Beer Brewing, Steam Engines, and the Fate of the Cosmos

Prof. David Kaiser

Monday, October 18, 2010, STS.003

Motion unit

Overarching questions:

Are the motions of objects subject to universal laws?
Does science drive technology, or the other way around?

I. Powering a Revolution

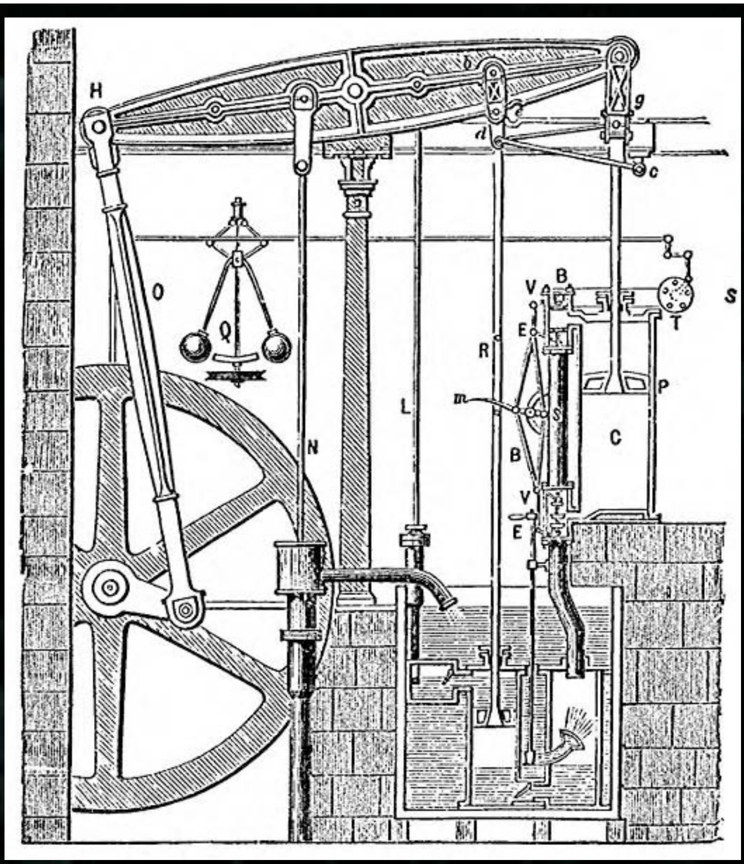
II. Heat as Fluid or Motion?

III. God, Man, and Waste

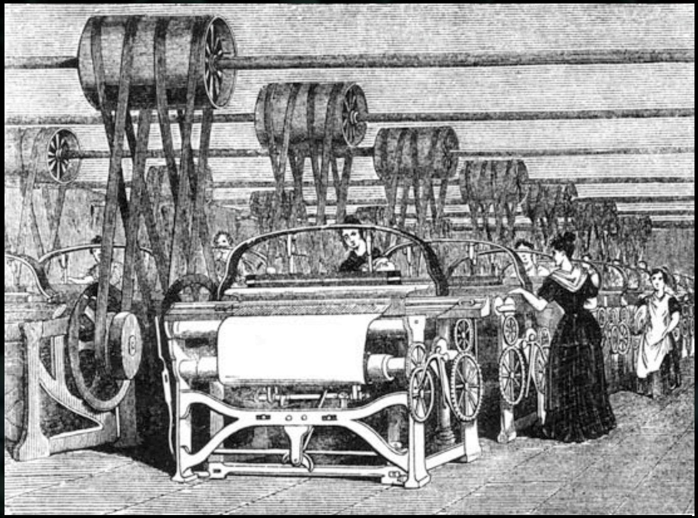
Readings: Joule, “Mechanical equivalent of heat,” 166-183;
Bowler and Morus, *Making Modern Science*, 79-102.

Powering a Revolution

Steam engines were invented in the early 18th century. Glasgow engineer James Watt made important improvements in the 1760s – 1780s.



James Watt's steam engine, ca. 1770s



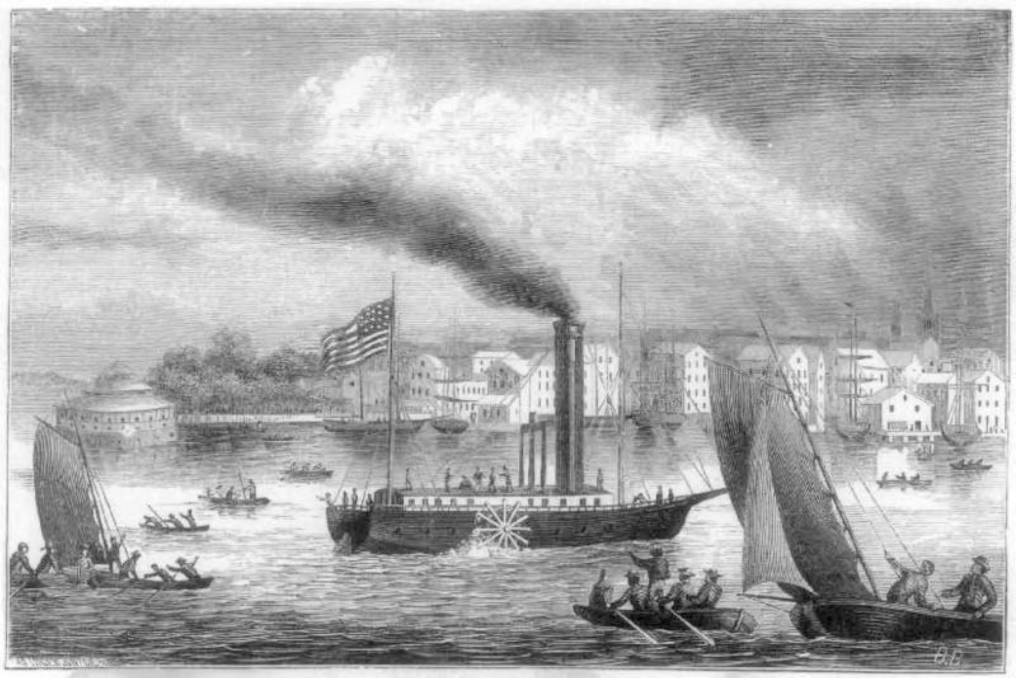
Steam-powered looms, England, 1844

England had already been the center of the textile industry. The steam engine helped automate the spinning of wool and cotton into fabrics – and thus helped launch the Industrial Revolution.

Steamships

Inventors began powering boats with steam engines soon after Watt's improvements.

Photo of a model of Marquie de Jouffroy d'Abbans's 1776 steamboat removed due to copyright restrictions.

