ψ

A Time Traveler's History of Physics

Robert Close, PhD.

Clark College
robert.close@classicalmatter.org

ABSTRACT

The history of science is often presented as a logical progression of better and better theories to explain increasingly accurate data. However, the reality is that misconceptions can persist long after better explanations are proposed or contrary evidence is available. Many advances in science have been subject to Planck's principle that new scientific truths do not triumph by convincing opponents, but rather because opponents eventually die off (science advances one funeral at a time). Nobel Laureate Paul Lauterbur recently commented that one could write the entire history of science in the last 50 years in terms of rejected papers.

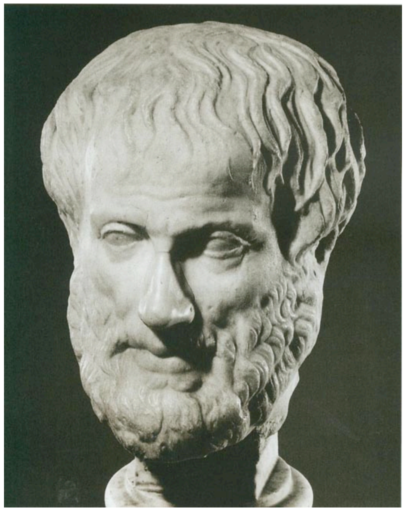
Is it possible to identify misconceptions in the present without waiting for historical judgment? One way to test the robustness of our ideas is to imagine how they would change if historical events had occurred in a different order. For example, if de Broglie's hypothesis of the wave nature of matter had preceded the Michelson-Morley experiment, then aether-drift experiments might have been regarded as tests of the wave nature of matter rather than as tests for the existence of an aether. We incorporate recent work and attempt to construct a logical rather than temporal history of physics. This procedure suggests that many common beliefs about modern physics are subject to reinterpretation.

INTRODUCTION

"Ignorance is preferable to error; and he is less remote from the truth who believes nothing, than he who believes what is wrong."

— Thomas Jefferson, *Notes on Virginia*

AETHER
384-322 BC



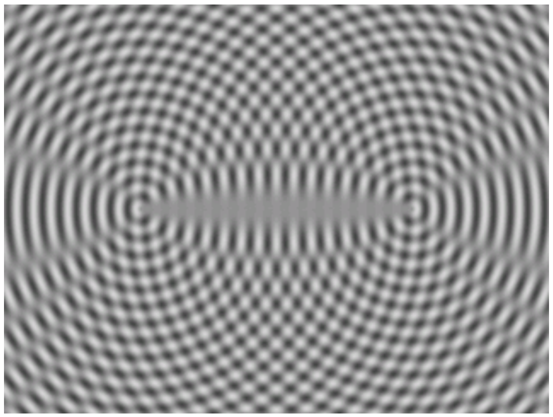
Aristotle regards aether as a fifth element (along with air, earth, fire, and water) that fills all of space ("nature abhors a vacuum").

1595-1650

René Descartes describes light as a disturbance of the "plenum" which fills the universe, in analogy with sound waves in air. Planetary motion is attributed to vortices in the plenum.

AETHER

1665



Robert Hooke proposes in *Micrographia* that light is similar to water waves.

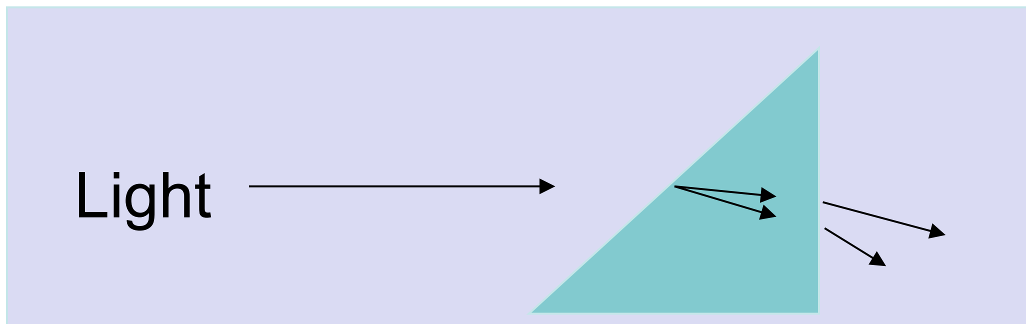
http://upload.wikimedia.org/wikipedia/en/d/dc/Interf.png (Guanaco, March 2004)

