Fluxions, Forces, and Fields

An overview of the mathematisation of physics in Europe through the modern period

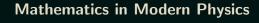
Zella Baig February 11, 2021 Fluxions, Forces, and Fields

2021-02-11

Fluxions, Forces, and Fields

February 11, 2021

A Look Back



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• 'Modern' physics is clearly mathematical...

1

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A Look Back

Mathematics in Modern Physics

Mathematics in Modern Physics

Mathematics in Modern Physics

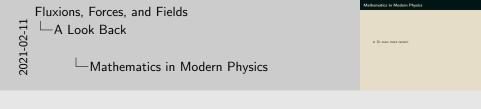
• 'Modern' physics is clearly mathematical...

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad \qquad \vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \qquad \vec{\nabla} \times \vec{B} = \mu_0 \left(\vec{J} + \epsilon_0 \frac{\partial \vec{E}}{\partial t} \right)$$

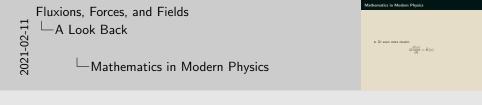


• Or even more recent:

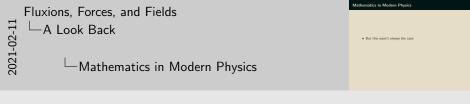


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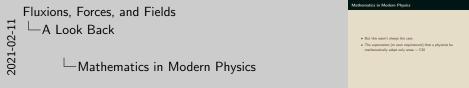
$$i\hbar rac{\partial \left| \psi
ight
angle }{\partial t} = \hat{H} \left| \psi
ight
angle$$



• But this wasn't always the case



- But this wasn't always the case
- ullet The *expectation* (or even requirement) that a physicist be mathematically adept only arose \sim C20



1. Mathematics within science is a somewhat recent idea - experiment was key

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└─A Look Back Mathematics in Modern Physics

. Vector notation had only been around for ~ 50 years!

Mathematics in Modern Physics

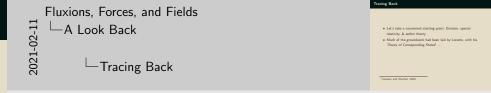
ullet Vector notation had only been around for \sim 50 years!

1. We will discuss vector notation later in fact

• Let's take a convenient starting point: Einstein, special relativity, & aether theory

1. No real reason, but more just commonly known as a 'big' event

- Let's take a convenient starting point: Einstein, special relativity, & aether theory
- Much of the groundwork had been laid by Lorentz, with his Theory of Corresponding States¹ ...



¹Janssen and Stachel, 2004.

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-Tracing Back

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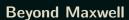
- Let's take a convenient starting point: Einstein, special relativity, & aether theory
- Much of the groundwork had been laid by Lorentz, with his Theory of Corresponding States¹ ... which generalised length-contraction theory to Maxwell's equations
- Interestingly, much of the work on length contraction was done by George Fitzgerald, who was also influenced greatly by Maxwell

Fluxions, Forces, and Fields 2021-02-11 —A Look Back . Let's take a convenient starting point: Einstein, special relativity. & aether theory Tracing Back

. Much of the groundwork had been laid by Lorentz, with his Theory of Corresponding States² ... which generalised length-contraction theory to Maxwell's equations · Interestingly, much of the work on length contraction was

1. So we can already begin to draw these links between these (famous) people

¹Janssen and Stachel. 2004.



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Fluxions, Forces, and Fields └─A Look Back

Beyond Maxwell

. Maxwell himself adept at maths - 2nd Wrangler

Beyond Maxwell

• Maxwell himself adept at maths - 2nd Wrangler

1. Explain what wrangler means

• Maxwell himself adept at maths - 2nd Wrangler

- 'Mentored' by William Thomson² (later Lord Kelvin)...

2021-02-11 └─A Look Back -Beyond Maxwell

Fluxions, Forces, and Fields

1. explain this was a professional/guiding relationship

. 'Mentored' by William Thomson2 (later Lord Kelvin)

²Smith, 1978.

5

- Maxwell himself adept at maths 2nd Wrangler
- 'Mentored' by William Thomson² (later Lord Kelvin)... who was a major figure in shaping physics (or natural philosophy) in C19

Fluxions, Forces, and Fields

A Look Back

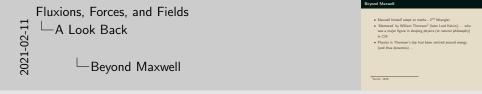
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- 'Mentored' by William Thomson² (later Lord Kelvin)... who was a major figure in shaping physics (or natural philosophy) in C19
- Physics in Thomson's day had been centred around energy (and thus dynamics)...



1. Mention how we will analyse why it was dynamics which dominated energy

²Smith, 1978.

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- 'Mentored' by William Thomson² (later Lord Kelvin)... who was a major figure in shaping physics (or natural philosophy) in C19
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Fluxions, Forces, and Fields

A Look Back

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- ... Which followed from continental development furthered by figures such as Lagrange and Laplace...
- ... Who worked using methods derived from Newton's work on celestial motion



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1. Mention how we can now see there's a clear line of succession, and we'll be looking at how each figure influenced the next

²Smith. 1978.



