15. The Science of Energy -- Chaps 12-14.

30-something Max

1. Maxwell's Demon

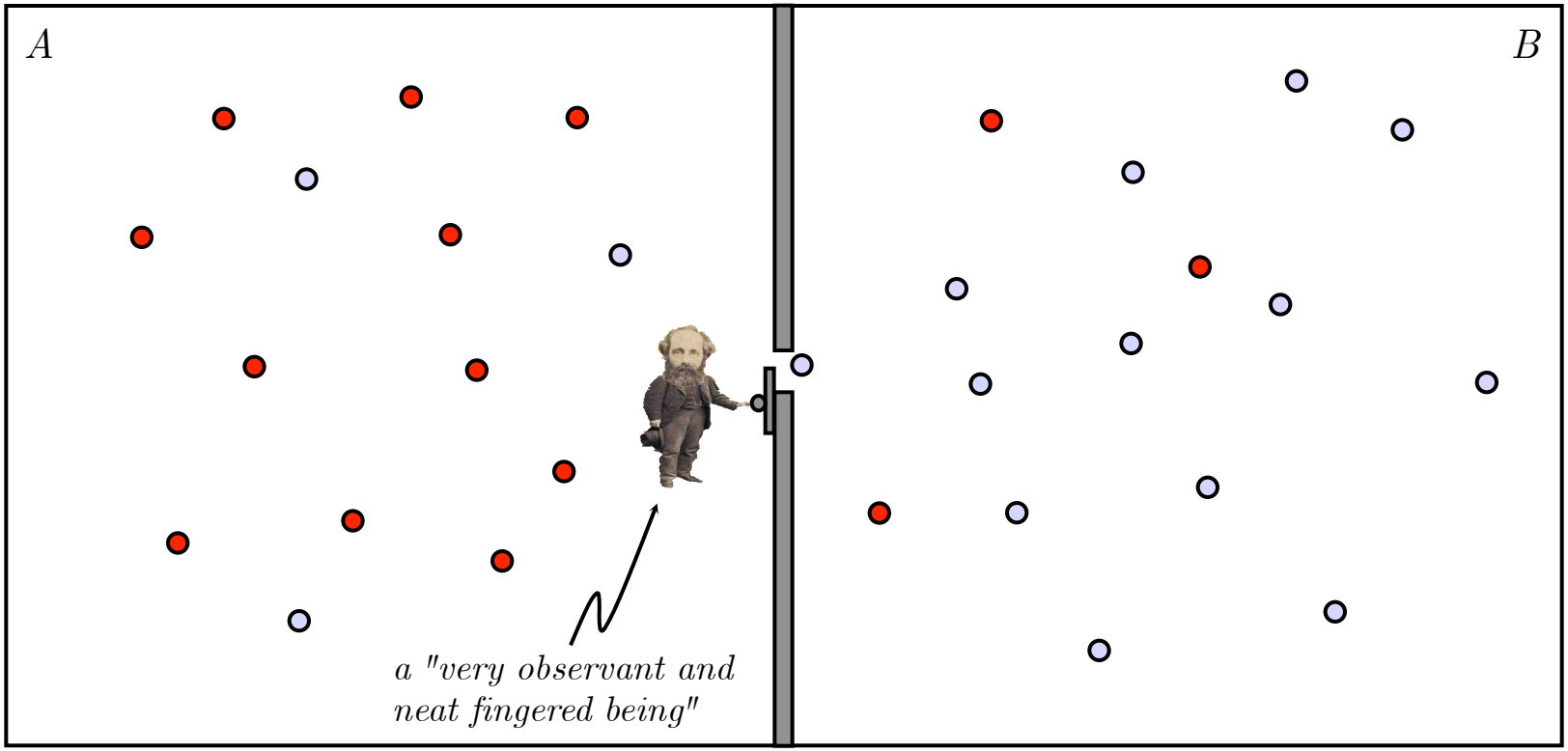
- *Maxwell's critique of scientific materialism:* It entails dynamical reversibility which is not observed in nature.
- *Thomson's Mantra:*

"Everything in the physical world is progressive."

- *Maxwell:*
  - Dissipation of energy gives "fresh meaning to the Christian perspective on beginnings and endings to the visible cosmos" and links the natural and moral orders.
  - *But*: What is the dynamical explanation for it?

