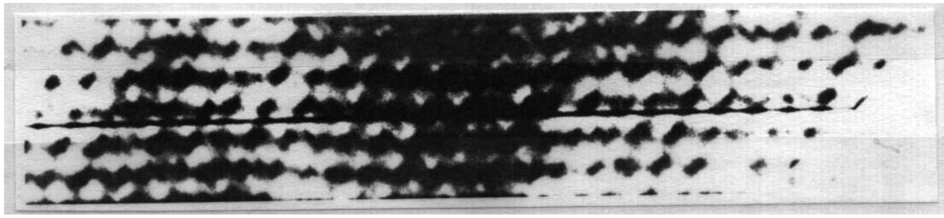
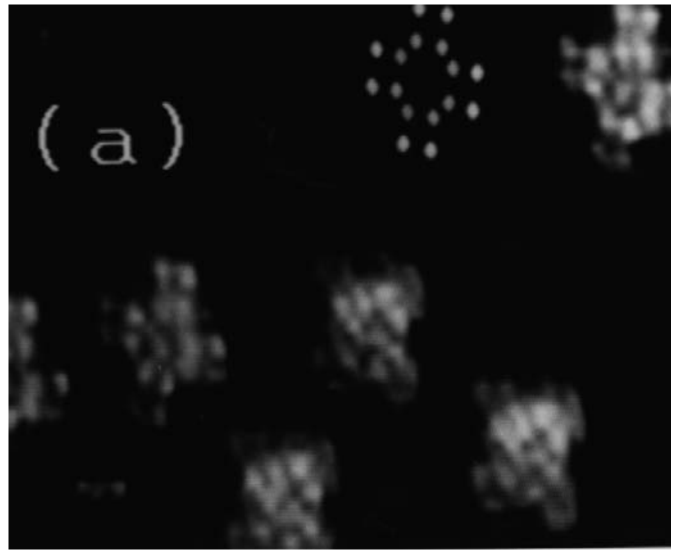
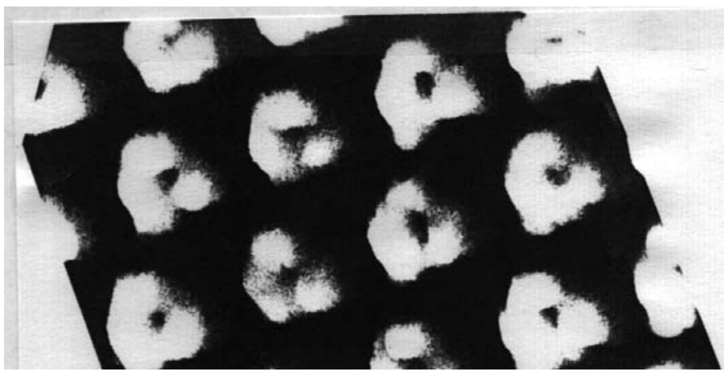
IMAGES OF THE MICROWORLD