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└─A Look Back └─Not Just Mathematics Of course, there are other overarching themes as well:

Not Just Mathematics

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Not Just Mathematics

Of course, there are other overarching themes as well:

Baconian ideals,

1. Explain what baconianism is - empiricism, collaboration, etc. Science was investigated. This leads on well to the next point

Not Just Mathematics

Of course, there are other overarching themes as well:

- Baconian ideals,
- Collaborative bodies such as the Royal Institute,

Fluxions, Forces, and Fields

A Look Back

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- And (again from Newton) hypotheses non fingoⁱ

Fluxions, Forces, and Fields —A Look Back

└─Not Just Mathematics

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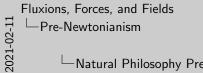
Not Just Mathematics

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ⁱTo be discussed later on

Pre-Newtonianism

- 'Physics' (or Natural Philosophy) focused largely on astronomy
 - the "noblest of all" mathematical disciplines³



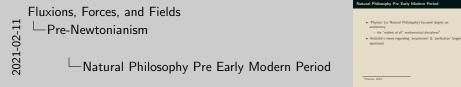


Natural Philosophy Pre Early Modern Period

Natural Philosophy Pre Early Modern Period

³Clavius, 1612.

- 'Physics' (or Natural Philosophy) focused largely on astronomy
 - the "noblest of all" mathematical disciplines³
- Aristotle's views regarding 'empiricism' & 'perfection' largely dominant



1. Discuss how this doesn't imply stagnation, but merely shaped how the world was viewed as well as the approach to science

³Clavius, 1612.

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Fluxions, Forces, and Fields

—Pre-Newtonianism

—Natural Philosophy Pre Early Modern Period

Mathematics influences	had been	largely	distinct,	again	due to	ancient

lavius, 1612.

Natural Philosophy Pre Early Modern Period

1. It still was studied, and it was rigourous, but it wasn't a science and was almost a 'plaything'

³Clavius, 1612.

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- First major (relevant) shift comes with Bacon & his *Novum Organum*⁴

Fluxions, Forces, and Fields

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Fluxions, Forces, and Fields

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Organum* - the birth of the scientific method?

D.

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⁴Bacon, 1620.

Isaac Newton (1642-1727)

Newtonian Mathematical Ideals

• Saw God as mathematical, with a fondness for geometryⁱⁱ

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Isaac Newton (1642-1727)

Newtonian Mathematical Ideals

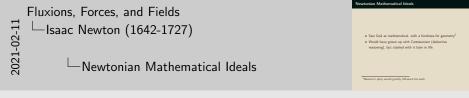
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- 1. Mention how in his work he would often discuss god, and the ancients
- 2. also bring up how his physical work is but a portion of his alchemy and other work

[&]quot;Newton's piety would greatly influence his work

Newtonian Mathematical Ideals

- Saw God as mathematical, with a fondness for geometry ii
- Would have grown up with Cartesianism (deductive reasoning), but clashed with it later in life

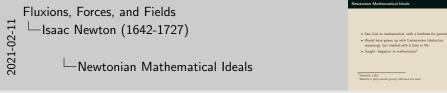


1. One major reason for this was the concept of force at a distance

[&]quot;Newton's piety would greatly influence his work

Newtonian Mathematical Ideals

- Saw God as mathematical, with a fondness for geometryⁱⁱ
- Would have grown up with Cartesianism (deductive reasoning), but clashed with it later in life
- Sought 'elegance' in mathematics⁵



1. As well as being haughty, he was also a very petty man - bring up removing 'esteemed' to 'mr'

⁵Westfall, 1981.

[&]quot;Newton's piety would greatly influence his work

Experimental Philosophy

• The method of resolution & composition:



1. Mention how sometimes it appears as if Newton himself didn't know what he meant; conflicting uses

Experimental Philosophy

- The method of resolution & composition:
 - 1. Observe and "come to the general properties of things" ⁶



⁶Newton and McGuire, 1970.

Experimental Philosophy

- The method of resolution & composition:
 - 1. Observe and "come to the general properties of things" ⁶
 - 2. Assume said properties and describe further phenomena



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 - 1. Observe and "come to the general properties of things" ⁶
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- Hypotheses non fingo⁷ -



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- The method of resolution & composition:
 - 1. Observe and "come to the general properties of things" 6
 - 2. Assume said properties and describe further phenomena
- **Hypotheses non fingo**⁷ ignorance is acceptable!
 - Now able to make predictions using mathematical tools without worrying about cause

Fluxions, Forces, and Fields

—Isaac Newton (1642-1727)

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Fluxions, Forces, and Fields

Isaac Newton (1642–1727)

Experimental Philosophy

Experimental Philosophy

Experimental Philosophy

| Control of Technology Control is comparation of Rings of Control of Technology Control is control for the Information of the Information

1. Discuss in detail - getting measurements from Flamsteed, the royal astronomer, and applying etc

⁶Newton and McGuire, 1970.

⁷Newton, Cohen, et al., 1999.

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 - Concept of forces at a distance

Fluxions, Forces, and Fields

LISABER Newton (1642-1727)

-Experimental Philosophy

Experimental Philosophy

Observe and "come to the general properties of things"
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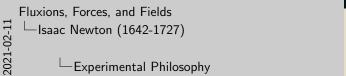
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 - Concept of forces at a distance
- Important to note the ramifications of geometric arguments



The method of resolution & composition:
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Concept of forces at a distance
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*Newton and McGuire, 1970.