1690

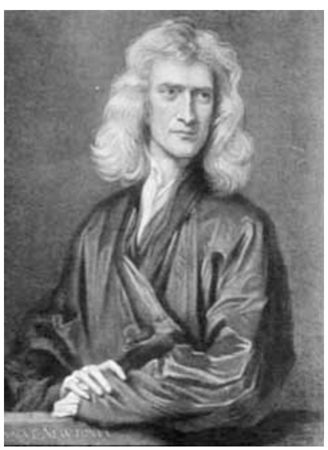
Christian Huygens publishes *Treatise on Light*. He regards light as waves propagating in a “lumeniferous aether” analogous to sound waves propagating in air.

AETHER
1690

- Huygens also reports that light may be separated into two “polarizations” using birefringent crystals.



1675-1704



Isaac Newton regards light as particles (corpuscles) because it seems to travel in straight lines and particle orientation can explain polarization. (*Hypothesis of Light* 1675, *Opticks* 1704)

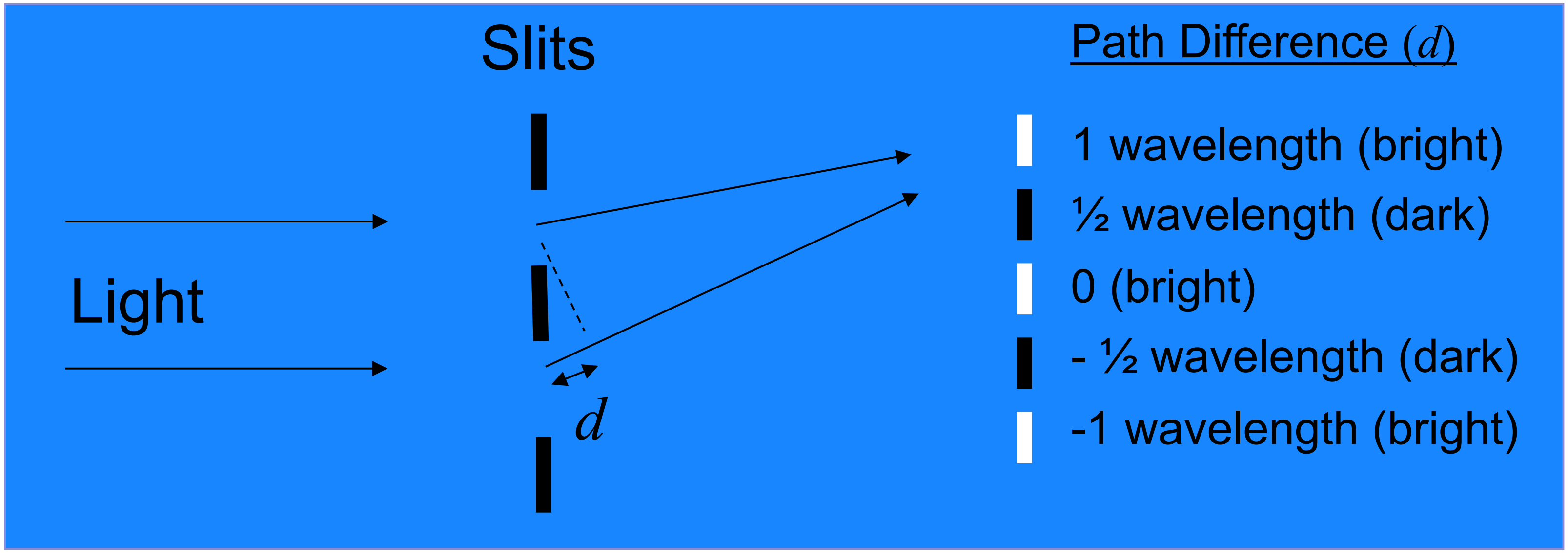
AETHER
1675

- Ole Rømer attributes variations in the observed orbital periods of Jupiter's moons to variable light propagation distance between Jupiter and Earth.