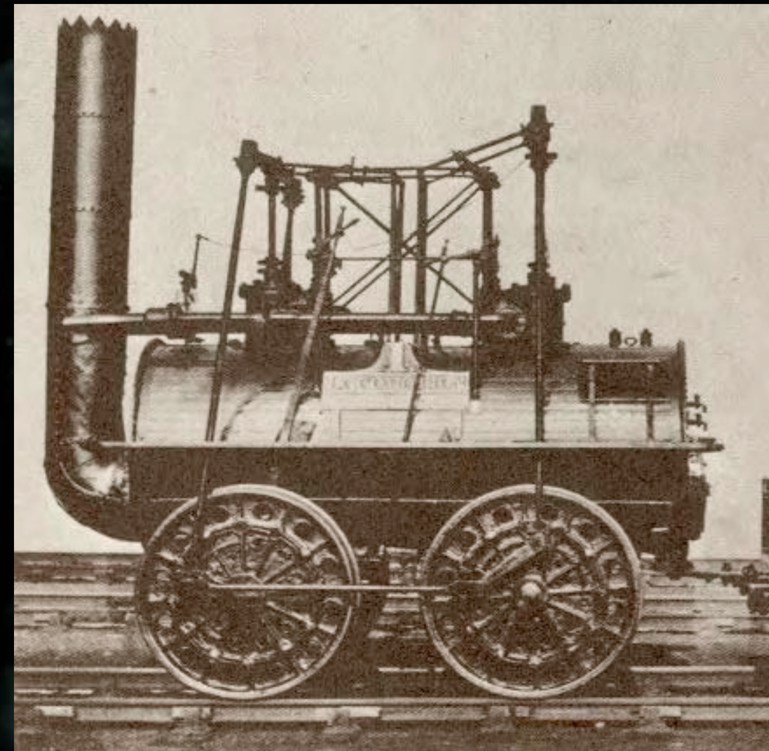


"Fulton's Monster": Robert Fulton's steamship on the Hudson, 1807

The first commercially viable steamship line was launched by Robert Fulton in 1807. The steamer went between New York City and Albany.

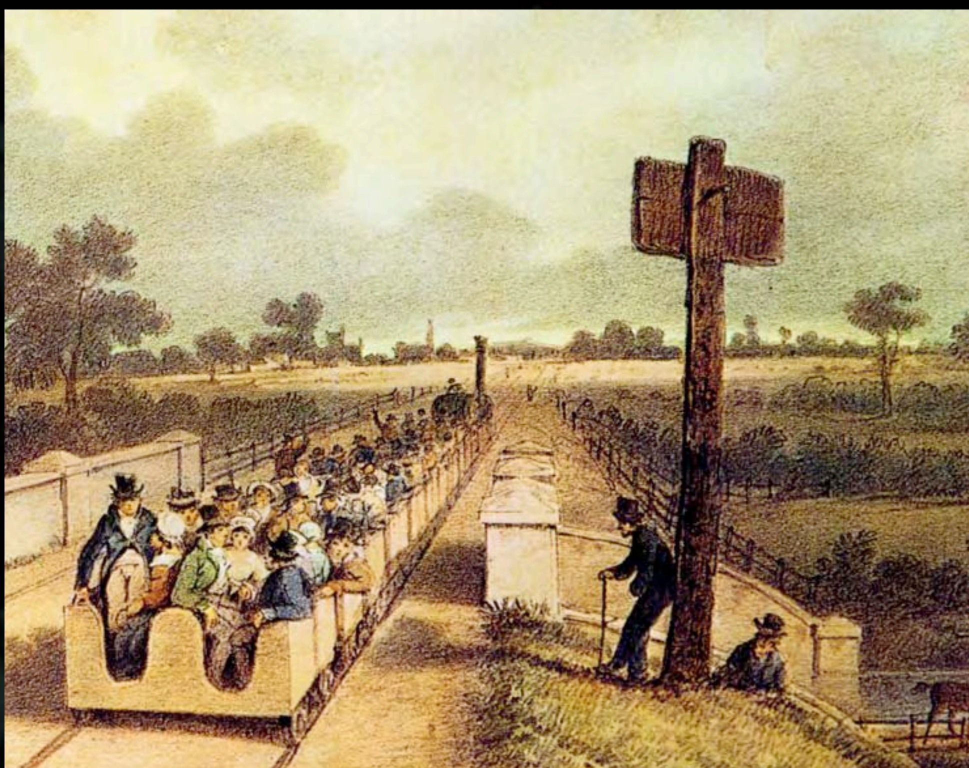
Railroads

By the early 19th century, steam engines were powering the first railroads as well.



First steam-powered locomotive, England, 1804

The first inter-city railway, complete with posted timetables, ran between Liverpool and Manchester, beginning in 1830.