*Newton. Cohen. et al., 1999.

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Experimental Philosophy

1. Religious backing, make his work iron clad as to prevent arguments against it

⁶Newton and McGuire, 1970.

⁷Newton, Cohen, et al., 1999.

• Who discovered calculus first?



1. Newton discovered first, as he claims, but leibniz published first. Newton quarrels as usual

- Who discovered calculus first?
- Leibnizian calculus seen as inelegant



1. Again newton preferring geometry, or perhaps to cover up that he had published later as he was perfecting it

- Who discovered calculus first?
- Leibnizian calculus seen as inelegant
- Some literature suggests Newton's notation might have impeded British science



 Discuss fluxions (which are adding eg a small dt term), and fluents which are both integrals and derivatives of functions of time.
 Mention sloppy notation usage

- Who discovered calculus first?
- Leibnizian calculus seen as inelegant
- Some literature suggests Newton's notation might have impeded British science
 - The Development of Newtonian Calculus⁸
 - Dot-Age⁹
 - The History of Calculus¹⁰

1. Discuss how this isn't likely the major factor, as the next head of the royal society was very anti newton

⁸Guicciardini, 1989.

⁹Guicciardini, 2004.

¹⁰Boyer, 2012.

- Who discovered calculus first?
- Leibnizian calculus seen as inelegant
- Some literature suggests Newton's notation might have impeded British science
 - The Development of Newtonian Calculus⁸
 - Dot-Age⁹
 - The History of Calculus¹⁰
- Regardless, we are interested in the physical influences of calculus

1. Newton's calculus more influential simply for the scientific ramifications - his philosophy and the discovery of Halley's comet

⁸Guicciardini, 1989.

⁹Guicciardini, 2004.

¹⁰Boyer, 2012.

The Dynamical Age: Continental Physics

Fluxions, Forces, and Fields

philosophy¹¹ to various problems, gradually verifying several

Putting Calculus to Use

• Euler, Clairaut, and others applied Newton's experimental philosophy¹¹ to various problems, gradually verifying several with observations

¹¹Shapiro, 2004.

Putting Calculus to Use

- Euler, Clairaut, and others applied Newton's experimental philosophy¹¹ to various problems, gradually verifying several with observations
 - Clairaut's work on the three-body problem particularly important

Fluxions, Forces, and Fields
The Dynamical Age: Continental Physics

- Condition of the Body and the special of the special of

1. This showed that newton's work really was quite important - it had allowed for major work towards the problem which had stumped many other mathematicians. Lent credit to newton

¹¹Shapiro, 2004.

Putting Calculus to Use

- Euler, Clairaut, and others applied Newton's experimental philosophy¹¹ to various problems, gradually verifying several with observations
 - Clairaut's work on the three-body problem particularly important
- Development of Lagrangian mechanics & applications to further contexts (such as the motion of sound)

Fluxions, Forces, and Fields

The Dynamical Age: Continental Physics

Putting Calculus to Use

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piro. 2004.

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• The rise of French scientific dominance

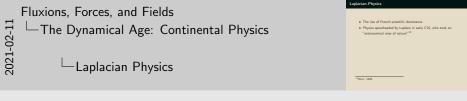
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The Dynamical Age: Continental Physics

Laplacian Physics

1. Discuss napoleons upbringing - had laplace as a teacher, was fond of mathematics

- The rise of French scientific dominance
- Physics spearheaded by Laplace in early C19, who took an "astronomical view of nature" 12

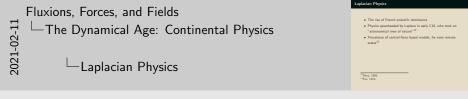


¹²Merz, 1896.

- The rise of French scientific dominance
- Physics spearheaded by Laplace in early C19, who took an "astronomical view of nature" 12
- Prevalence of central-force based models, for even minute scales¹³

¹²Merz, 1896.

¹³Fox, 1974.



1. these had traditionally been the bread and butter of newtonian calculus

- The rise of French scientific dominance
- Physics spearheaded by Laplace in early C19, who took an "astronomical view of nature" 12
- Prevalence of central-force based models, for even minute scales¹³
- Competitions set-up with e.g. the Society of Arcueil to promote mathematical collaboration

Fluxions, Forces, and Fields

The Dynamical Age: Continental Physics

Laplacian Physics

Laplacian Physics

Laplacian Physics

The Dynamical Age: Continental Physics

Laplacian Physics

Laplacian Physics

The Dynamical Age: Continental Physics

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Physics spatialed by Laplace is well CIS, who took an **

Physics spatial activation of control force bear inside spatial activation of the CIS and the control force bear inside spatial activation of the CIS and the CIS

1. Allowed for great development of ideas internationally

¹²Merz, 1896.

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Fluxions, Forces, and Fields

—The Dynamical Age: Continental Physics

-Laplacian Physics

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1896. 974.

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¹²Merz. 1896.

¹³Fox, 1974.