Using Cassini's recent measurement of interplanetary distances, the speed of light is estimated as 2.1×10^8 m/s (the currently accepted value is 2.99792×10^8 m/s).

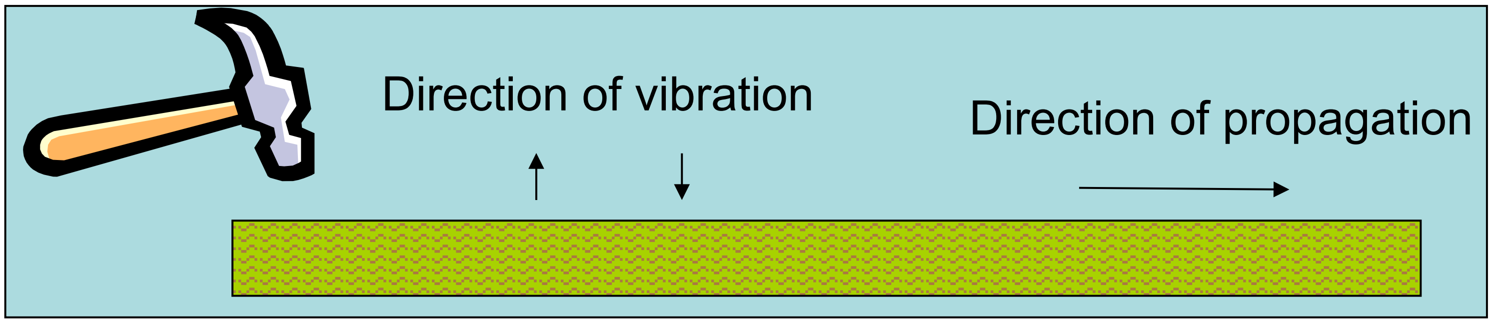
AETHER
1773-1829

- Because light, unlike particles, propagates at a characteristic speed, Thomas Young is convinced that light consists of waves.
- Young demonstrates this wave nature by producing interference fringes from light passing through two narrow slits.



AETHER
1817

- Young explains polarization of light waves as transverse vibrations such as occur in an elastic solid.



1788-1827

Augustin Fresnel adopts Young's wave model to explain diffraction and interference in addition to reflection and refraction. He supposes the aether to resist distortion in the same manner as an elastic solid whose density is proportional to the square of the refractive index.

AETHER

- One difficulty with the solid aether model is that aether density variations (e.g. at the interface between vacuum and medium) would lead to coupling between transverse and longitudinal waves, a phenomenon not observed for light waves.

AETHER
1839

James MacCullagh avoids the problem of longitudinal waves by proposing a 'rotationally elastic' aether whose potential energy Φ depends only on rotation (approximated by curl of displacement $\mathbf{a}$):

$$\Phi = \frac{1}{2}\mu(\nabla \times \mathbf{a})^2$$

- The resulting wave equation is:

$$\rho \frac{\partial^2 \mathbf{a}}{\partial t^2} = -\mu \nabla \times (\nabla \times \mathbf{a})$$

which is simply the equation of elastic shear waves for infinitesimal rotations. Matter is now presumed to alter the elasticity of the aether rather than its density.

AETHER
1868

- Joseph Boussinesq treats the aether as an ordinary elastic solid whose physical properties (density and elasticity) are unchanged in the presence of matter, also avoiding the problem of longitudinal waves.
- Any classical optical phenomenon is modeled by finding the appropriate interaction between matter and aether.