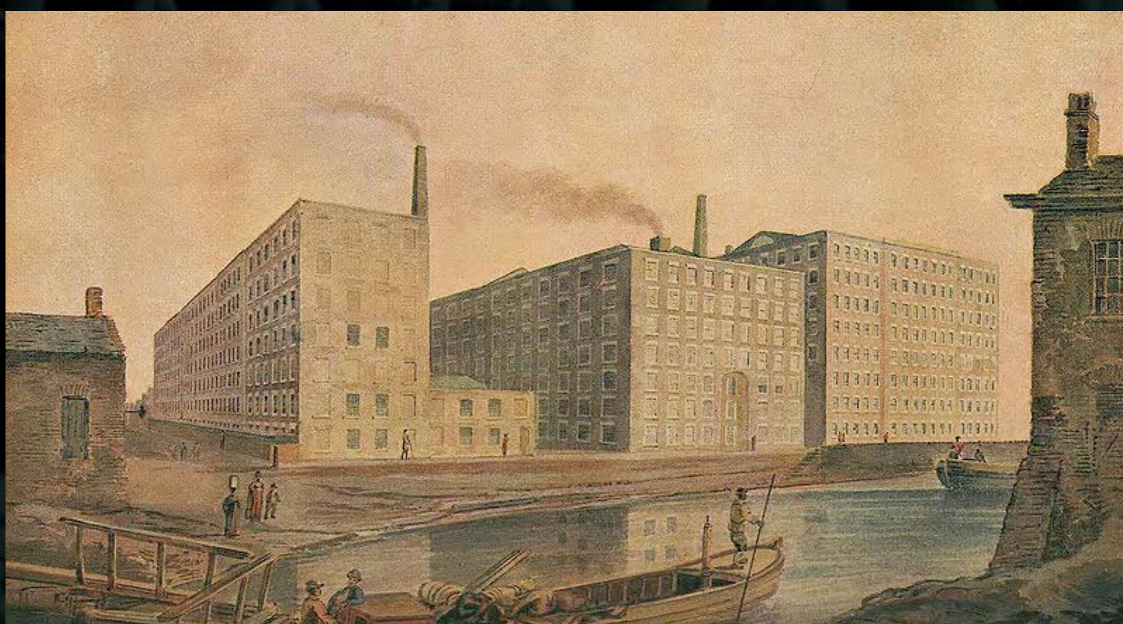


A. B. Clayton, *Inaugural Journey of the Liverpool and Manchester Railway*, 1830

Industrial Cities

Glasgow:
84k in 1801;
270k in 1840

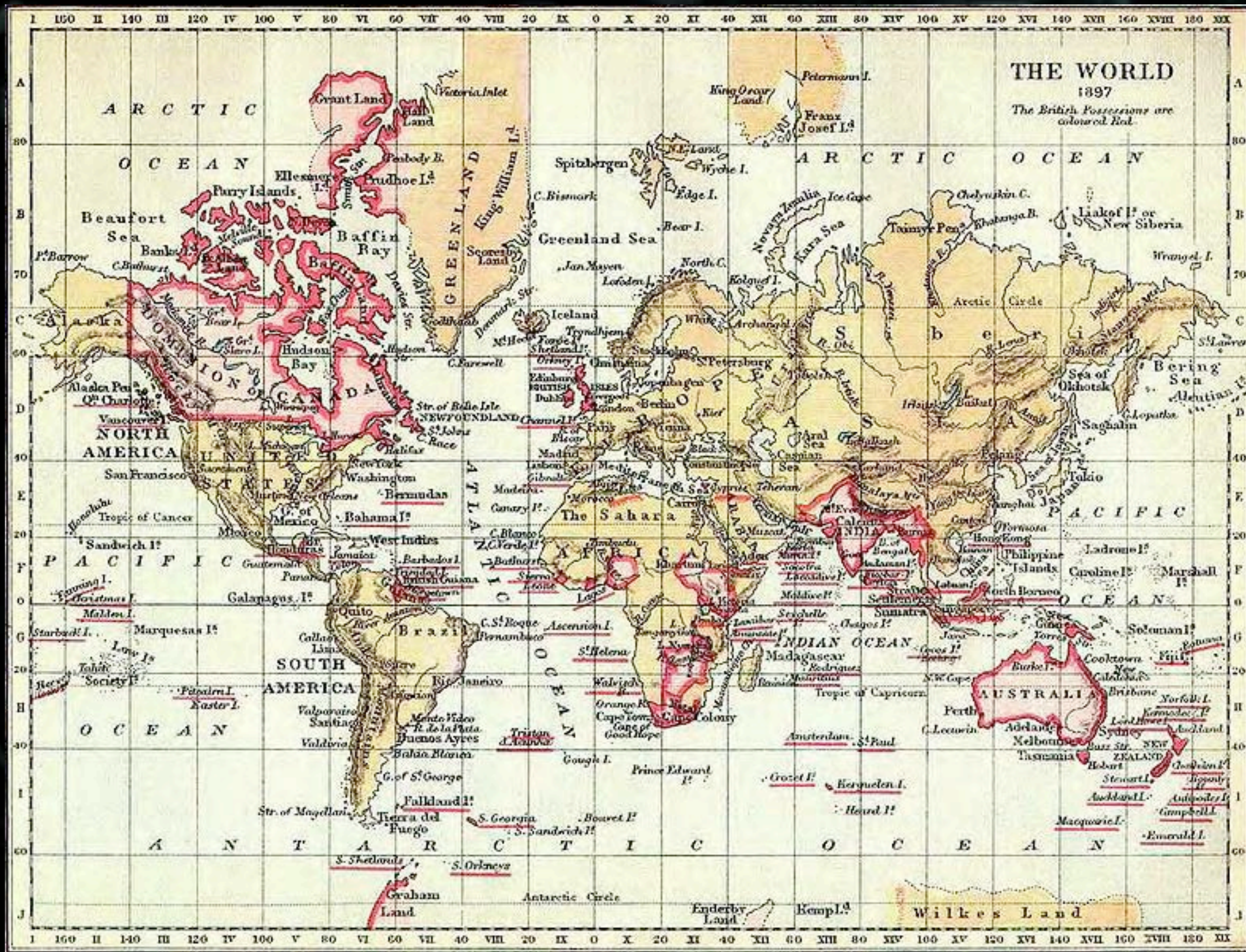
John Grimshaw, *Shipping on the Clyde*, Glasgow, 1881



McConnel & Co.'s cotton mills, Manchester, ca. 1820

Manchester:
20k in 1750;
300k in 1850

Engines and Empire



Britain built its empire with sail; it governed with steam. Constant focus on improving *efficiency* of steam engines. E.g., could a steamship travel all the way to Australia without stopping to refuel?

Heat as Fluid

Lavoisier, 1780s: heat is a form of matter – an "imponderable fluid" that Lavoisier named *caloric*.

Heat exchange occurred because caloric flowed from one body to another.

Jacques-Louis David, *Monsieur de Lavoisier and his wife, Marie-Anne Paulze*, 1788

Natural philosophers puzzled over caloric in the light of phase transitions. E.g., ice could absorb heat without rising in temperature.

Carnot and French Heat

Sadi Carnot (1796 – 1832) was a French engineer. He sought to understand heat flow and the efficiency of engines for both scientific and political reasons.

Sadi Carnot, in the military dress uniform of the *Ecole Polytechnique,* ca. 1812

Photo of Ecole Polytechnique removed due to copyright restrictions.

Paul Delarouche, *Napolean abdicated in Fontainebleau,* 1845

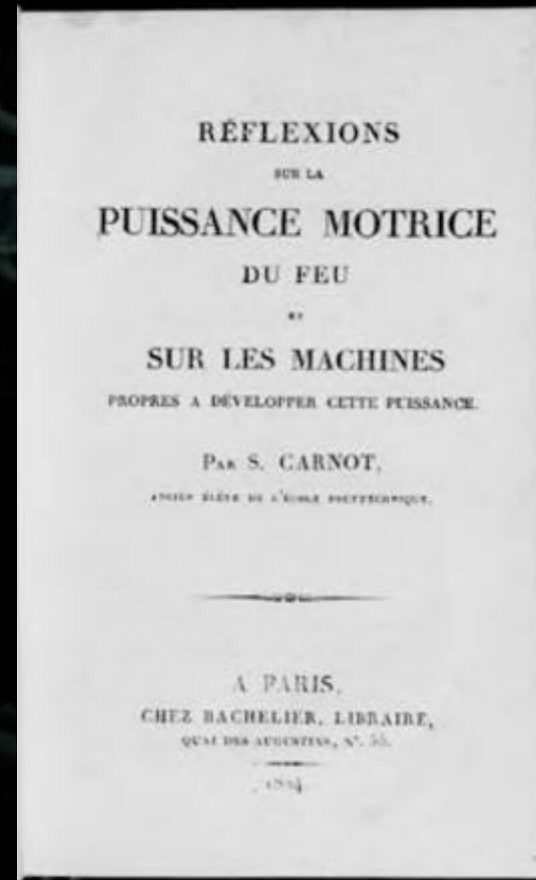
Following Napolean's defeat by the British in 1815, several British-designed steam engines appeared in France. Carnot sought to understand how the British had advanced so far beyond the French in steam-engine design.

Carnot Cycle

Lavoisier: matter is neither created nor destroyed.

Carnot: caloric, too, must be conserved.

Heat engines did work by getting caloric to flow from a high-T reservoir to a low-T one.