GOLD

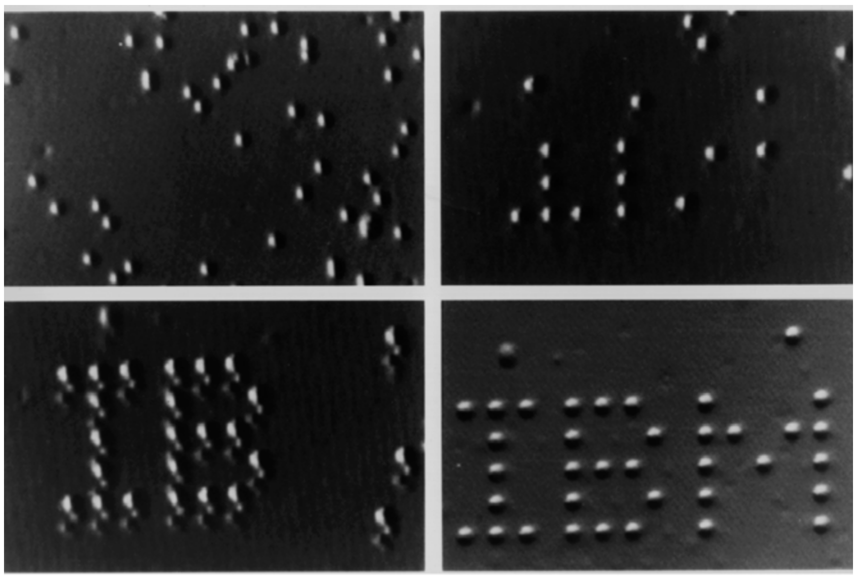


Copper-Phthalocyanine

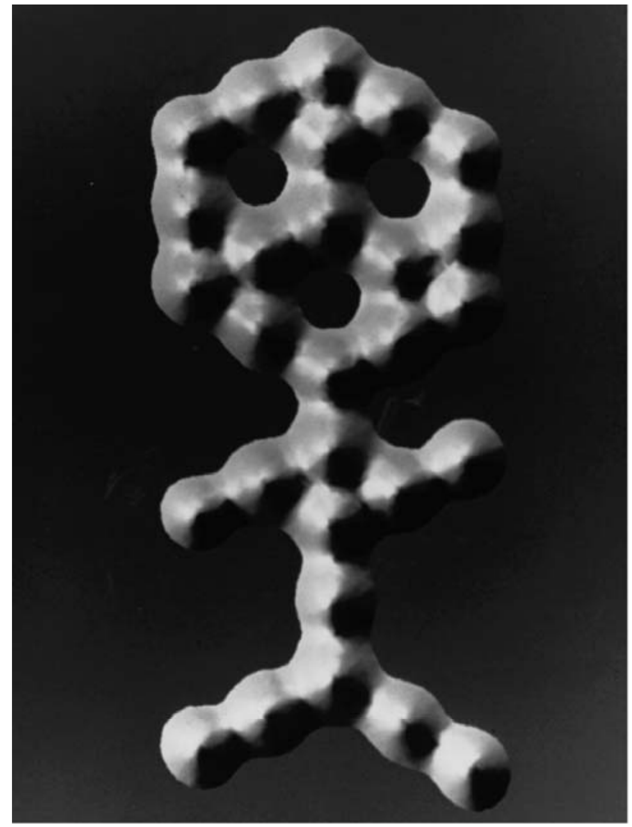


Benzene

MICRO-ADVERTISING

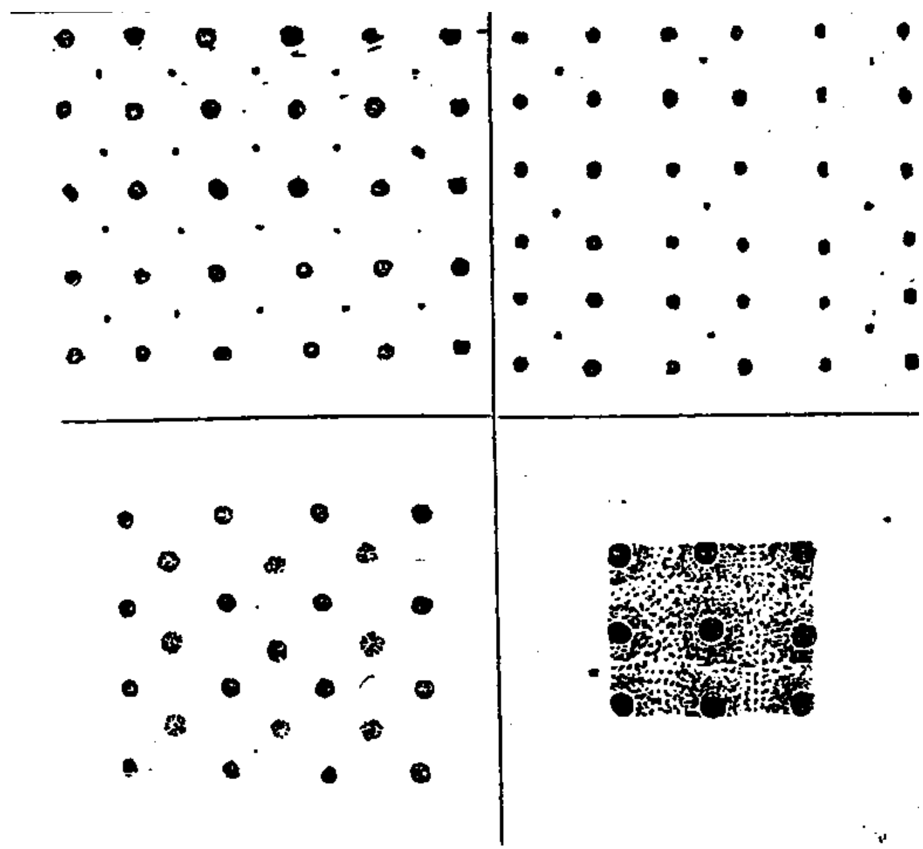


The atomic LOGO



Molecular man, by
Peter Zippenfeld

Microstructure in 1842



FORMS OF LABORATORY ACTIVITY

construction

To obtain information about a micro-object through a *probe* (an instrument that produces information about an object by interacting with it in a way that does not change the object's fundamental properties).

destruction

To obtain information about a micro-object by first reducing it to pieces and then probing the pieces.

FORMS OF PAPER ACTIVITY

rectification

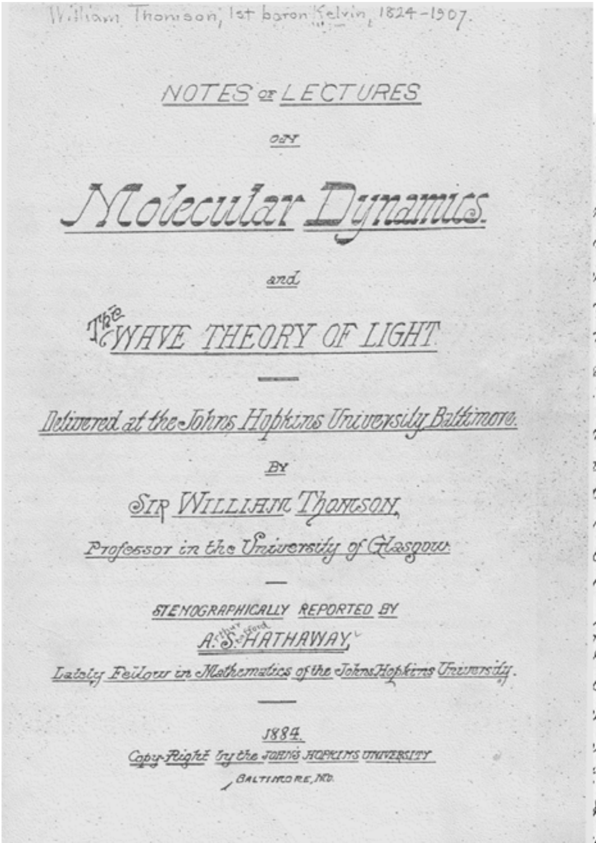
The repairing of defective knowledge on the basis of micro-physics.

reproduction

An attempt to *reproduce* known phenomena from micro-physical structures.

production

The generation of entirely novel effects by constructions based on micro-processes.


William Thomson, 1st baron Kelvin, 1824-1907.

NOTES OF LECTURES

ON

Molecular Dynamics

and

The WAVE THEORY OF LIGHT

Delivered at the Johns Hopkins University, Baltimore.

BY

SIR WILLIAM THOMSON,

Professor in the University of Glasgow.