1867. Letter from Maxwell to Tait.

- Consider the 2nd Law in the form: "If two things are in contact, the hotter cannot take heat from the colder without external agency."
- Maxwell's counterexample:



- The neat-fingered being only lets hot molecules through to A and cold molecules through to B.

- *Upshot*:

"The hot system has got hotter and the cold colder and yet no work has been done, only the intelligence of a very observant and neat fingered being has been employed."

- *Moral #1*:

"The 2nd Law of Thermodynamics has only statistical certainty."

- *In other words:* It's very probable, but *not* completely certain, that "If two things are in contact, the hotter cannot take heat from the colder without external agency."

- *Moral #2*: Attempts to derive the 2nd Law from (deterministic) mechanics will fail.

"...it is rare sport to see those learned Germans contending for the priority of the discovery that the 2nd law of [thermodynamics] is the Hamiltonische Princip... [It] soars along in a region unvexed by statistical considerations while the German Icari flap their waxen wings in *nephelo coccygia* amid those cloudy forms which the ignorance and finitude of human science have invested with the incommunicable attributes of the invisible Queen of heaven."

- *Moral #3*: The distinction between dissipated energy (heat that we cannot make use of) and energy available for work depends on our state of knowledge.

> [If we supposed]... our senses sharpened to such a degree that we could trace the motions of molecules as easily as we now trace those of large bodies... the distinction between work and heat would vanish...
>
> [The truth of the 2nd Law depends]... on the fact that the bodies we deal with consist of millions of molecules and that we can never get hold of a single molecule."

- *In other words*: If we were neat-fingered beings capable of knowing the positions and velocities of molecules, the 2nd Law would not apply.

Vexing Unanswered Questions:

(1) *Why* is the 2nd Law only statistical?

- Are the probabilities really subjective? Do they really reflect our lack of knowledge of the micro-physics (Moral #3)?
  - But then why do the vast majority of observable macroscopic systems obey the 2nd Law?
- Are the probabilities objective? Do they reflect an instrinsic probabilitistic nature of micro-physical objects?
- Subsequent development of statistical mechanics and attempts to derive 2nd Law within it.

(2) Should the Demon itself be subject to thermodynamics?

- *Must be:* Otherwise why would we care if a non-thermodynamic demon was capable of violating the 2nd Law of thermodynamics?
- *But:* If so, then shouldn't we "naturalize" the Demon?
  - Perhaps a comprehesive thermodynamical analysis of Demon-plus-system will indicate that the 2nd Law is not violated.
  - Subsequent 20th-century history of the Demon:
    - Fluctuation phenomena (*eg.*, Brownian motion) as naturalized demons.
    - Information-theoretic analyses of entropy.
    - Big mess of less-than-critical literature.

- *General Moral* (Earman & Norton 1998): To investigate the conceptual significance of the 2nd Law, look to securing the foundations of statistical mechanics, as opposed to demon-bashing.

2. Germans *vs.* Brits

- 1871. Demon made public in Maxwell's textbook *Theory of Heat*.
- Clausius protests:

"[In Maxwell's text] my writings are left quite unmentioned; and my name occurs only once, when it is said I introduced the word *entropy*... [A]nyone who derives his knowledge of the matter solely from this book must conclude that I have contributed nothing to the development of the mchanical theory of heat."

- Tait counterpunches:

"When Professor Clausius succeeds in making his own countrymen regard him as the discoverer of the Dissipation of Energy... it will be time enough to complain that foreigners do not give him that credit."

- Maxwell (1878) distains theoretical approach of Clausius:

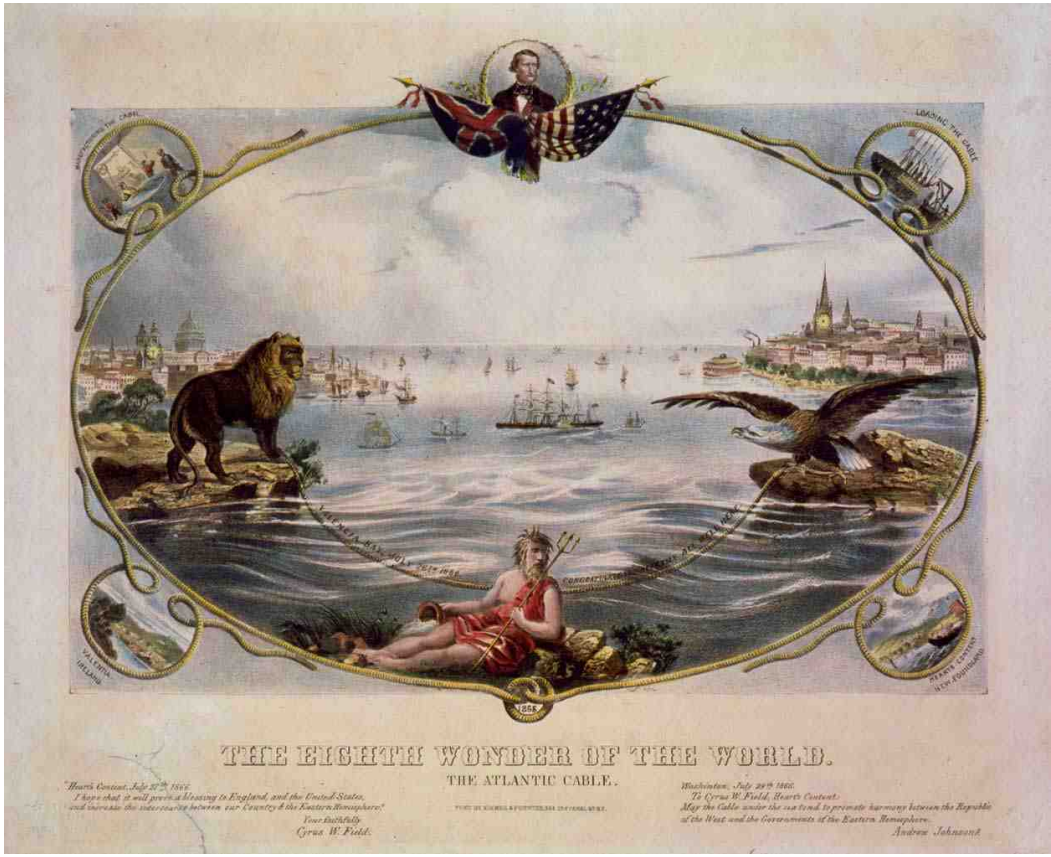
"Clausius, having begun by breaking up the energy of the body into its thermal and ergonal content, has gone on to break up its entropy into the transformational value of its thermal content and the disgregation. Thus both the energy and the entropy, *two quantities capable of direct measurement*, are broken up into four quantities, all of them quite beyond the reach of experiment..."

- <u>*German scientific culture:*</u>
  - theoretical
  - mechanistic/materialistic paradigm
  - action-at-a-distance forces between point particles
- <u>*British scientific culture:*</u>
  - practical
  - implicit Christian (Presbytarian/Anglican) metaphysics
  - local energy transformations of fields

3. The Apparatus of the Market Place

- *At issue:* The accurate measurement of electrical quantities:
  - resistance, current intensity, electromotive force, quantity of charge.

- *At state:*
  - *Profit:* Accuracy and dependability of trans-Atlantic telegraph cables.
  - *Scientific credibility:* Further support for energy physics.
  - *National pride:* British system *vs.* German system.



- *Key notion*:

"The ideology of a successful cultural elite must generate space, must become inscribed in space if it is to avoid disappearing into disembodied and impotent realms of mere signs, abstract descriptions and fantasies." (Smith, pg. 270.)

Weber's Absolute System for Resistance

Wilhelm Weber

- 1851: "On the Measurement of Electrical Resistance According to an Absolute Standard"
- *Relative* system of measurement: resistance measured relative to a specific standard (*eg.* that of copper).
  - Requires special fundamental unit of measurement for resistance.
- *Weber*: Use an absolute system instead:

"... no special fundamental measure for electric resistance is needed if there are measures for electromotive force and for instensity of the current..."