RÉFLEXIONS

PUISSANCE MOTRICE

DU FEU

SUR LES MACHINES

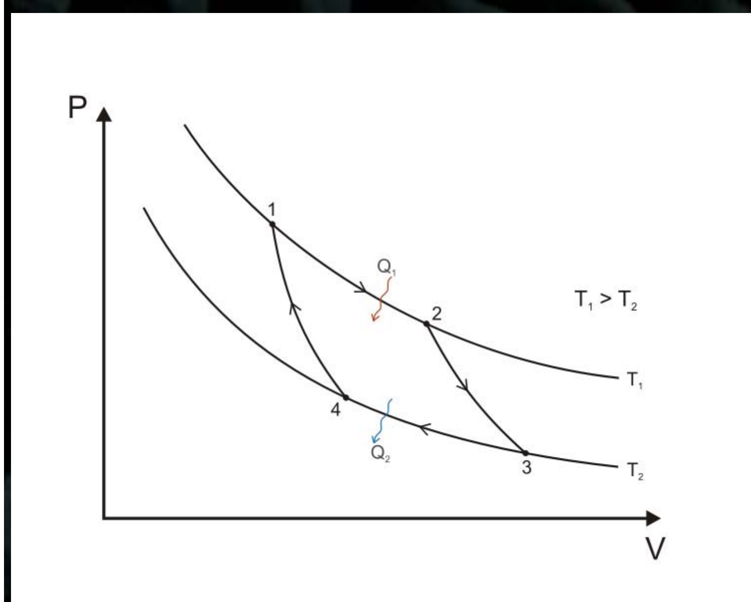
PROPRES A DÉVELOPPER CETTE PUISSANCE.

PAR S. CARNOT,

A PARIS,

CHEZ BACHELIER, LIBRAIRE,

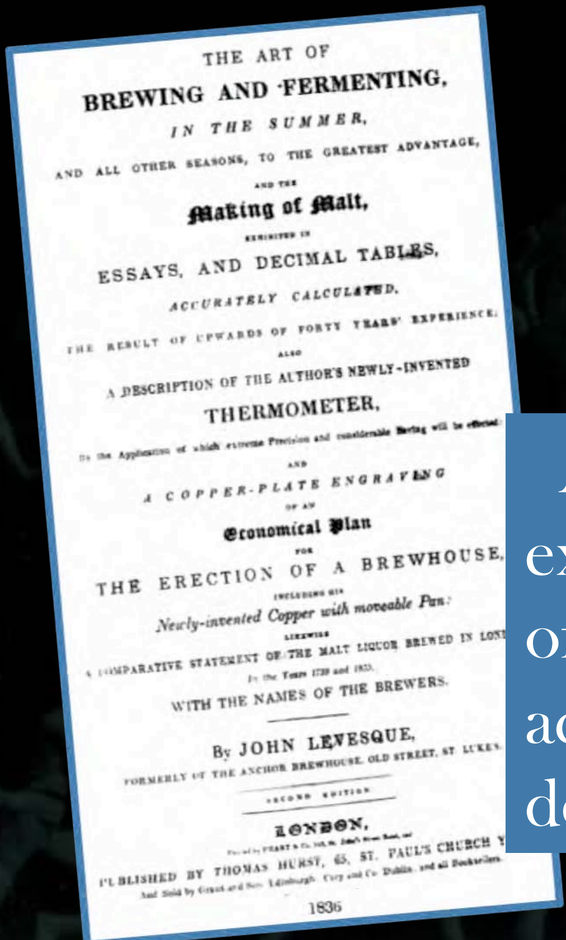
Carnot, *Reflexions*, 1824



"The production of motive power is then due in steam engines not to actual consumption of the caloric but to its transportation from a warm body to a cold body."

A Brewer's Son

James Joule (1818 – 1889) was the son of a wealthy brewer in Manchester. He was tutored by John Dalton (of atomism fame); his father built him his own laboratory at home.



THE ART OF
BREWING AND FERMENTING,
IN THE SUMMER,
AND ALL OTHER SEASONS, TO THE GREATEST ADVANTAGE,
AND THE
Making of Malt,
EXHIBITED IN
ESSAYS, AND DECIMAL TABLES,
ACCURATELY CALCULATED,
THE RESULT OF UPWARDS OF FORTY YEARS' EXPERIENCE:
ALSO
A DESCRIPTION OF THE AUTHOR'S NEWLY-INVENTED
THERMOMETER,
By the Application of which extreme Precision and considerable Saving will be effected:
AND
A COPPER-PLATE ENGRAVING
OF AN
Economical Plan
FOR
THE ERECTION OF A BREWHOUSE,
INCLUDING HIS
Newly-invented Copper with moveable Pan:
LIKEWISE
A COMPARATIVE STATEMENT OF THE MALT LIQUOR BREWED IN LON
WITH THE NAMES OF THE BREWERS.

By JOHN LEVESQUE,
FORMERLY OF THE ANCHOR BREWHOUSE, OLD STREET, ST. LUKE'S.

SECOND EDITION

LONDON.
PUBLISHED BY THOMAS HURST, 65, ST. PAUL'S CHURCH Y
1836

James Prescott Joule, ca. 1880

At the time, brewers had the most experience with delicate measurements of temperature. They also had the most accurate thermometers (good to 1/20th degree F).

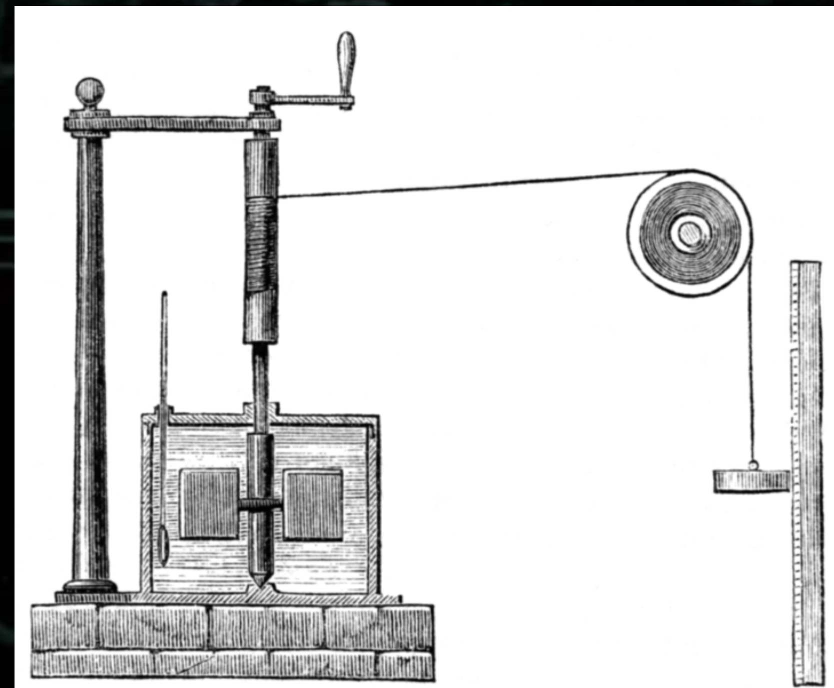
"Fomerly the lower classes who were, and still are, the principal consumers of beer, thought it a mark of effiminate refinement to require a glass to drink their beer from; and however thick the fluid, it flowed from the pewter pot, with inexpressible zest down their callous throats, and all was well: but not so in the present day! Nothing less than a clean glass filled with ale of sparkling brilliancy will suffice for the lowest of the low ... Formerly the brewer was required to furnish beer to the public at the age of one, two, and three years... But such beer will not now be commonly drunk, and the brewer is required to brew all the year through, and to furnish it to the public at the end of a few days after brewing, perfectly mild, full, and transparent. Now to do this in hot weather, is certainly no easy task to the uninitiated."