Energy Physics

• Ideas of *vis-viva* around since Leibniz, *caloric* furthered by e.g. Carnot in early C19



1. Energy ideas were floating around - it being created, being a fluid, etc

- Ideas of *vis-viva* around since Leibniz, *caloric* furthered by e.g. Carnot in early C19
- Natural philosophy shifted towards a focus on (conservation of) energy - in particular heat¹⁴

Fluxions, Forces, and Fields

Energy Physics

William Thomson (1824-1907)

1. Many reasons for this - perhaps discuss steam engines, practical applications. Baconiamism - applications of science to improving lives

¹⁴Smith, 1978.

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 - Appealing due to all physics being related (perhaps even dynamically!)

Fluxions, Forces, and Fields

Energy Physics

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Fluxions, Forces, and Fields
—Energy Physics

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Fluxions, Forces, and Fields

Energy Physics

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	Heat a "dynamical form of mechanical effect", with there being "absolute numerical relations" between heat and power ¹⁵
¹⁴ Smith, 1978. ¹⁶ Thomson, 1851.	

─William Thomson (1824-1907)

1. Thomson knew there was something relating heat and energy, investigated it

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¹⁴Smith, 1978.

¹⁵Thomson, 1851.

Thomson & Tait

• Together, they publish *Treatise on Natural Philosophy*: ¹⁶ the first high-level mathematically-inclined physics textbookiii, as well as a synthesis of their work on energy

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└─Thomson & Tait

¹⁶Thomson and Tait, 1867.

iiiIn fact, 'energy' as a concept was not taught much at all

Thomson & Tait

- Together, they publish *Treatise on Natural Philosophy*: ¹⁶ the first high-level mathematically-inclined physics textbookiii, as well as a synthesis of their work on energy
- Intended to "give in three moderate volumes a far more complete course of Physics, Experimental and Mathematical, than exists" 17

Fluxions, Forces, and Fields 2021-02-11 Energy Physics

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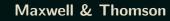
-Thomson & Tait

¹⁶Thomson and Tait, 1867.

¹⁷Tait, 1861.

iiiIn fact, 'energy' as a concept was not taught much at all

James Maxwell (1831-1879)



¹⁸Gooding and James, 1985.

2021-02-1

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└─James Maxwell (1831-1879)

└─Maxwell & Thomson

Fluxions, Forces, and Fields

Both mathematically inclined Scottish physicists (contrasting to e.g. Faraday)³³

Maxwell & Thomson

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- Fluxions, Forces, and Fields
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Maxwell & Thomson

- Both mathematically inclined Scottish physicists (contrasting to e.g. Faraday)¹⁸
- Thomson guided Maxwell's intellectual pursuits both directly and indirectly:

- 1. Thomson busy with other pursuits, told to read on faraday as thomson (and the world) recognised his brilliance
- 2. faraday the opposite of a mathematician almost all practical work, but amazing experimenter; give brief overview

¹⁸Gooding and James, 1985.

Maxwell & Thomson

- Both mathematically inclined Scottish physicists (contrasting to e.g. Faraday)¹⁸
- Thomson guided Maxwell's intellectual pursuits both directly and indirectly:
 - "The discussion of the various forms of energy ... constitutes the whole of physical science" ¹⁹



1. Quote from several years later but you can see how thomson influenced maxwell

¹⁸Gooding and James, 1985.

¹⁹Maxwell, 1877.

Maxwell & Thomson

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- On electromagnetism, pondered the nature of the 'store' of energy, e.g. in his *Dynamical Theory*²⁰

Fluxions, Forces, and Fields

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Gooding and James, 1985.
 Maxwell, 1877.
 Maxwell, 1865.

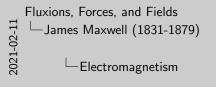
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¹⁸Gooding and James, 1985.

¹⁹Maxwell, 1877.

²⁰Maxwell, 1865.

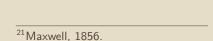
• Faraday had done groundbreaking work on electromagnetism, but almost entirely qualitative

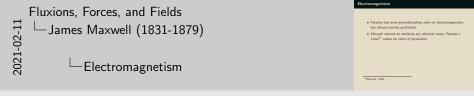


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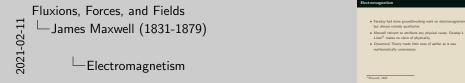
- Faraday had done groundbreaking work on electromagnetism, but almost entirely qualitative
- Maxwell reticent to attribute any physical cause; *Faraday's Lines*²¹ makes no claim of physicality





1. Instead claims to be a mathematical model which he uses to develop Faraday's work

- Faraday had done groundbreaking work on electromagnetism, but almost entirely qualitative
- Maxwell reticent to attribute any physical cause; Faraday's Lines²¹ makes no claim of physicality
- Dynamical Theory made little note of aether as it was mathematically unnecessary



1. This was interesting given how much of a headache aether theory had caused EM models

²¹Maxwell. 1856.

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- *Physical Lines*²² first postulates light being electromagnetic, as well as displacement current

Fluxions, Forces, and Fields

—James Maxwell (1831-1879)

-Electromagnetism

magnetism

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Masswell, 1856. Masswell, 1861.

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²¹Maxwell, 1856.

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Electromagnetism

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- Work culminates in his *Treatise*²³

Fluxions, Forces, and Fields

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-Electromagnetism

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²¹Maxwell, 1856.