STENOGRAPHICALLY REPORTED BY

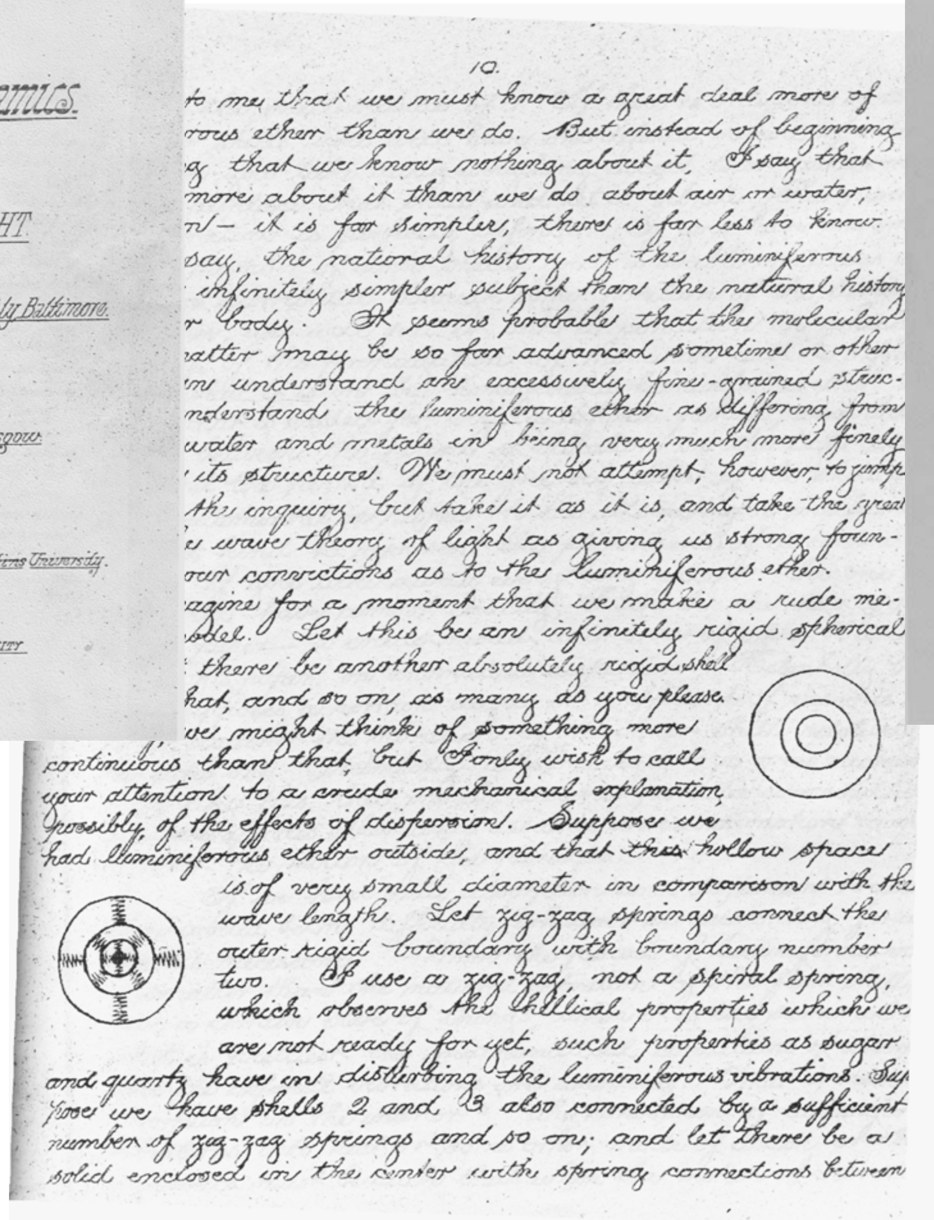
A. S. HATHAWAY,

Lately Fellow in Mathematics of the Johns Hopkins University.

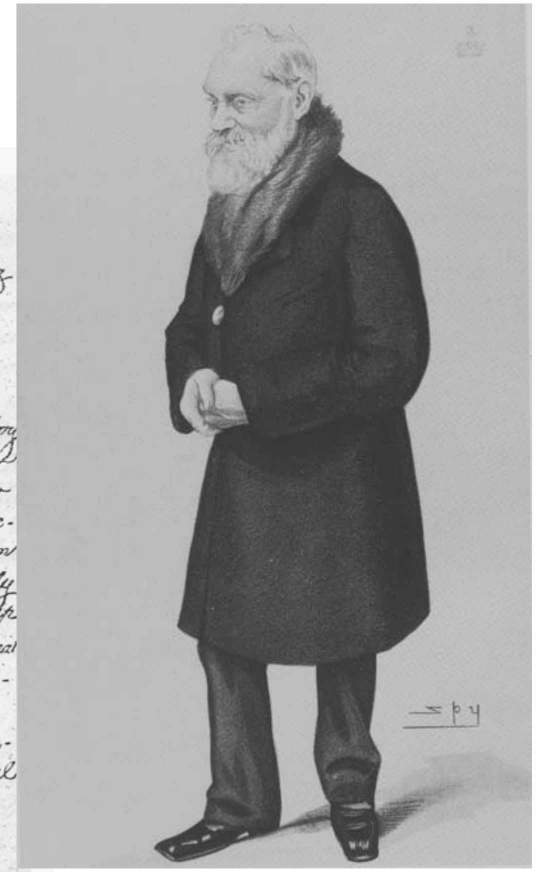
1884.

Copy-Right by the JOHNS HOPKINS UNIVERSITY

BALTIMORE, MD.


10.

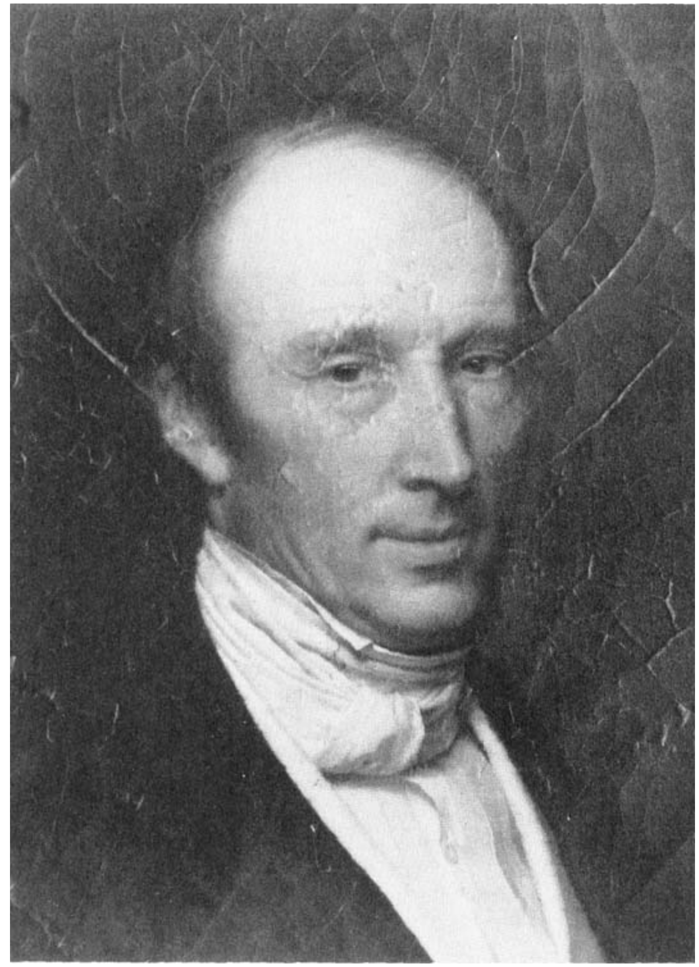
to me that we must know a great deal more of
rous ether than we do. But instead of beginning
g that we know nothing about it, I say that
more about it than we do about air or water,
n/— it is far simpler, there is far less to know.
say, the natural history of the luminiferous
infinitely simpler subject than the natural history
r body. It seems probable that the molecular
atter may be so far advanced sometime or other
m understand an excessively fine-grained struc-
nderstand the luminiferous ether as differing from
water and metals in being very much more finely
its structure. We must not attempt, however, to jump
the inquiry, but take it as it is, and take the great
e wave theory of light as giving us strong foun-
our convictions as to the luminiferous ether.
agine for a moment that we make a rude me-
odel. Let this be an infinitely rigid spherical
there be another absolutely rigid shell
hat, and so on as many as you please.
we might think of something more
continuous than that, but I only wish to call
your attention to a crude mechanical explanation,
possibly, of the effects of dispersion. Suppose we
had luminiferous ether outside, and that this hollow space
is of very small diameter in comparison with the
wave length. Let zig-zag springs connect the
outer rigid boundary with boundary number
two. I use a zig-zag, not a spiral spring,
which observes the hellical properties which we
are not ready for yet, such properties as sugar
and quartz have in disturbing the luminiferous vibrations. Sup
pose we have shells 2 and 3 also connected by a sufficient
number of zig-zag springs and so on; and let there be a
solid enclosed in the center with spring connections between