- <u>However, the problem of elastic waves with finite rotations remains unsolved.</u>

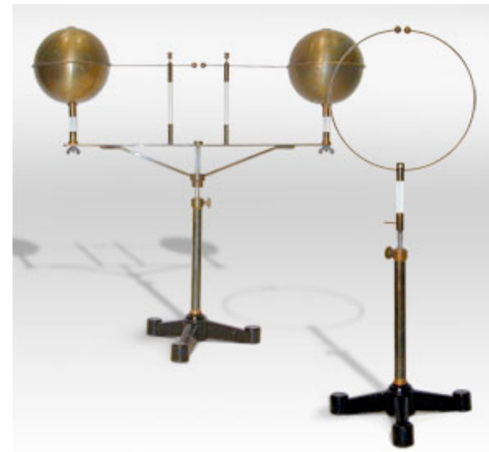
ELECTROMAGNETISM 1862-1873

- James Maxwell discusses the aether hypothesis: “But what if these molecules, indestructible as they are, turn out to be not substances themselves, but mere affections of some other substance?”
  - (Introductory Lecture on Experimental Physics, 1871)

- Maxwell concludes that light is electromagnetic radiation. Maxwell envisions the aether as a lattice of rotating elastic cells separated by rolling particles whose excess or deficiency represents electric charge. (*On Physical Lines of Force 1862, A Treatise on Electricity and Magnetism 1873*)

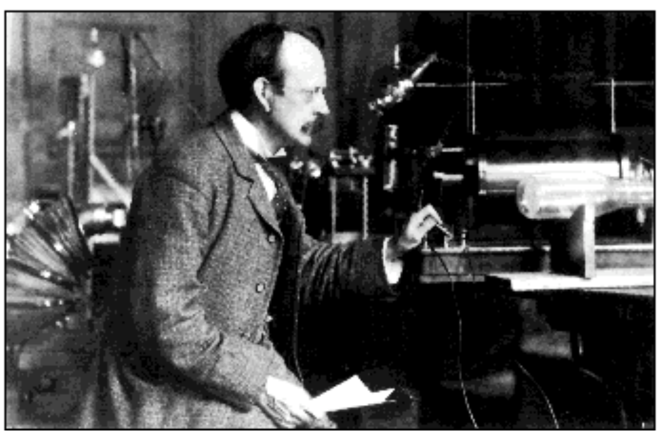
ELECTROMAGNETISM
1887

- Heinrich Hertz confirms Maxwell's predictions experimentally, demonstrating propagation of electromagnetic energy through space.



http://www.sparkmuseum.com/BOOK_HERTZ.HTM

1897



- J.J. Thomson's study of cathode rays leads to his discovery of the electron.

http://www.udayton.edu/~cps/cps460/notes/displays/crt/Disc-of-Electron-Images.html

ELECTROMAGNETISM
1879

- Sir George Gabriel Stokes declares, *"… a great step would be made when we should be able to say of electricity that which we say of light, in saying that it consists of undulations."*

ELECTROMAGNETISM
1900

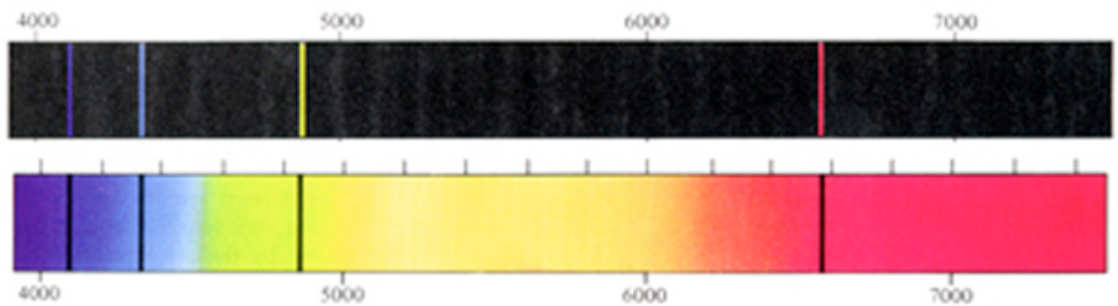
Max Planck derives the correct formula for blackbody radiation by supposing light to be emitted by vibrators whose energy is an integral multiple n of a constant h multiplied by the frequency f.