²²Maxwell, 1861.

²³Maxwell, 1873.

Vortex Model

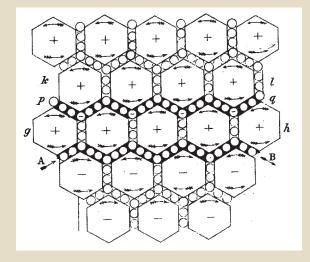


Figure 1: Maxwell's 'vortex & idle-wheel' model, in *Physical Lines*

Fluxions, Forces, and Fields

—James Maxwell (1831-1879)

Figure 1: Mountain various de discussion années de Principal

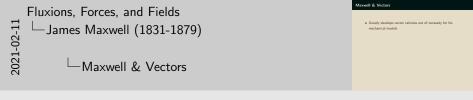
└─Vortex Model

1. Describe the motion of the wheels and current particles; explain how it led to the curl dependence

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Maxwell & Vectors

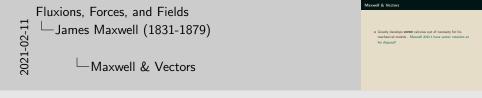
• Greatly develops vector calculus out of necessity for his mechanical models



Maxwell & Vectors

his disposal!

 Greatly develops vector calculus out of necessity for his mechanical models - Maxwell didn't have vector notation at



☐ James Maxwell (1831-1879)

-Maxwell & Vectors

Maxwell & Vectors

- Greatly develops vector calculus out of necessity for his mechanical models
- Modern formulation only introduced in 1884, by Heavyside²⁴

²⁴Hunt, 2012.

18

Maxwell & Vectors

- Greatly develops vector calculus out of necessity for his mechanical models
- Modern formulation only introduced in 1884, by Heavyside²⁴
 - From 20 equations to 4

²⁴Hunt, 2012.

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Fluxions, Forces, and Fields
—James Maxwell (1831-1879)

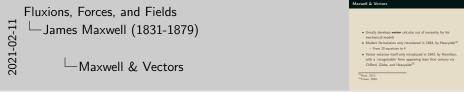
└─Maxwell & Vectors

Maxwell & Vectors
 Greatly develops vester calculus out of necessity for his mechanical models
Modern formulation only introduced in 1884, by Heavyside ²⁴
- From 20 equations to 4
³⁴ Hust. 2012.

- 1. Discuss how there were various other parameters each representing components of fields along certain axes
- 2. Also mention how this led to conceptual complexity dealing with so many interconnected equations

Maxwell & Vectors

- Greatly develops vector calculus out of necessity for his mechanical models
- Modern formulation only introduced in 1884, by Heavyside²⁴
 - From 20 equations to 4
- Vector notation itself only introduced in 1843, by Hamilton, with a 'recognisable' form appearing later that century via Clifford, Gibbs, and Heavyside²⁵



 Discuss how this was brought about with textbook usage by Clifford and Gibbs mainly, when lecturing in the US. Heavyside was mainly consolidating Maxwell's work

²⁴Hunt. 2012.

²⁵Crowe. 1994.

Aether Theory & Special Relativity

 Following Maxwell's work, electromagnetism became dominant²⁶ Fluxions, Forces, and Fields

—Aether Theory & Special Relativity

—The First Cracks

1. Dominant in the sense it led to an explosion of work around electromagnetism, light, and energy.

²⁶Hunt, 1994.

- Following Maxwell's work, electromagnetism became dominant²⁶
- The nature of the aether^{iv} was hotly debated due to conflicting theories and results (often from the same experiment)

1. Discuss michelson morley experiment and conflicting results - stokes' dragging hypotheses, fizeaus water experiment etc.

²⁶Hunt, 1994.

ivIn fact, Newton's initial work necessitated a vacuum in space

- Following Maxwell's work, electromagnetism became dominant²⁶
- The nature of the aether^{iv} was hotly debated due to conflicting theories and results (often from the same experiment)
- Following inconsistencies with Maxwell's equations & Fizeau's experiment Lorentz develops ideas of 'local time' & 'corresponding states' (co-ordinate transforms - but only of EM waves)

Fluxions, Forces, and Fields

Aether Theory & Special Relativity

-The First Cracks

The First Cracks

Following Maxwell's work, electromagnetism became

description 28

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experiment Lorentz develops ideas of 'local time' & 'corresponding states' (co-ordinate transforms - but only of EM waves)

⁶Hust, 1994. "In fact, Newton's initial work necessitated a vacuum in spa

²⁶Hunt, 1994.

^{iv}In fact, Newton's initial work necessitated a vacuum in space

- Following Maxwell's work, electromagnetism became dominant²⁶
- The nature of the aether^{iv} was hotly debated due to conflicting theories and results (often from the same experiment)
- Following inconsistencies with Maxwell's equations & Fizeau's experiment Lorentz develops ideas of 'local time' & 'corresponding states' (co-ordinate transforms - but only of EM waves)
 - A **purely** mathematical construction²⁷

Fluxions, Forces, and Fields

Aether Theory & Special Relativity

└─The First Cracks

The First Cocks

* Following Manuell's work, disctromagnetism became distributed by the State of the State's was body detailed due to coolfools between and small (ofther from the same operance).