William Thomson,
Lord Kelvin

FRENCH PARTICLES

FRESNEL

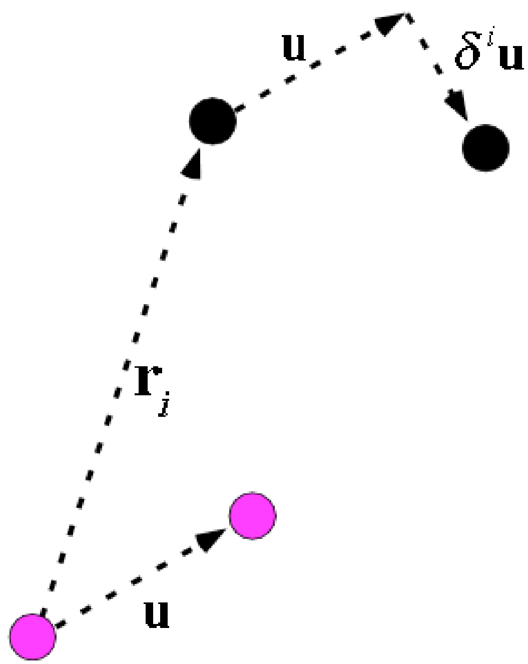


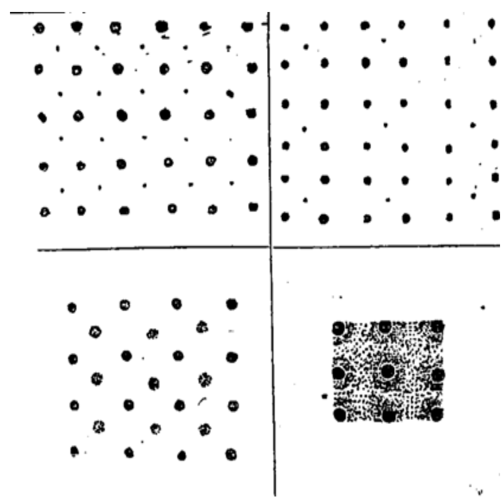
CAUCHY

CAUCHY'S LATTICE

$$\frac{\partial^2 \mathbf{u}}{\partial t^2} = \sum_i m^i \left(\frac{f(r^i)}{r^i} \right) \delta^i \mathbf{u} + \sum_i \left[m^i \frac{\partial \left(f(r^i)/r^i \right)}{\partial r^i} \left[\mathbf{e}_{r^i} \cdot \delta^i \mathbf{u} \right] \right] \mathbf{e}_{r^i}$$

provided the force on each point vanishes in equilibrium



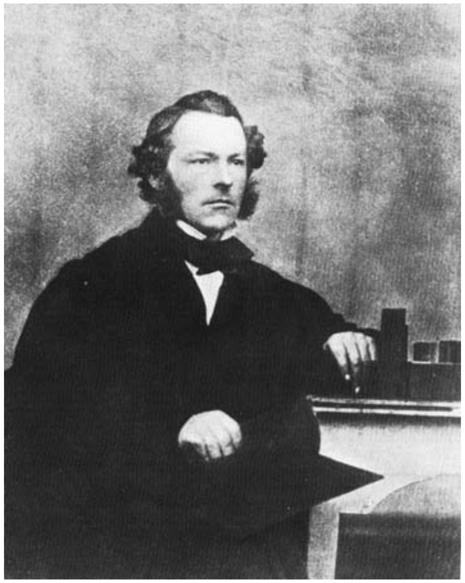


complicating matters

George Gabriel Stokes
Lucasian professor and master of the continuum

mid 1840s - late 1860s

- aberration
- scalar diffraction
- birefringence
- the Fresnel ratios
- the Stokes parameters
- fluorescence



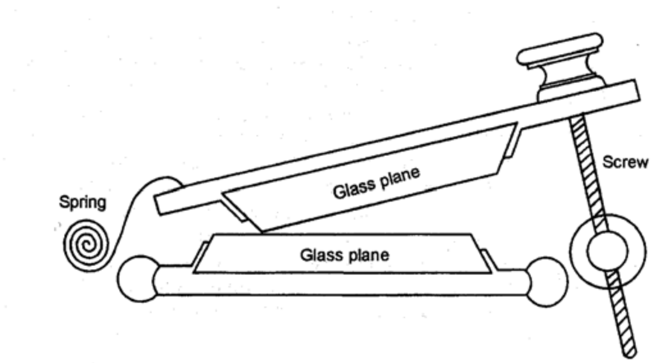
$$\rho\left(\frac{Du}{Dt} - X\right) + \frac{dp}{dx} - \mu\left(\frac{d^2u}{dx^2} + \frac{d^2u}{dy^2} + \frac{d^2u}{dz^2}\right) - \frac{\mu}{3}\frac{d}{dx}\left(\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz}\right) = 0$$

Stokes' form of the "Navier-Stokes" equation

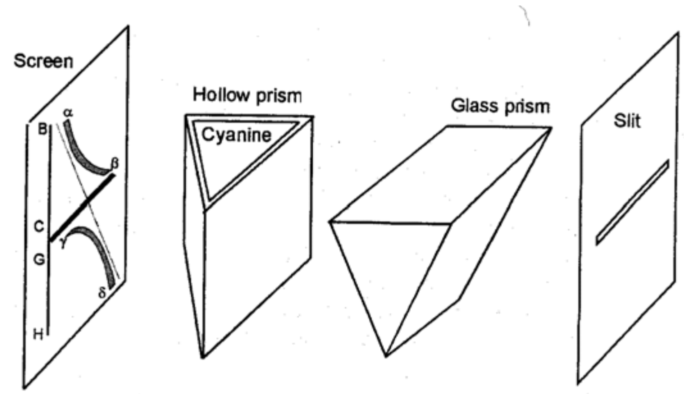
$$\rho\frac{d^2\alpha}{dt^2} = \frac{1}{3}(mA + B)\frac{d}{dx}\left(\frac{d\alpha}{dx} + \frac{d\beta}{dy} + \frac{d\gamma}{dz}\right) + B\left(\frac{d^2\alpha}{dx^2} + \frac{d^2\beta}{dy^2} + \frac{d^2\gamma}{dz^2}\right) = 0$$

Stokes' equations for an elastic solid. Here m represents a factor due to adiabatic heating

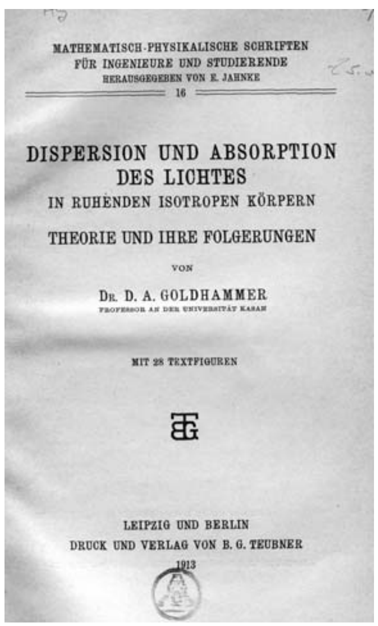
The Discovery of Anomalous Dispersion and Its Relationship to Selective Absorption: 1870