Planck's discovery is consistent with a model of matter as soliton waves, since transitions from one soliton state to another must release a quantized amount of energy.

ELECTROMAGNETISM 1913

- Niels Bohr explains the hydrogen atomic spectrum by proposing that electrons orbit the nucleus with quantized angular momentum and energy levels.

http://honolulu.hawaii.edu/distance/sci122/Programs/p27/p27.html



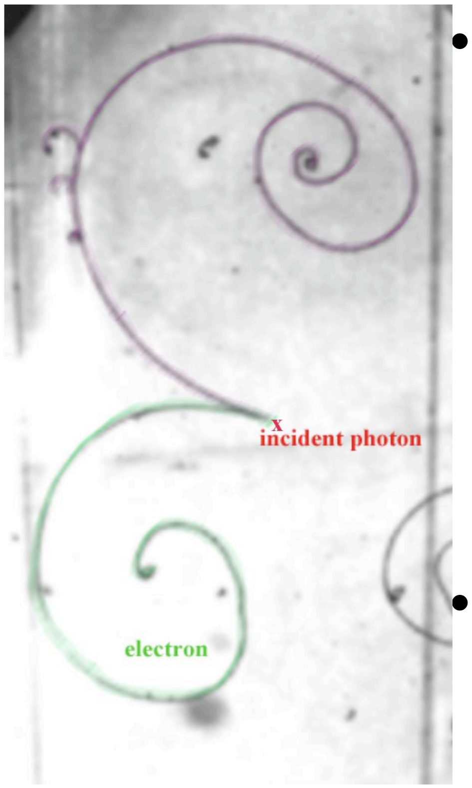
The Hydrogen Spectrum
Above: Emission
Below: Absorption

ELECTROMAGNETISM
1924

- Louis Victor de Broglie proposes that electrons have a wave-like character with energy proportional to frequency and momentum proportional to wave vector.
- Bohr's quantization rules are now explained by the requirement of azimuthal continuity along circular electron wave orbits:

$$2\pi r = n\lambda$$

ELECTROMAGNETISM 1933



- Patrick Blackett discovers opposing spiral tracks in a magnetized cloud chamber, indicating positron/electron pair production from cosmic gamma rays. This conversion of electromagnetic wave energy to matter confirms de Broglie's wave hypothesis.

- <u>Matter, like light, evidently consists of "affections" of the aether as envisioned by Maxwell.</u>

http://teachers.web.cern.ch/teachers/archiv/HST2002/Bubblech/mbitu/ELECTRON-POSITRON2-piece.jpg

RELATIVITY

- The wave nature of matter implies that the speed of light in vacuum cannot be measured directly. Any attempted measurement of c in vacuum will yield a constant value for any inertial observer. Any clock made of matter will behave like a light clock.
- It is predicted that Earth's motion through the aether must be undetectable since any variation of light propagation would equally affect the apparatus attempting to measure it.

RELATIVITY

1887

- The predicted inability to detect aether drift is confirmed by Albert Michelson (pictured) & Edward Morley, further confirming the wave nature of matter consistent with the solid aether model.

1904

- Hendrik Lorentz combines length contraction and time dilation to obtain the complete coordinate transformations between observers making measurements using only waves.

