter the human mind and remain without fruit.

....

In December 1867 it happened to him to find much interest in writing a text on heat. At the time his longtime friend Tait requested to read draft chapters of his '<u>Sketch of Thermodynamics</u>'.
Remembering that Maxwell defeated Clausius' work on the collisions of particles in 1859, Tait, Maxwell's longtime friend, had a special partiality for Maxwell. Probably due to this effect, reading Tait's manuscript, Maxwell was confused about the significance of Clausius' contribution to thermodynamics, particularly over the introduction of 'entropy'.

Recently I was shocked by reading the following sentences in Maxwell's postcard to Tait on 12 February 1872:
"In my spare moments, I mean to take such draughts of Clausiustical Ergon as to place me in that state of disgregation in which one becomes conscious of the increase of the general sum of Entropy. Meanwhile till Ergal & Virial from their thrones be cast and end their strife with suicidal yell."

But as he finally came to realize, his confusion over the meaning of 'entropy' had disfigured the text of his book.
By April 1873 Maxwell was beginning to correct the proofs of the Theory of Heat.

Drafts of lecture on 'Molecules'

Lecture delivered to the meeting of the British Association for the Advancement of Science in Bradford on 22 September 1873.

[1] Molecular Phenomena
[2] The Data of Molecular Science
[3] The Method of Molecular Science
[4] The Statistical Method: The Section concerned with 'Economic Science and Statistics'
[5] The Statistical Method: From absolute certainty to high probability
[6] The Statistical Method: A new kind of regularity –the regularity of averages.

The final parts of Maxwell's career were broached in 1873: the planning and writing of articles for the ninth edition of Encyclopaedia Britarica; an interest in communicating his ideals to wider public.

Cavendish Laboratory:

Established in 1874
First director: Maxwell
The Chancellor of the University at Cambridge at that time was Duke of Devonshire, who offered the funds requested for building and apparatus.
2nd director: Lord Rayleigh
3rd director: J. J. Thomson
4th director: Sir Ernest Rutherford