Photo of a glass of beer removed due to copyright restrictions.

G. A. Wigney, *An Elementary Dictionary for the use of Malsters, Brewers, Destillers* (1838)

“Mechanical Equivalent of Heat”

“In 1845 and 1847, I employed a paddle wheel to produce the fluid friction, and obtained the equivalents 781.5, 782.1, and 787.6 [foot-pounds], respectively, from the agitation of water, sperm oil, and mercury.”



Joule’s apparatus, *Harper’s New Monthly Magazine*, 1869

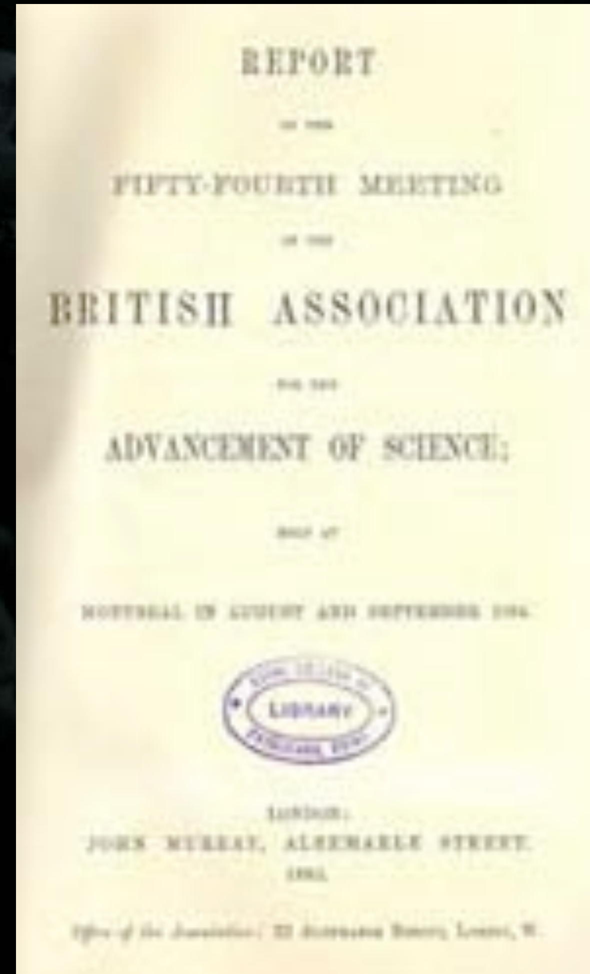
Image of Joule's paddle-wheel removed due to copyright restrictions.

“Results so closely coinciding with one another, and with those previously derived from [other] experiments, ... left no doubt on my mind as to the existence of an equivalent relation between force [or motion] and heat.”

Heat as Motion

Joule considered his experiments to be clear proof that heat was simply a form of *motion*, not a conserved fluid like caloric.

Though he managed to publish several papers and present his work at meetings like the British Association for the Advancement of Science (BAAS), few took his work seriously.


REPORT

FIFTY-FOURTH MEETING

BRITISH ASSOCIATION

ADVANCEMENT OF SCIENCE;

LIBRARY

LONDON:
JOHN MURRAY, ALBEMARLE STREET.

No one could replicate his findings; and his claimed accuracy was beyond what most natural philosophers could believe, much less achieve.

Glaswegian Theorist

William Thomson (later Lord Kelvin, 1824 – 1907) was one of the few to listen to Joule. Thomson had an ideal background for the topic: his brother, James, was a steam engineer, and William grew up tinkering with machines.

William Thomson, 1846

Images of "Energy and Empire: A Biographical Study of Lord Kelvin" and "The Science of Energy: A Cultural History of Energy Physics in Victorian Britain," Crosbie Smith, removed due to copyright restrictions.

Cambridge Training

Thomson had been trained in mathematical physics at Cambridge. His work relied on mathematical analogies, e.g., heat flow and hydrodynamics.

Image of Cambridge University removed due to copyright restrictions.

$$\nabla \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{\partial x}{\partial x} + \frac{\partial y}{\partial y} + \frac{\partial z}{\partial z} = 3$$

$$\nabla (x^2 + y^2 + z^2) = \begin{bmatrix} 2x \\ 2y \\ 2z \end{bmatrix}$$

$$\nabla \times \begin{bmatrix} x \\ y \\ z \end{bmatrix} =$$

In 1848-49, Thomson tried to reconcile Carnot's work (based on caloric) with Joule's experiments. In the process, Thomson invented the absolute temperature scale (˚Kelvin), including absolute zero.

Mathematical Tripos

Image of "Masters of Theory: Cambridge and the Rise of Mathematical Physics," Andrew Warwick, removed due to copyright restrictions.

730 THE GRAPHIC JUNE 24, 1893

The Mathematical Tripos

THE Cambridge Mathematical Tripos list which was published last week contained no surprises. The senior wrangler was Mr. G. T. Manley, of Christ College, who was born at Hull in 1872, and educated at Wakefield Grammar School. Mr. G. H. J. Hurst, of King's, and Mr. C. P. Sanger, of Trinity, were bracketed second. The former was educated at Eton and the later at Winchester.—Our portrait of Mr. Manley is from a photograph by Hall, Wakefield; that of Mr. Hurst, by Hills and Saunders, Cambridge; that of Mr. Sanger, by Thomson, Grosvenor Street, W.