- Just use Ohm's Law:

$$\text{(resistance)} = \text{(electromotive force)}/\text{(current intensity)}$$

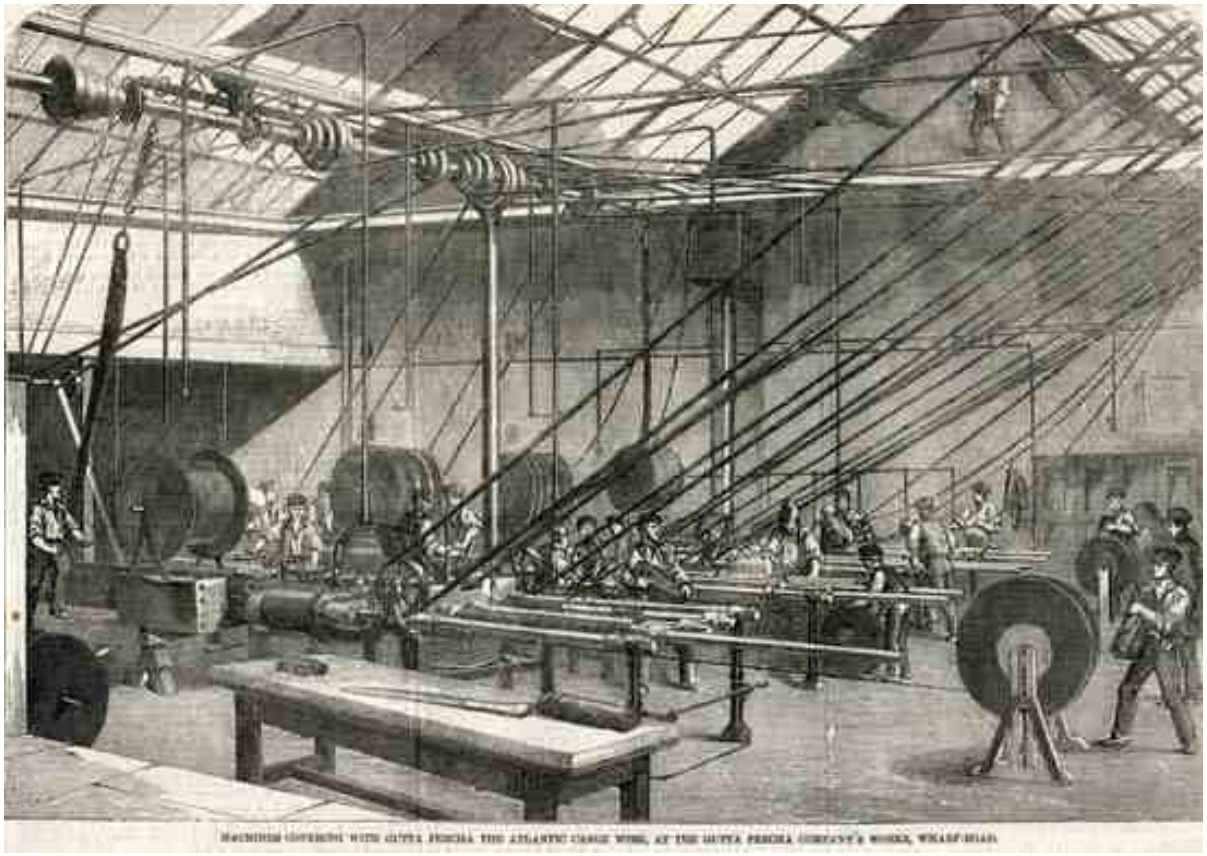
- Measurements of electromotive force and current intensity can be based on an analysis of *magnetic forces*:
  - Electromotive force associated with a conductor = the force exerted by the earth's magnetism on it.
  - Electromotive intensity =

"... the intensity of that current which, when it circulates through a plane of the magnitude of the unit of measure, exercises, according to electro-magnetic laws, the same action at a distance as a bar magnet which contains the unit of measure of bar magnetism."

- *And*: Can now use the system of absolute measure for bar and earth magnetism developed earlier by Gauss (1833).

But:

- Weber's unit of resistance was "less than 10^{-8} times the resistance of a mile of copper wire". (Smith pg. 272)



!?!!??

- Weber's unit embedded in a German metaphysics of action-at-a-distance forces (in the German tradition of Helmholtz, Clausius, *et al.*).

***Thomson's Absolute System*:**

- 1845. Fresh out of Cambridge ("First Smith's Prizeman" and "Second Wrangler".)
- The mechanical equivalent of electricity.

Heat produces mechanical effect.