* Following inconsistencies with Manuell's operance in support of the same operance of the State of the Stat

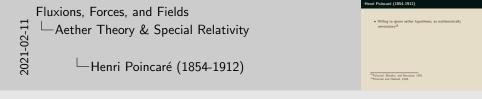
 Stress this point - Lorentz was seemingly not aware of the physical connotations; had merely shown that this was a hypothesis that could work. Also had funnily enough made a factor of 2 error in his work

²⁶Hunt. 1994.

²⁷Brown, 2005.

ivIn fact, Newton's initial work necessitated a vacuum in space

• Willing to ignore aether hypotheses, as mathematically unnecessary ²⁸

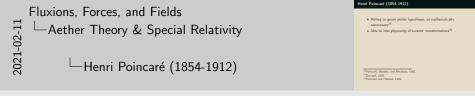


²⁸Poincaré, Blondin, and Neculcea, 1901.

²⁹Poincaré and Halsted, 1929.

• Willing to ignore aether hypotheses, as mathematically unnecessary²⁸

• Able to infer physicality of Lorentz' transformations²⁹



²⁸Poincaré, Blondin, and Neculcea, 1901.

²⁹Darrigol, 1995.

³⁰Poincaré and Halsted, 1929.

- Willing to ignore aether hypotheses, as mathematically unnecessary²⁸
- Able to infer physicality of Lorentz' transformations²⁹
- Develops theory to be (functionally) identical to modern Lorentz transformations

Henri Poincaré (1854-1912) Fluxions, Forces, and Fields 2021-02-11 —Aether Theory & Special Relativity ☐ Henri Poincaré (1854-1912)

· Able to infer physicality of Lorentz' transformations²

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 - Unwilling to assign physicality to ideas: "Of hypotheses there is never lack" ³⁰

Fluxions, Forces, and Fields

Aether Theory & Special Relativity

Henri Poincaré (1854-1912)

Henri Poincaré (1854-1912)

1. He may also have been unwilling to let go of the idea of aether theory, or alternatively he may not have actually grasped the ramifications of what this implied for aether theory

²⁸Poincaré, Blondin, and Neculcea, 1901.

²⁹Darrigol, 1995.

³⁰Poincaré and Halsted. 1929.

- Willing to ignore aether hypotheses, as mathematically unnecessary²⁸
- Able to infer physicality of Lorentz' transformations²⁹
- Develops theory to be (functionally) identical to modern Lorentz transformations
 - Unwilling to assign physicality to ideas: "Of hypotheses there is never lack" 30
- Einstein would soon go on to have his *annus mirabilis* and completely shift away from aether theory

Fluxions, Forces, and Fields

Aether Theory & Special Relativity

─Henri Poincaré (1854-1912)

Henri Poincaré (1854-1912)

 Willing to ignore aether hypotheses, as mathematically unnecessary²⁸

Able to infer physicality of Lorentz' transformations²⁹
 Develops theory to be (functionally) identical to modern

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- Unwilling to assign physicality to ideas: "Of hypotheses there is never lack" 10

 Einstein would soon go on to have his annus mirabilis and completely shift away from aether theory

sincaré, Blondin, and Neculcea, 1903 errigol, 1995. sincaré and Halsted, 1929.

²⁸Poincaré, Blondin, and Neculcea, 1901.

²⁹Darrigol, 1995.

³⁰Poincaré and Halsted. 1929.

Conclusion

Conclusion

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Fluxions, Forces, and Fields -Conclusion

. Initial shift with Newton's development of experimental

└─To Sum Up...

• Initial shift with Newton's development of experimental philosophy and quantisation of nature

- Initial shift with Newton's development of experimental philosophy and quantisation of nature
- Development of continental force-based physics

Fluxions, Forces, and Fields 2021-02-11 -Conclusion └─To Sum Up...

. Development of continental force-based physics

- Initial shift with Newton's development of *experimental philosophy* and quantisation of nature
- Development of continental force-based physics
- Shift towards disciplinary rigour with Thomson and others

Fluxions, Forces, and Fields
Conclusion
To Sum Up...

um Up...

- Initial shift with Newton's development of experimental ability and experiencing of exture
- Produced of continued from hand above
- Shift towards disciplinary rigour with Thomson and others

- Initial shift with Newton's development of *experimental philosophy* and quantisation of nature
- Development of continental force-based physics
- Shift towards disciplinary rigour with Thomson and others
- Maxwellian development of electromagnetic theory

Fluxions, Forces, and Fields
Conclusion
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- Initial shift with Newton's development of experimental shifteenby and experiencing of exture
- Development of continental force-based physic
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- Initial shift with Newton's development of *experimental philosophy* and quantisation of nature
- Development of continental force-based physics
- Shift towards disciplinary rigour with Thomson and others
- Maxwellian development of electromagnetic theory
- The final steps away from the aether after thousands of years

 discuss how we have had a massive shift in just the period of a few hundred years - can link it with the explosive rate of human growth as well. Discuss how it has led to so much advance in science and mathematics, as the lines between the two are blurred.