MR. G. T. MANLEY
Senior Wrangler

MR. G. H. J. HURST
Bracketed Second Wrangler

MR. C. P. SANGER,
Bracketed Second Wrangler

THE CAMBRIDGE MATHEMATICAL TRIPOS

Rural Notes

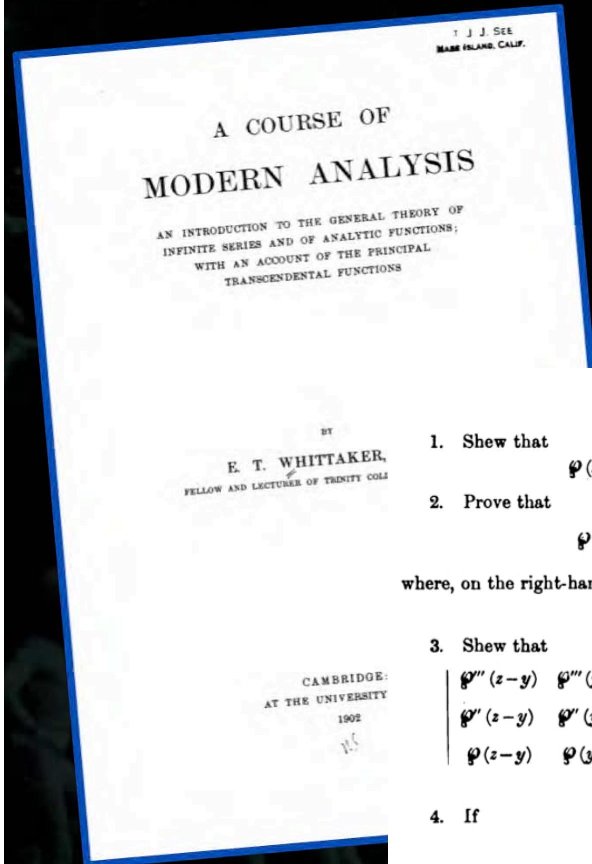
THE DROUGHT

FIELD AND GARDEN

Tripos: 3-day exam, rank-order results published in national newspapers. One's score determined one's future prospects.

James Ward's 1875 diary:

1. To be out of bed by 7:35 (or on Sundays 8:45)
2. To do 5 hours work before hall [lunch]
3. At least one hours [athletic] *exercise* after hall
4. Three hours work after hall
5. Finish work by 11 and be in bed by 11:30 (except on Saturday when it is 12)
6. A fine of 3d to be paid for the first rule broken on any day and 1d every other rule broken on the same day
7. A halfpenny to be allowed out of the fund to every member waking another between 6:35 and 7:35 on weekdays and between 7:45 and 8:45 on Sundays
8. Work before 8am may count either for morning or evening work of the day
9. Time spent at Church Society meeting counts for half the same time's work and also allows the member attending to work till 11:30 and stay up till 12
10. These rules binding till further notice and any alteration of them requires unanimity.



J. J. See
Mare Island, Calif.

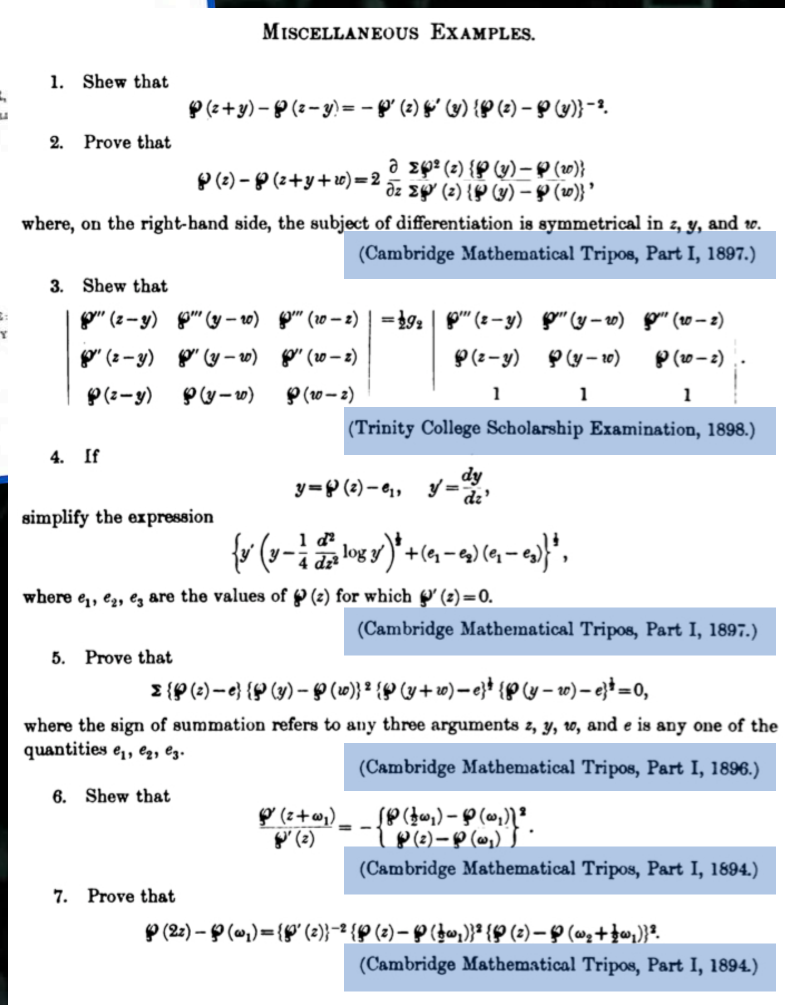
A COURSE OF
MODERN ANALYSIS

AN INTRODUCTION TO THE GENERAL THEORY OF INFINITE SERIES AND OF ANALYTIC FUNCTIONS; WITH AN ACCOUNT OF THE PRINCIPAL TRANSCENDENTAL FUNCTIONS

BY

E. T. WHITTAKER,
FELLOW AND LECTURER OF TRINITY COLL

CAMBRIDGE:
AT THE UNIVERSITY
1902



Miscellaneous Examples.

1. Shew that

$$\wp(z+y) - \wp(z-y) = -\wp'(z)\,\wp'(y)\,\{\wp(z) - \wp(y)\}^{-2}.$$

2. Prove that

$$\wp(z) - \wp(z+y+w) = 2\frac{\partial}{\partial z}\frac{\Sigma\wp^2(z)\,\{\wp(y) - \wp(w)\}}{\Sigma\wp'(z)\,\{\wp(y) - \wp(w)\}},$$

where, on the right-hand side, the subject of differentiation is symmetrical in z, y, and w.

(Cambridge Mathematical Tripos, Part I, 1897.)

3. Shew that

$$\begin{vmatrix} \wp'''(z-y) & \wp'''(y-w) & \wp'''(w-z) \\ \wp'(z-y) & \wp'(y-w) & \wp'(w-z) \\ \wp(z-y) & \wp(y-w) & \wp(w-z) \end{vmatrix} = \tfrac{1}{2}g_2 \begin{vmatrix} \wp'''(z-y) & \wp''(y-w) & \wp''(w-z) \\ \wp(z-y) & \wp(y-w) & \wp(w-z) \\ 1 & 1 & 1 \end{vmatrix}.$$

(Trinity College Scholarship Examination, 1898.)

4. If

$$y = \wp(z) - e_1, \quad y' = \frac{dy}{dz},$$

simplify the expression

$$\left\{y'\left(y - \frac{1}{4}\frac{d^2}{dz^2}\log y'\right)^{\frac{1}{2}} + (e_1 - e_2)(e_1 - e_3)\right\}^{\frac{1}{2}},$$

where e_1, e_2, e_3 are the values of $\wp(z)$ for which $\wp'(z) = 0$.

(Cambridge Mathematical Tripos, Part I, 1897.)

5. Prove that

$$\Sigma\{\wp(z) - e\}\{\wp(y) - \wp(w)\}^2\{\wp(y+w) - e\}^{\frac{1}{2}}\{\wp(y-w) - e\}^{\frac{1}{2}} = 0,$$

where the sign of summation refers to any three arguments z, y, w, and e is any one of the quantities e_1, e_2, e_3.