So does electricity!

$$\left(\begin{array}{l}\textit{The mechanical effect}\\ \textit{produced by a change}\\ \textit{of distance of two}\\ \textit{conducting spheres}\end{array}\right) = \left(\begin{array}{l}\textit{The force}\\ \textit{exerted by each}\\ \textit{on the other.}\end{array}\right) \times \left(\begin{array}{l}\textit{The change}\\ \textit{in distance}\end{array}\right)$$

- Thomson's 1853 electrometer.
  - Electric force between two conductors balanced by weights.

Max

"An apparatus of the market place!"

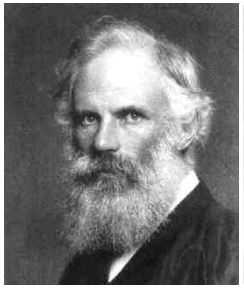
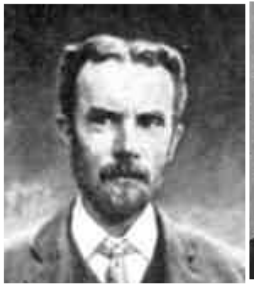
- Allows measurements of electricity without the need for an underlying theory of electricity.
- Based on energy concepts (work, mechanical effect) and not action-at-a-distance forces.

The BAAS Standard

- 1860's: British Association for the Advancement of Science (BAAS) Committee on Standards of Electrical Resistance.
- 1863 Report:
  - Four electrical quantities susceptible to measurement: electromotive force (E), current (I), resistance (R), quantity of charge (Q).
  - Two relations:
    - Ohm's Law: $I = E/R$
    - Faraday's Relation: $Q = It$
  - Two *mechanical effects* due to electricity:
    - Joule's Law: $W = I^2Rt$ (current does work)
    - Coulomb's Law: $F = Q/d^2$ (charged objects exert a force)
  - Recommends adopting Joule's Law to derive measure of resistance.
- 1881: First International Congress on Electrical Standards adopts BAAS standard for resistance.

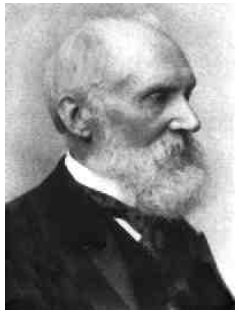
4. Late 19th Century Developments

- *Question*: What is Maxwell's theory about?
- 1880's. "Maxwellians".
  - G. F. Fitzgerald
  - Oliver Heaviside
  - Oliver Lodge


- Reification of energy: Energy as a substance in its own right, as opposed to a mechanical effect identified as a material object's capacity to do work.
- Mawell's theory is about energy located in the electromagnetic ether.

- Elder Thomson scoffs:



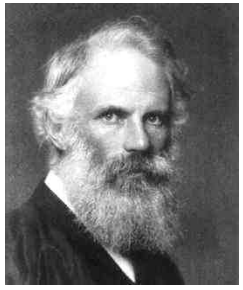
Old Thomson

"It is mere nihilism, having no part or lot in Natural Philosophy, to be contented with two formulas for energy, electrostatic and electromagnetic, and to be happy with a vector and delighted with a page of symmetrical formulas."

- 1885. Heaviside reformulates Maxwell's theory of electromagnetism in terms of 4 field equations ("Maxwell's Equations").
  - Explicit emphasis on fields and energy (as opposed to potentials and forces).

- 1888. Heinrich Hertz generates and detects electromagnetic waves in free space.
  - Are there such things as electromagnetic waves traveling in the aether?
  - *Hertz's view:* Maxwell's theory *just is* "Maxwell's system of equations".

- The Maxwellians are aggrieved:



"Any exposition of Maxwell's theory which does not clearly put before the reader that energy is stored in the ether by stresses working on strains, is a very incomplete representation of Maxwell's theory."

- Further aggrievement: Joseph Lamour's (1900) *Aether and Matter*.
  - *Claim*: Electric current is due to the motion and interactions of particles ("electrons") through the aether.

"One effect of admitting a molecular synthesis of dynamical principles such as the one here described is to depose the conception of energy from the fundamental or absolute status that is sometimes assigned to it; if a molecular constitution of matter is fundamental, energy cannot also be so."

- *New debate*: Atomic theory (material atoms are fundamental) *vs.* energeticism (energy is fundamental).

- Ernst Mach's phenomenalism (1883 *Science of Mechanics*).
  - Rejection of both views.
  - *Claim*: Sensory perceptions constitute the object of physical research, and not unobservable entities like atoms or energy.