Thank You

References

- Bacon, F. Novum organum Scientiarum. Londini, 1620.
- Boyer, C. B. The History of the Calculus and Its Conceptual Development. Courier Corporation, 2012.
- [3] Brown, H. R. Physical Relativity: Space-Time Structure from a Dynamical Perspective. Oxford University Press, 2005.
- Clavius, C. Opera Mathematica. Vol. 3. 1612, p. 2.
- [5] Clifford, W. and Tucker, R. Elements of Dynamic: An Introduction to the Study of Motion and Rest in Solid and Fluid Bodies, v. 1-3. MacMillan and Company, 1878.
- [6] Craik, A. D. D. "Calculus and Analysis in Early 19th-Century Britain: The Work of William Wallace". In: Historia Mathematica 26.3 (1999).
- Crowe, M. J. A History of Vector Analysis: The Evolution of the Idea of a Vectorial System. Courier Corporation, 1994.
- Darrigol, O. "Henri Poincaré's Criticism of Fin De Siècle Electrodynamics". In: Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 26 (1995), pp. 1-44.

- [11] Bacon, F. Novum organum Scientianum, Londini, 1620. 121 Bover, C. B. The History of the Calculus and its Conceptual Development
- Courier Corporation, 2012. [3] Brown, H. R. Physical Relativity: Space-Time Structure from a Dynamical
- HI Clavius, C. Opera Mathematica, Vol. 3, 1612, p. 2.
- 151 Clifford, W. and Tucker, R. Elements of Dynamic: An Introduction to the Study
- [6] Craik, A. D. D. "Calculus and Analysis in Early 19th-Century Britain: The Work of William Wallace". In: Historia Mathematica 26.3 (1999).
- 181 Daniest, O. "Henri Poincaré's Criticism of Fin De Siècle Electrodynamics". I

- [9] Fox, R. "The Rise and Fall of Laplacian Physics". In: Historical Studies in the Physical Sciences 4 (1974), pp. 89-136.
- Gooding, D. Final Steps to the Field Theory: Faraday's Study of Magnetic Phenomena, 1845-1850. Berkeley, 1981.
- Gooding, D. and James, F. A. J. L. In Nature's School': Faraday as an Experimentalist. London: Macmillan Education UK, 1985, pp. 105–136.
- Greenberg, J. L. "Mathematical Physics in Eighteenth-Century France". In: Isis 77.1 (1986), pp. 59–78.
- Guicciardini, N. "Dot-Age: Newton's Mathematical Legacy in the Eighteenth Century". In: Early Science and Medicine 9.3 (2004), pp. 218-256.
- Guicciardini, N. The Development of Newtonian Calculus in Britain, 1700-1800. Cambridge: Cambridge University Press, 1989.
- Hunt, B. J. "Oliver Heaviside: A First-Rate Oddity". In: Physics Today 65.11 (2012), pp. 48-54.
- Hunt, B. J. The Maxwellians. Cornell University Press, 1994.
- Janssen, M. and Stachel, J. J. The Optics and Electrodynamics of Moving Bodies. Max-Planck-Institute for the History of Science, 2004.

191 Fox. R. "The Rise and Fall of Laplacian Physics". In: Historical Studies in the Physical Sciences 4 (1974), pp. 89-136.

Phenomena, 1945-1950. Berkeley, 1961.

Experimentalist London: Macmillan Education UK, 1995, pp. 105-136. [12] Greenberg, J. L. "Mathematical Physics in Eightmeeth-Century France". In: Air

77.1 (1986), pp. 59-78. [13] Guicciardini, N. 'Dot-Age: Newton's Mathematical Legacy in the Eighteenth

Century". In: Early Science and Medicine 9.3 (2004), op. 219-256. [14] Guicciardini, N. The Development of Newtonian Calculus in Britain

[15] Hunt, B. J. "Oliver Heaviside: A First-Rate Oddfor". In: Physics Today 65.11

[16] Hurt, B. J. The Manuellans, Cornell University Press, 1994.

[17] Janssen, M. and Stachel, J. J. The Optics and Electrodynamics of Moving

Bodier, Max-Planck-Institute for the History of Science, 2004.

- [18] Maxwell, J. C. "A Dynamical Theory of the Electromagnetic Field". In: Philosophical Transactions of the Royal Society of London 155 (1865), pp. 459-512.
- Maxwell, J. C. A Treatise on Electricity and Magnetism. Oxford: Clarendon Press. 1873.
- Maxwell, J. C. Matter and Motion. Dover, 1877, pp. 89–90.
- Maxwell, J. C. "On Faraday's Lines of Force.". In: Cambridge: Cambridge University Press. 1856.
- Maxwell, J. C. On Physical Lines of Force. London: Royal Society, 1861.
- Maxwell, J. C. and Niven, W. D. The Scientific Papers of James Clerk Maxwell. New York: Dover Publications, 1965.
- Merz, J. A History of European Thought in the Nineteenth Century. A History of European Thought in the Nineteenth Century. Blackwood & Sons: London, 1896. Pp. xiv+. 458.
- Newton, I. MS Add., f. 243r. Portsmouth Collection, 1670-1710.
- Newton, I., Cohen, B., et al. The Principia: Mathematical Principles of Natural Philosophy. 3rd ed. University of California Press, 1999, p. 943.

2021-

[18] Manuell, J. C. "A Dynamical Theory of the Electromagnetic Field". In: Philosophical Transactions of the Royal Society of London 155 (1865)

Press, 1873.