(Cambridge Mathematical Tripos, Part I, 1896.)

6. Shew that

$$\frac{\wp'(z+\omega_1)}{\wp'(z)} = -\left\{\frac{\wp(\frac{1}{2}\omega_1) - \wp(\omega_1)}{\wp(z) - \wp(\omega_1)}\right\}^2.$$

(Cambridge Mathematical Tripos, Part I, 1894.)

7. Prove that

$$\wp(2z) - \wp(\omega_1) = \{\wp'(z)\}^{-2}\{\wp(z) - \wp(\tfrac{1}{2}\omega_1)\}^2\{\wp(z) - \wp(\omega_2 + \tfrac{1}{2}\omega_1)\}^2.$$

(Cambridge Mathematical Tripos, Part I, 1894.)

Increasing Disorder

Rudolf Clausius (1822 – 1888) followed Thomson's papers closely. He was the first to reconcile Carnot and Joule, in 1850.

The *essential* point of Carnot's work (said Clausius) was that the heat engine worked by getting heat to flow from hot to cold. One need not further assume that heat (or caloric) was conserved.

Rudolf Clausius, ca. 1870

Clausius: whenever work was produced by heat, some heat (proportional to the work done) must be *consumed*. He went on to define *entropy*: $\Delta S = \Delta Q / T \geq 0$.

Indestructible, but Dissipative

Thomson in turn built upon Clausius's work. By early 1851, Thomson showed that Clausius's results implied that total energy was conserved – energy was *indestructible* – and yet some portion of it would be *dissipated* into an unusable form in the process of generating work.

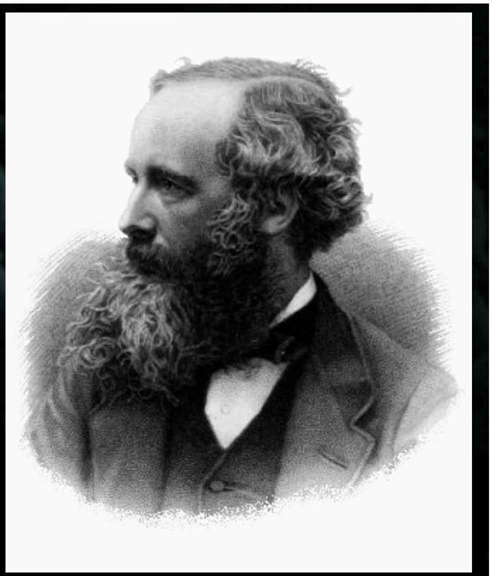
Image of "Entropy," Sidney Harris, removed due to copyright restrictions.
See: http://www-lmmb.ncifcrf.gov/~toms/thermodynamics.html

Thomson, Clausius, and others thus articulated the first two laws of thermodynamics, ca. 1850.

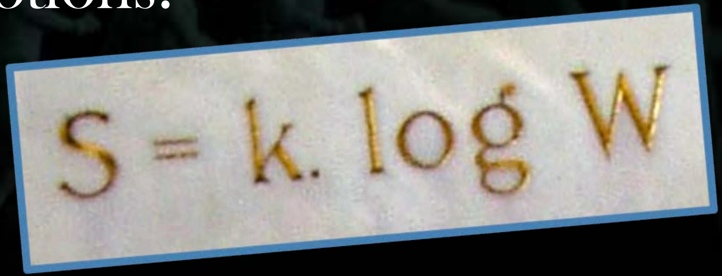
Statistically Speaking

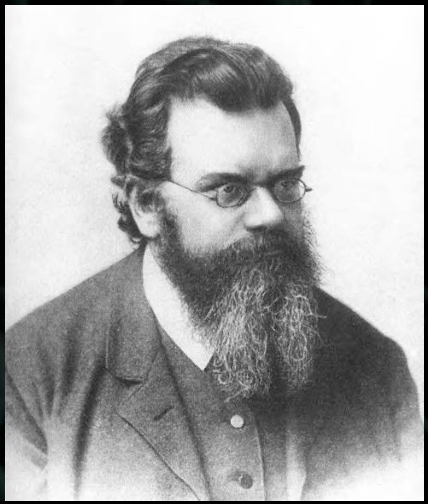
Clausius and Thomson considered entropy increase to be a universal law, akin to Newton's laws.

James Clerk Maxwell and Ludwig Boltzmann agreed that heat was just the *motion* of small bodies; they tried to formulate a *statistical* treatment of all those tiny motions.



James Clerk Maxwell
(1831 – 1879)





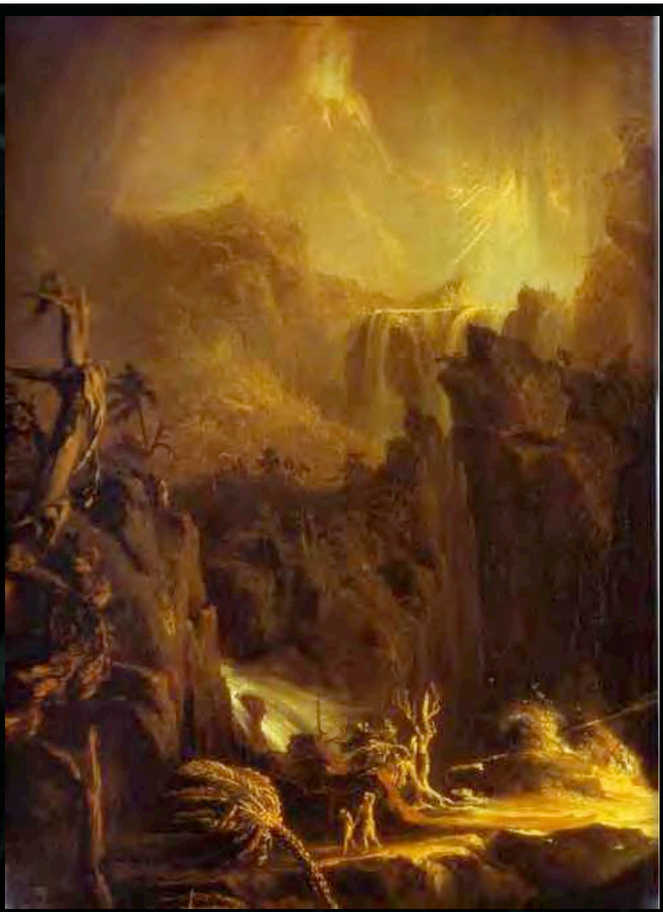
Ludwig Boltzmann (1844 – 1906)

$\Delta S \geq 0$ is a *statistical regularity*, but not an unbreakable *law*. Back to Aristotle: "always or for the most part." First serious check on Newtonian *determinism*.

God and Motion

For Thomson, the 1st and 2nd laws of thermodynamics fit a larger theological view.

In his strict Scottish Presbyterian view, the material world is in constant *flux* and *decay*.