Christiansen's apparatus, 1870



Kundt's setup, 1871



MATHEMATISCH-PHYSIKALISCHE SCHRIFTEN
FÜR INGENIEURE UND STUDIERENDE
HERAUSGEGEBEN VON E. JAHNKE
16

DISPERSION UND ABSORPTION
DES LICHTES
IN RUHENDEN ISOTROPEN KÖRPERN

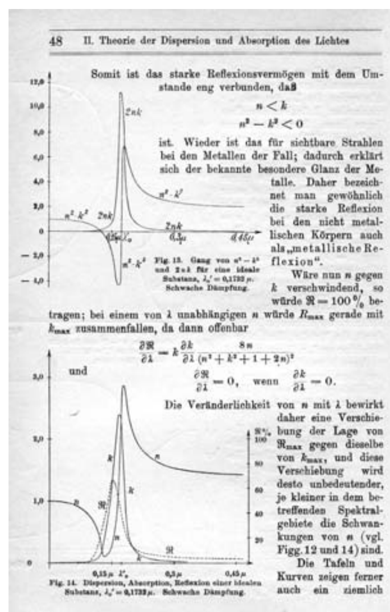
THEORIE UND IHRE FOLGERUNGEN

VON

DR. D. A. GOLDHAMMER
PROFESSOR AN DER UNIVERSITÄT KASAN

MIT 28 TEXTFIGUREN

LEIPZIG UND BERLIN
DRUCK UND VERLAG VON B. G. TEUBNER
1913



48 II. Theorie der Dispersion und Absorption des Lichtes

Somit ist das starke Reflexionsvermögen mit dem Umstande eng verbunden, daß

$$n < k$$
$$n^2 - k^2 < 0$$

ist. Wieder ist das für sichtbare Strahlen bei den Metallen der Fall; dadurch erklärt sich der bekannte besondere Glanz der Metalle. Daher bezeichnet man gewöhnlich die starke Reflexion bei den nicht metallischen Körpern auch als „metallische Reflexion".

Fig. 13. Gang von $n^2 - k^2$ und $2nk$ für eine ideale Substanz, $\lambda_0' = 0{,}1732\,\mu$. Schwache Dämpfung.

Wäre nun n gegen k verschwindend, so würde $\Re = 100\,\%$ betragen; bei einem von λ unabhängigen n würde R_{max} gerade mit k_{max} zusammenfallen, da dann offenbar

$$\frac{\partial \Re}{\partial \lambda} = k \frac{\partial k}{\partial \lambda} \frac{8n}{(n^2 + k^2 + 1 + 2n)^2}$$

und

$$\frac{\partial \Re}{\partial \lambda} = 0, \quad \text{wenn} \quad \frac{\partial k}{\partial \lambda} = 0.$$

Die Veränderlichkeit von n mit λ bewirkt daher eine Verschiebung der Lage von $\Re_{max}$ gegen dieselbe von k_{max}, und diese Verschiebung wird desto unbedeutender, je kleiner in dem betreffenden Spektralgebiete die Schwankungen von n (vgl. Figg. 12 und 14) sind. Die Tafeln und Kurven zeigen ferner auch ein ziemlich

Fig. 14. Dispersion, Absorption, Reflexion einer idealen Substanz, $\lambda_0' = 0{,}1732\,\mu$. Schwache Dämpfung.

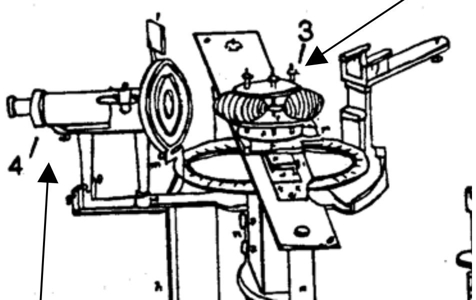
Helmholtz's Mechanical Twin Equations (1875)

$$\rho_{ether}\frac{\partial^2\mathbf{u}_{ether}}{\partial t^2} = -a^2{}_{ether}\nabla^2\mathbf{u}_{ether} + \beta_{ether-matter-link}\left(\mathbf{u}_{matter}-\mathbf{u}_{ether}\right)$$

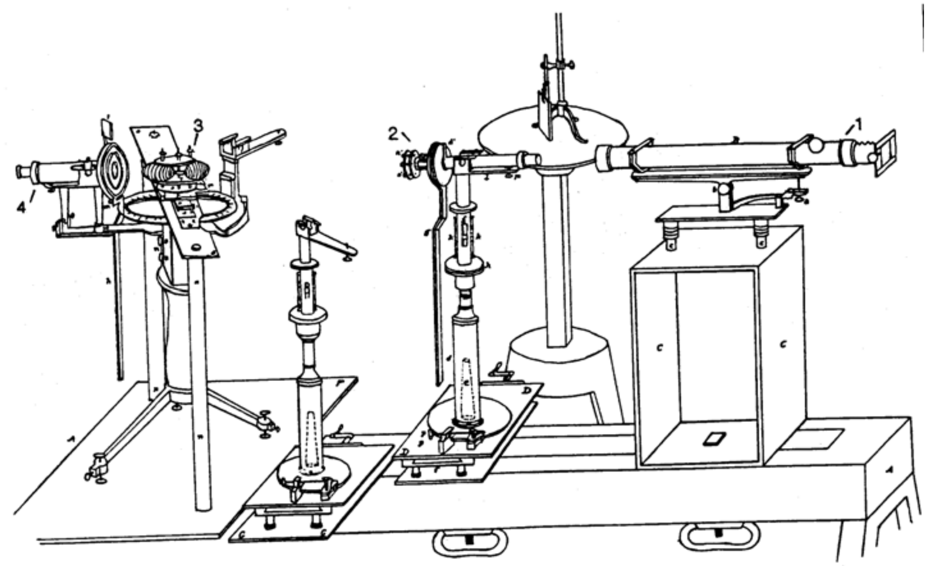
$$\rho_{matter}\frac{\partial^2\mathbf{u}_{matter}}{\partial t^2} = -b^2{}_{matter}\mathbf{u}_{matter} - \gamma_{dissipative}\frac{\partial\mathbf{u}_{matter}}{\partial t} - \beta_{ether-matter-link}\left(\mathbf{u}_{matter}-\mathbf{u}_{ether}\right)$$

Remmelt Sissingh's Device: 1891

Electromagnet and specimen



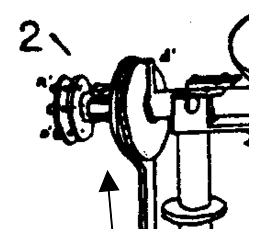
polarizer



Experiments can be **polar** or **equatorial**, with the magnetic field (respectively) orthogonal or parallel to the reflecting surface.

'minimum' experiments: fix either polarizer or analyzer in or orthogonally to plane of incidence and then rotate (respectively) the analyzer or polarizer to minimize the elliptically-polarized reflection.

'null' experiments: adjust the polarizer by setting it nearly in or nearly normal to the plane of incidence to achieve a linearly polarized reflection. Rotate the analyzer to annul the resultant.



analyzer

Experimental Sensitivities

1. **Minimum** observations are much **more sensitive to amplitude than to phase**.
2. **Null** observations are the reverse: much **more sensitive to phase than to amplitude**, and are simpler to perform.