[20] Manuell, J. C. Matter and Motion Dover, 1877, pp. 89-90. [21] Manwell, J. C. "On Faraday's Lines of Force.". In: Cambridge: Cambridge

[23] Manuell, J. C. and Nives, W. D. The Scientific Papers of James Clerk Manuel New York: Dover Publications, 1965.

[24] Merz, J. A History of European Thought in the Nineteenth Century. A History

1251 Newton, I. MS Add. f. 243r. Portsmouth Collection, 1670-1710.

1261 Newton, I., Cohen, B., et al. The Principla: Mathematical Principles of Natural

Philosophy. 3rd ed. University of California Press, 1999, p. 943.

- [27] Newton, I. and McGuire, J. E. "Newton's "Principles of Philosophy": An Intended Preface for the 1704 "Opticks" and a Related Draft Fragment". In: The British Journal for the History of Science 5 (1970), pp. 178–186.
- [28] Newton, I. and Whiteside, D. T. The Mathematical Papers of Isaac Newton. Vol. 7. Cambridge, 1967–1981.
- [29] Poincaré, H., Blondin, J., and Neculcea, E. Electricité et Optique. La lumière et les Théories électrodynamiques (Sorbonne lectures of spring 1888, 1890, and 1899. 1901, pp. 403–420.
- [30] Poincaré, H. and Halsted, G. B. The Foundations of Science: Science and Hypothesis, the Value of Science, Science and Method. Science Press, 1929, p. 147.
- [31] Rees, G. "Mathematics And Francis Bacon's Natural Philosophy". In: Revue Internationale de Philosophie 40 (159 (4) 1986), pp. 399–426.
- [32] Rindler, W. "Einstein's Priority in Recognizing Time Dilation Physically". In: American Journal of Physics 38 (1970), pp. 1111–1115.
- [33] Shapiro, A. E. "Newton's "Experimental Philosophy"". In: Early Science and Medicine 9.3 (2004), pp. 185–217.

[27] Newton, I. and McGuine, J. E. "Newton's "Principles of Philosophy": An Intended Preface for the 1704 "Opticies" and a Related Druft Fragment". In: The Billian Journal for the History of Science 5 (1970), pp. 178–186.

The Bittish Journal for the History of Science 5 (1970), pp. 179-186.

[28] Newton, I. and Whiteside, D. T. The Mathemacical Papers of Issac Newton

100 7 Combidies 1907-1901.

[26] Poincaré, H., Blondin, I., and Neculcus, E. Electricité et Optique. La lumière et les Thérine électrodynamiques (Sorbonne inctures of spring 1989, 1990, and 1990-1901, pp. 403–420.

 Internet metropromopore portions lictures of spring 1869, 1860, and 1809, 1801, pp. 403–420.
 Poincaré, H. and Halted, G. B. The Foundations of Science Science and Hypothesis, the Vallet of Science, Science and Method. Science, Naver 1670.

[46] Postado, H. and Hattier, St. III. The Foundations of Science Science and Hypothesis, the Value of Science, Science and Method. Science Press, 1929 p. 147.

p. 147.
[11] Res, G. "Mathematics And Francis Bacon's Natural Philosophy". In: Revue Internationals de Philosophie 40 (159 (4) 1696), pp. 399–426.

Attenuationale de Philosophie 40 (159 (4) 1085), pp. 299-455.

[12] Rindler, W. "Einstein's Priority in Recognizing Time Dilation Physics by". In

[12] Rindler, W. "Einmein's Priority in Recognizing Time Dilation Physics by". In American Journal of Physics 38 (1970), pp. 1111–1115.
D.E. Stonio, A.E. "Nearbole," Compression Philosophy." In Proc. Phys. Lett. 111.

Shapiro, A. E. "Newton's "Experimental Philosophy". In: Early Science Medicine 9.3 (2004), pp. 185–217.

- Smith, C. "A New Chart for British Natural Philosophy: The Development of Energy Physics in the Nineteenth Century". In: History of Science (1978), pp. 231-279.
- Tait, P. G. Letter from Tait to Thomson, 12 December 1861. Kelvin Papers. 1861.
- Thomson, W. On the Dynamical Theory of Heat, with Numerical Results Deduced from Mr Joule's Equivalent of a Thermal Unit, and M. Regnault's Observations on Steam. Vol. 20. Transactions of the Royal Society of Edinburgh. 1851. 261-288.
- Thomson, W. and Tait, P. G. Treatise on Natural Philosophy. Clarendon Press, 1867.
- Westfall, R. S. Never at Rest: A Biography of Isaac Newton. Cambridge: Cambridge University Press, 1981.

2021-

D4E Smith, C. "A New Chart for British Natural Philosophy: The Development of [35] Tait, P. G. Letter from Tait to Thomson, 12 December 1861. Helvin Papers.

[36] Thomson, W. On the Dynamical Theory of Heat, with Numerical Results

Deduced from Mr Joule's Equivalent of a Thermal Unit, and M. Regnault

[37] Thomson, W. and Talt, P. G. Treatile on Natural Philosophy. Clarendon Press,

[38] Westfull, R. S. Never at Rest: A Biography of Issac Newton. Cambridge.