Thomas Cole, *Expulsion from the Garden of Eden*, ca. 1827

To Thomson, everything that God made is perfect and eternal, but everything that people make is imperfect and corruptible.

Work and Waste

To Thomson, the conservation of energy (1st law) meant that only God can create and destroy energy.

But people can *dissipate* that energy – not destroy it, but render it into a less-useful state (2nd law). The 2nd law seemed to open space for human *free will* – but also for human responsibility.

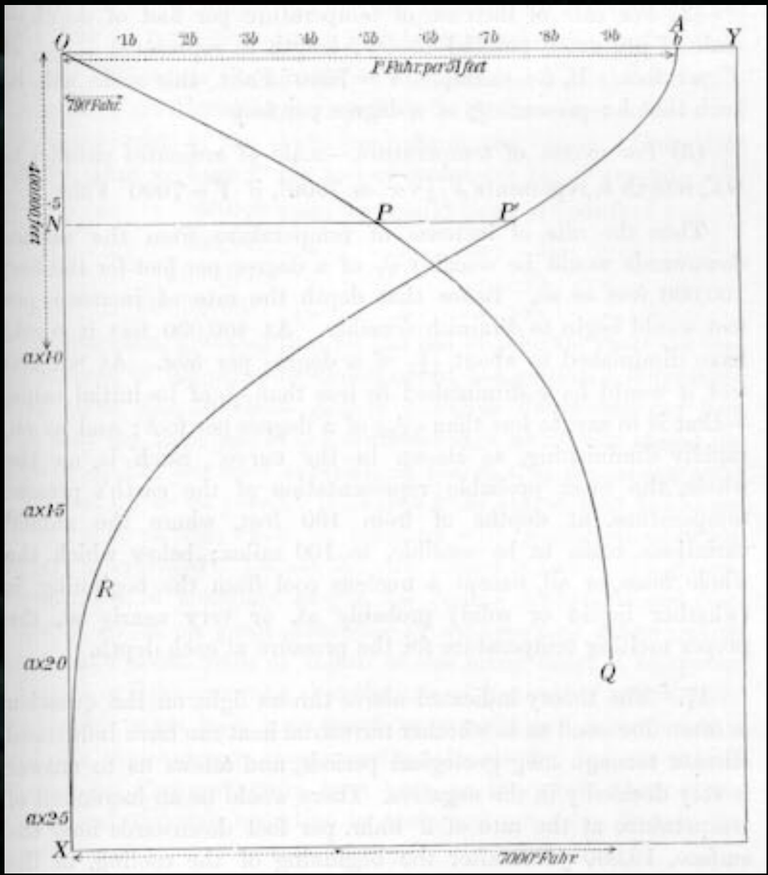
Photo of the grave stone of W. Thomson, Lord Kelvin, removed due to copyright restrictions.

Thus the 2nd law entailed a *moral* requirement, bolstering the famous “Protestant work ethic”: always do what you can to conserve useful work. Work hard, waste not.

Directionality

The 2nd law of thermodynamics also implied that the universe has a *direction*. Newton's laws of motion are perfectly reversible. Not so a heat-filled world.

Akin to the historical impulse that flourished in the 19th century, in fields like natural history, geology, and evolution.



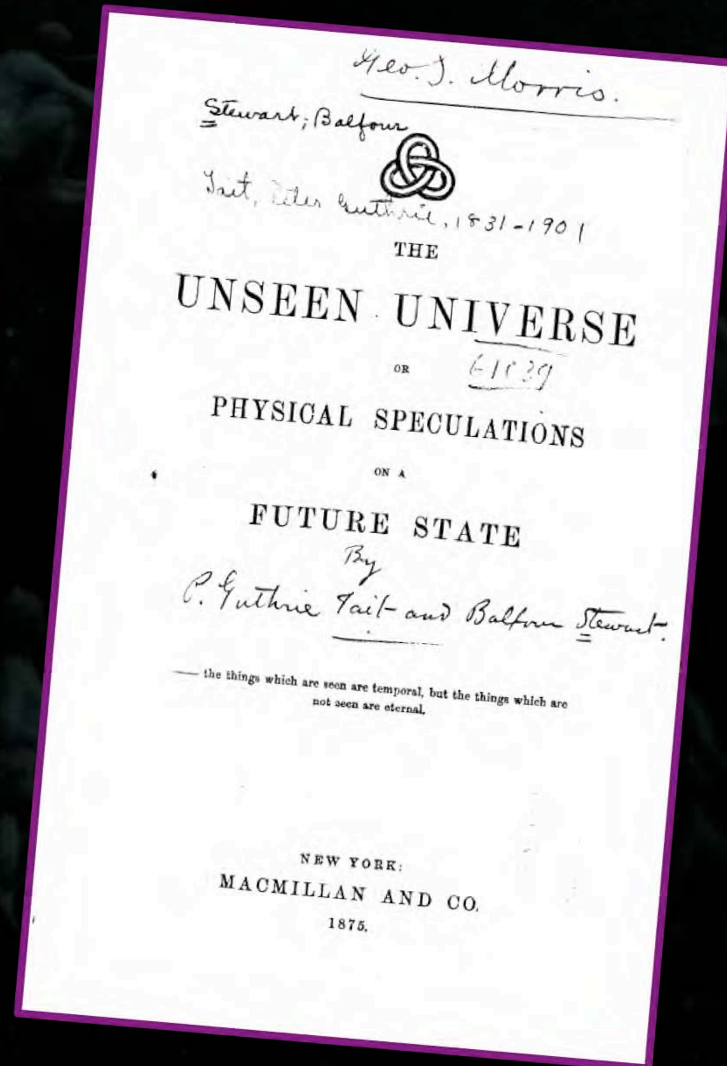
Lord Kelvin, "On the secular cooling of the Earth," 1862

But when Thomson calculated how old the earth could be, based on its rate of cooling from molten rock, he found $t = 20 - 400$ million years. Much too short to match geological and evolutionary ideas.

An Unseen World

Thomson read a *progressive* lesson in the directionality of the 2^{nd} law.

His colleagues, Peter Tait and Balfour Stewart, went further. Only in our physical surroundings does useful energy degrade and dissipate. That dissipated energy cycles back to an unseen (spiritual) world, which is perfect and unchanging.


Geo. J. Morris.

Stewart; Balfour

THE

UNSEEN UNIVERSE

OR

PHYSICAL SPECULATIONS

ON A

FUTURE STATE

By P. Guthrie Tait and Balfour Stewart.

— the things which are seen are temporal, but the things which are not seen are eternal.

NEW YORK:

MACMILLAN AND CO.

1875.

"We endeavor to show that immortality is strictly in accordance with" the latest developments in thermodynamics.

An Unhappy Ending...

Rudolf Clausius: Upon reaching a state of maximum entropy, “the universe from that time forward would be condemned to a state of eternal rest.”

Camille Flammarion, *Le fin du monde*, 1893

Camille Flammarion, *Le fin du monde*, 1893

“The universe would be in a state of unchanging death.”
Rudolf Clausius, 1867