- There are multiple sources of inaccuracy in both theoretical and experimental computations, particularly due to problematic values for the metallic constants.

What is compared with what at the time?

The **rotations themselves can be computed, but the calculations involve amplitudes**, which are highly sensitive to measurement error.

The **observed rotations can however also be used just to find the phases** of the magneto-optic reflection components, from which a number can in turn be derived that should have a constant value.

Differences between theories can be localized in the value of this constant, which we'll call the "**SISSINGH PHASE**".

The General Magneto-Optic Equation and Boundary Conditions - Late 1880s - Early 1890s

Modify the 'Faraday' Law to read

(Lorentz) $\mathbf{E} = -\dfrac{\partial \mathbf{A}}{\partial t} - \mathbf{h} \times \left(\sigma + \varepsilon \dfrac{\partial}{\partial t} \right) \mathbf{E}$ or

(J.J. Thomson-Drude-Goldhammer) $\mathbf{E} = -\dfrac{\partial \mathbf{A}}{\partial t} - \mathbf{h} \times \left(\varepsilon \dfrac{\partial}{\partial t} \right) \mathbf{E}$

H. A. Lorentz

$$\frac{\partial^2 \mathbf{H}}{\partial t^2} = R^{-2} e^{-2i\alpha} \left(\nabla^2 \mathbf{H} + e^{i\mu} \left(\mathbf{h} \cdot \nabla \right) \left(\nabla \times \frac{\partial \mathbf{H}}{\partial t} \right) \right)$$

J. J. Thomson and Drude: $\mu = 0$ and $\mathbf{h} = \varepsilon \mathbf{h}'$

Goldhammer: $\mu = \left(2\alpha - \pi\right) - \delta_{Sissingh}$ and $\mathbf{h} = R^2 \mathbf{h}'$

J. J. Thomson

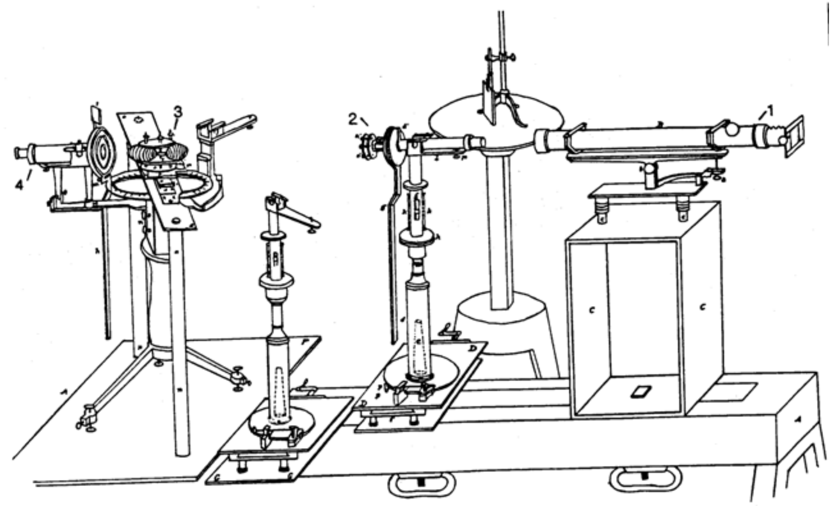
Boundary Conditions

$\mathbf{H}_{\mathrm{tan}}$ continuous

$$\left[R^{-2} e^{-2i\alpha} \left(\left(\nabla \times \mathbf{H} \right) + e^{i\mu} \mathbf{h} \times \left(\nabla \times \frac{\partial \mathbf{H}}{\partial t} \right) \right) \right]_{\mathrm{tan}} \quad \text{continuous}$$

Paul Drude

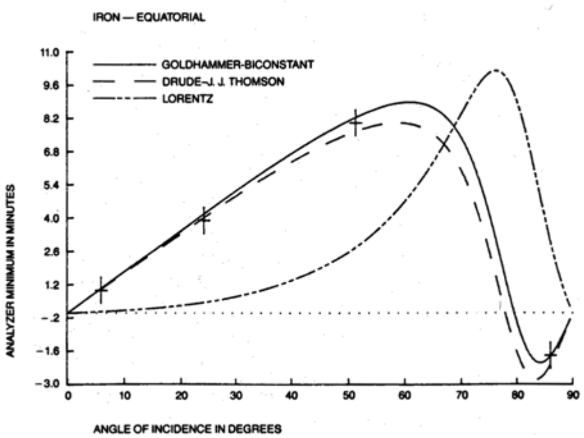
How does iron do?

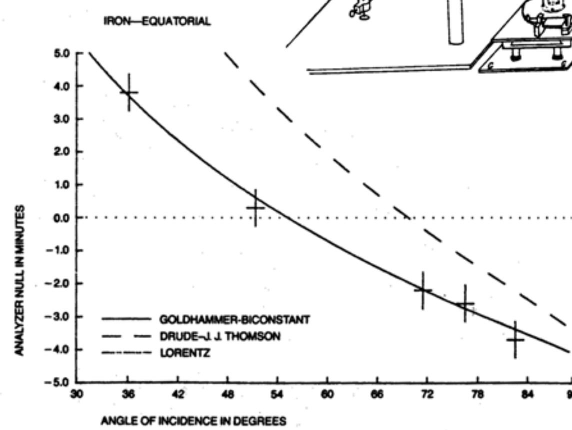


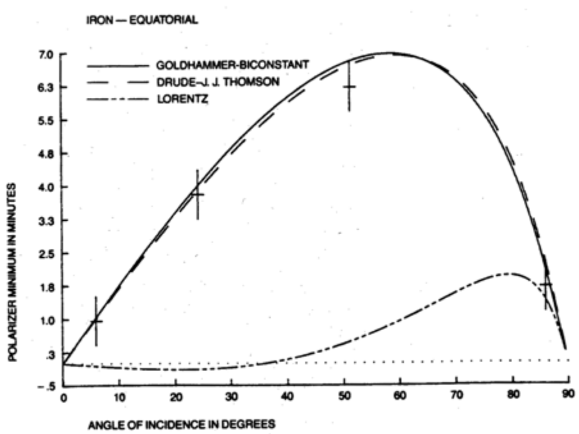
The Sissingh phase:

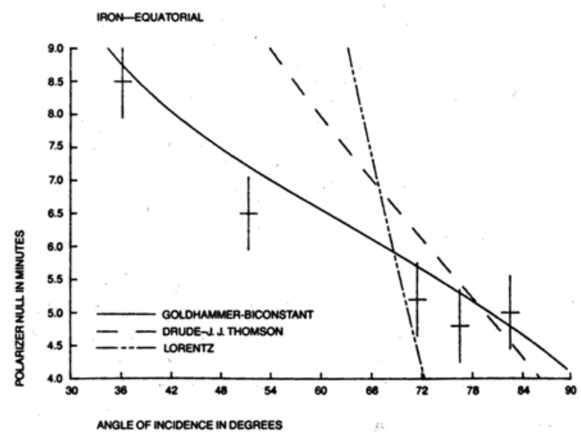
observed $84^o53.5'$

Thomson-Drude: $76^o16'$







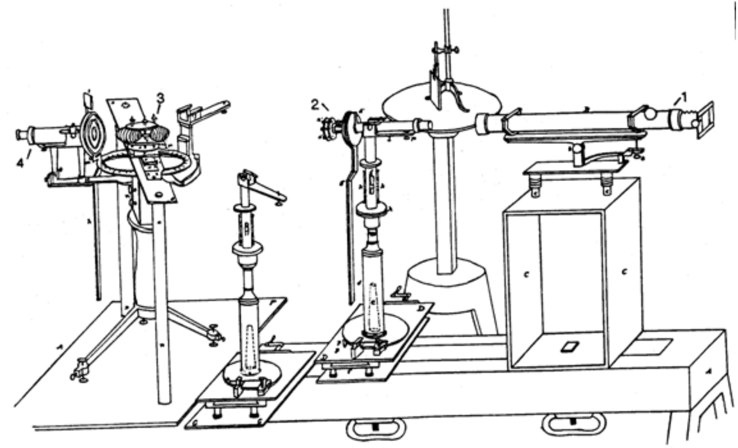


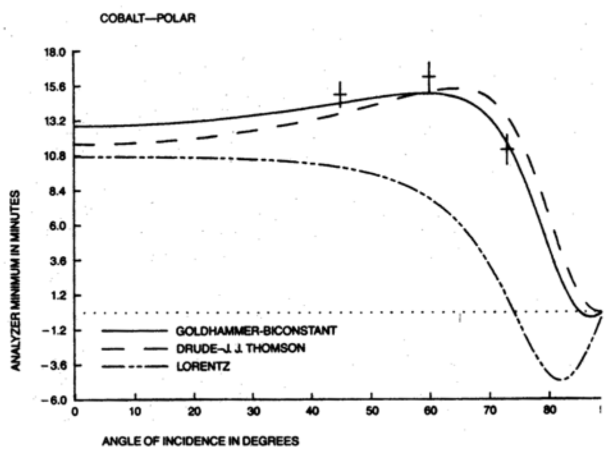
Zeeman’s Cobalt: 1893

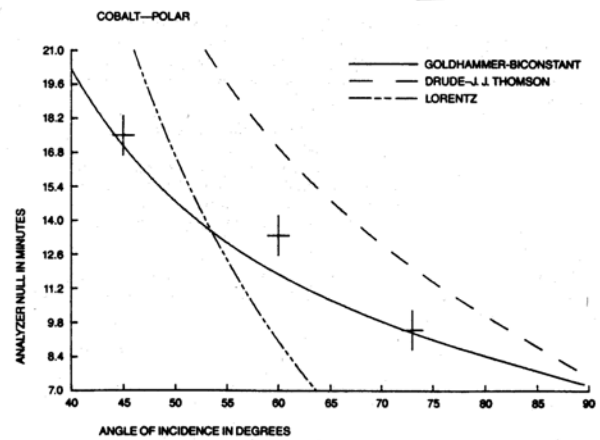
The Sissingh phase:

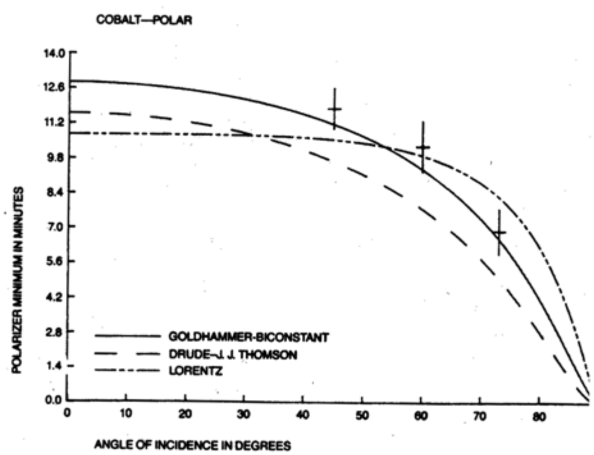
observed 49^o

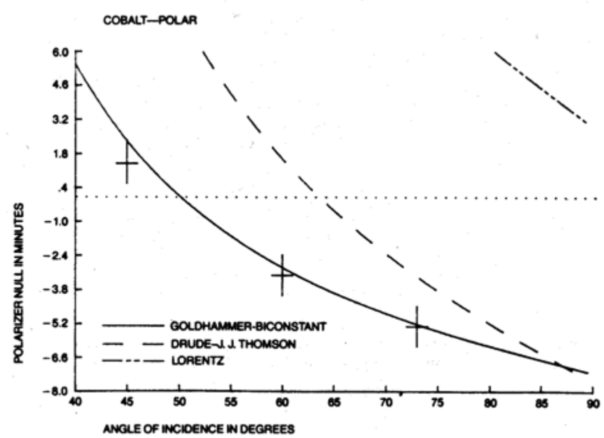
Thomson-Drude: 65^o











Pieter Zeeman

Early Microphysics: Paul Drude

One can interpret the form I chose for the "Erklärungssystem" in this way: that the magnetic polarisation which obtains in the ether has added to it a polarisation brought in by the ponderable molecules (molecular-magnets) of the magnetically active body; the x-component of this added polarisation is either:

$$b\partial X / \partial A \text{ or } b\partial X / \partial A + b'\partial / \partial t \partial X / \partial A$$

according as one *(b)* or two *(b* and *b')* magneto-optic constants are introduced. X signifies the x-component of the electric force, its first differential quotient in the direction (A) of the magnetisation. - ***These equations may be physically explained if a molecular magnet possesses electric charges of the same kind at its ends (and charges opposite to these in its interior***).

PHYSIK DES AETHERS

AUF

ELEKTROMAGNETISCHER GRUNDLAGE

VON

DR. PAUL DRUDE,

UNIVERSITÄTSPROFESSOR IN GÖTTINGEN.

MIT 66 ABBILDUNGEN.

STUTTGART.

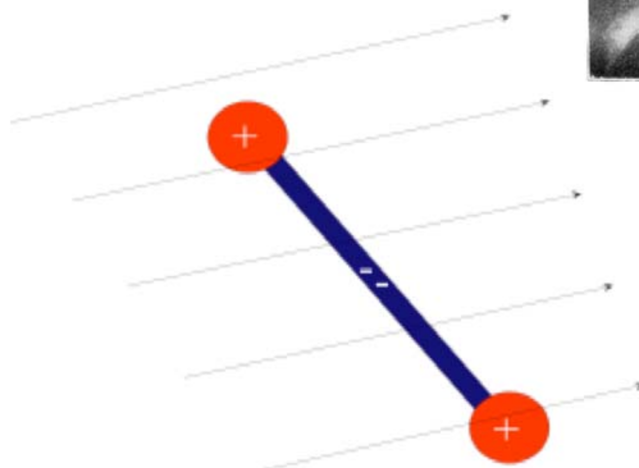
VERLAG VON FERDINAND ENKE.

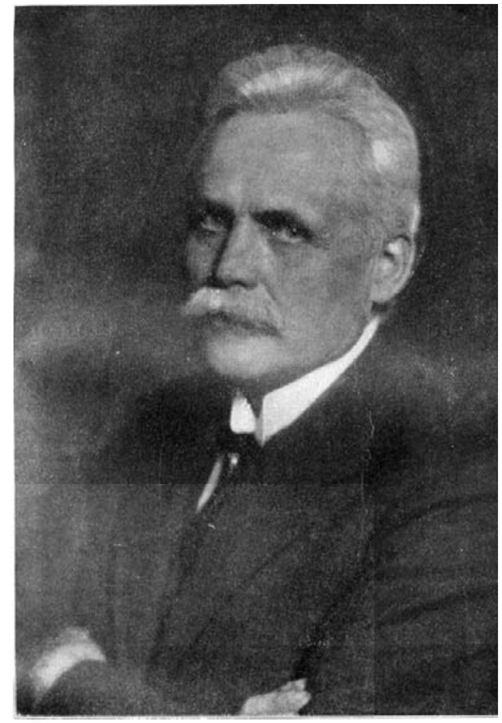
1894.

Privatdozent Dr. Trautz

Goethestrasse 60

Freiburg i. Br.





Helmholtz's Electromagnetic Twin Equations (1893)

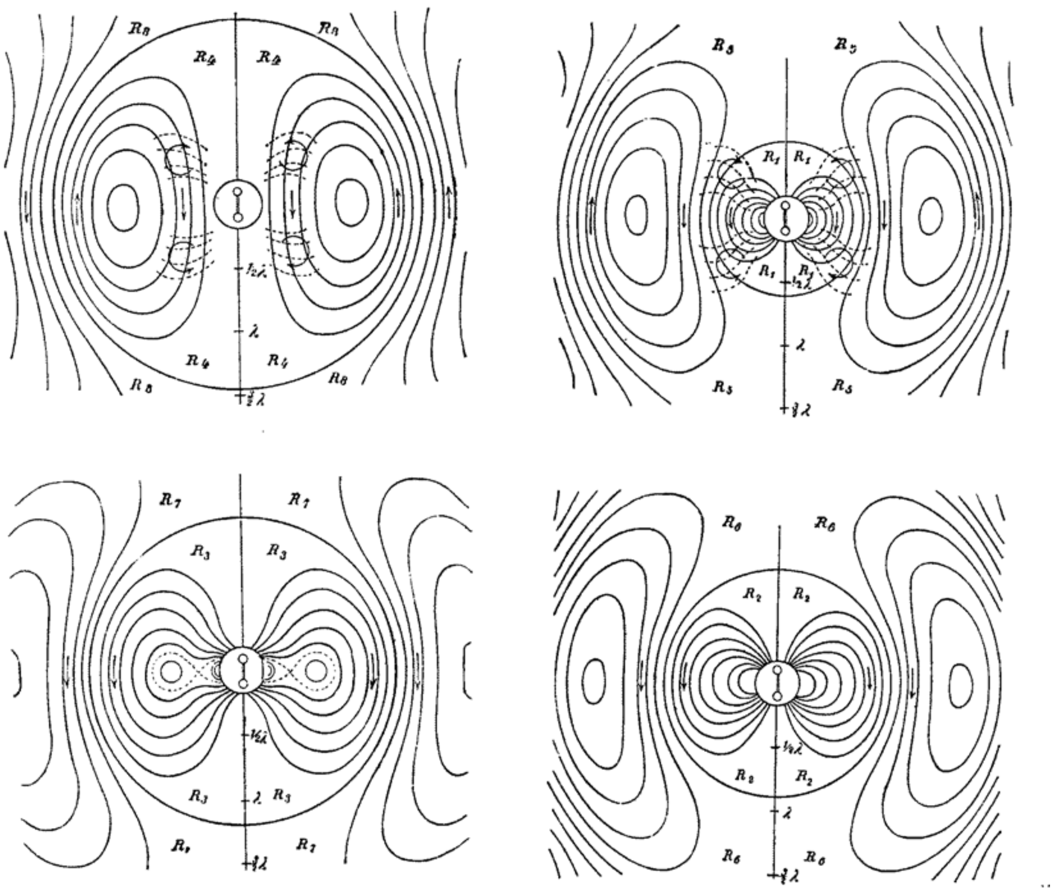
$$m_{ionic\ mass}\frac{\partial^2\mathbf{p}_{ionic\ moment}}{\partial t^2}=-\theta_{harmonic}\mathbf{p}_{ionic\ moment}-\kappa_{dissipative}\frac{\partial\mathbf{p}_{ionic\ moment}}{\partial t}+\frac{\mathbf{D}}{\varepsilon}$$

$$\left.\begin{aligned}\nabla\times\frac{\mathbf{D}}{\varepsilon}&=-\frac{\partial\mathbf{B}}{\partial t}\\ \nabla\times\frac{\mathbf{B}}{\mu}&=\frac{\partial\mathbf{D}}{\partial t}+\frac{\partial\mathbf{p}_{ionic\ moment}}{\partial t}\end{aligned}\right\}\frac{\partial^2\mathbf{D}}{\partial t^2}=-\frac{1}{\varepsilon\mu}\nabla\times(\nabla\times\mathbf{D})+\frac{\partial^2\mathbf{p}_{ionic\ moment}}{\partial t^2}$$

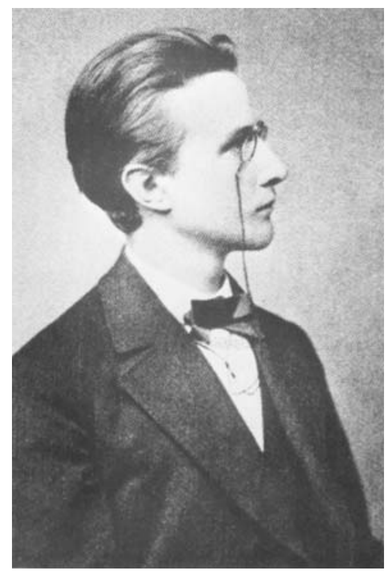
$$\rho_{ether}\frac{\partial^2\mathbf{u}_{ether}}{\partial t^2}=-a^2{}_{ether}\nabla^2\mathbf{u}_{ether}+\beta_{ether-matter-link}\left(\mathbf{u}_{matter}-\mathbf{u}_{ether}\right)$$

$$\rho_{matter}\frac{\partial^2\mathbf{u}_{matter}}{\partial t^2}=-b^2{}_{matter}\mathbf{u}_{matter}-\gamma_{dissipative}\frac{\partial\mathbf{u}_{matter}}{\partial t}-\beta_{ether-matter-link}\left(\mathbf{u}_{matter}-\mathbf{u}_{ether}\right)$$

Heinrich Hertz's Dipole *circa* 1890



Hertz in 1878



Planck in 1879