RELATIVITY
1904

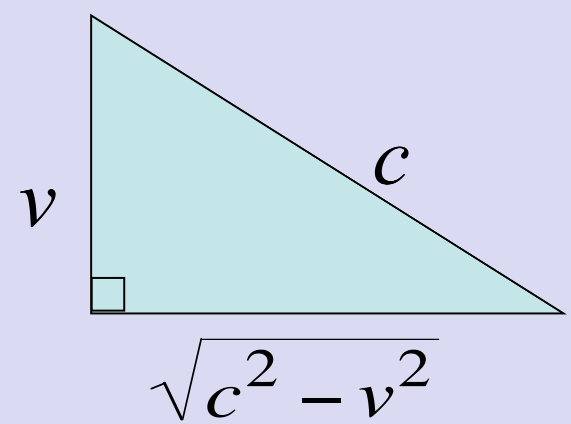
- Henri Poincaré gives the name ‘Principle of Relativity’ to the doctrine that absolute motion is undetectable. He also deduces that inertia increases with velocity and that no velocity can exceed the speed of light.

1905

- Albert Einstein uses the constancy of the measured speed of light to derive a comprehensive theory of relativity with new predictions.

RELATIVITY
1904

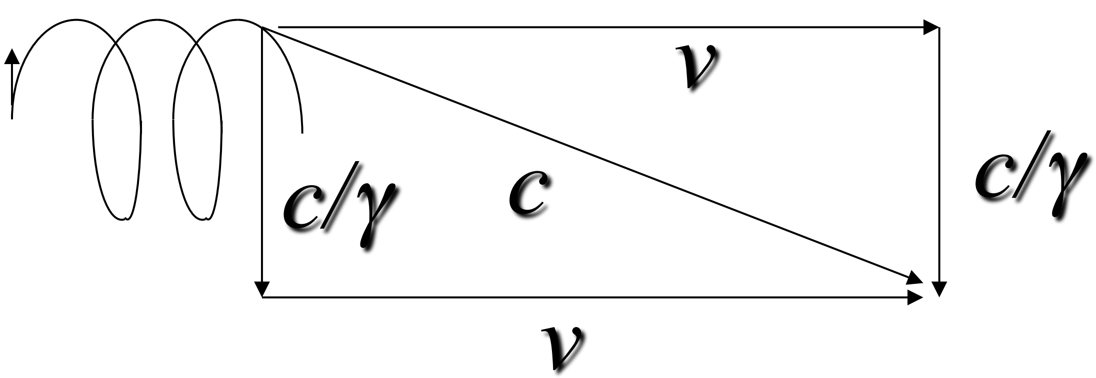
- A key feature of relativistic transformations is the factor γ, which is the ratio between the speed of light and a component of propagation orthogonal to bulk velocity:



$$\gamma = \frac{c}{\sqrt{c^2 - v^2}}$$

RELATIVITY
1990

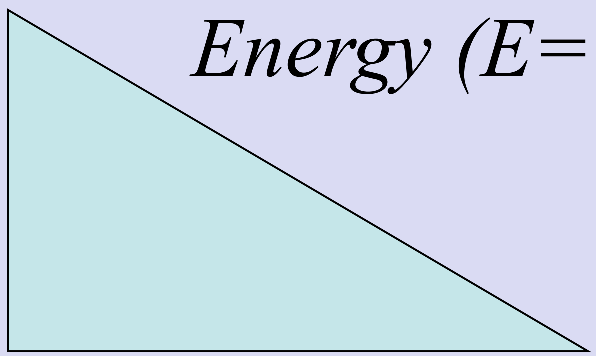
- David Hestenes proposes that elementary particles propagate at the speed of light in helical orbits. (Found. Physics., Vol. 20, No. 10, (1990) 1213-1232)
- Standing waves in three dimensions could also be modeled as superposition of circulating waves propagating in circles.



RELATIVITY
1905

- Mass, momentum, and energy form a Pythagorean relationship as inferred from the spiral (or cycloidal) propagation.

Momentum $(pc=\gamma m_0 cv)$



Energy $(E=\gamma m_0 c^2)$

$$E^2 = m_0^2 c^4 + p^2 c^2$$

Rest Mass $\left(\gamma m_0 c\sqrt{c^2 - v^2} = m_0 c^2\right)$

RELATIVITY

- Although physical space is Galilean, the space of measurements is Minkowski space.

- Lorentz invariance of matter, like Lorentz invariance of other types of waves, is due to the spatio-temporal properties of waves.

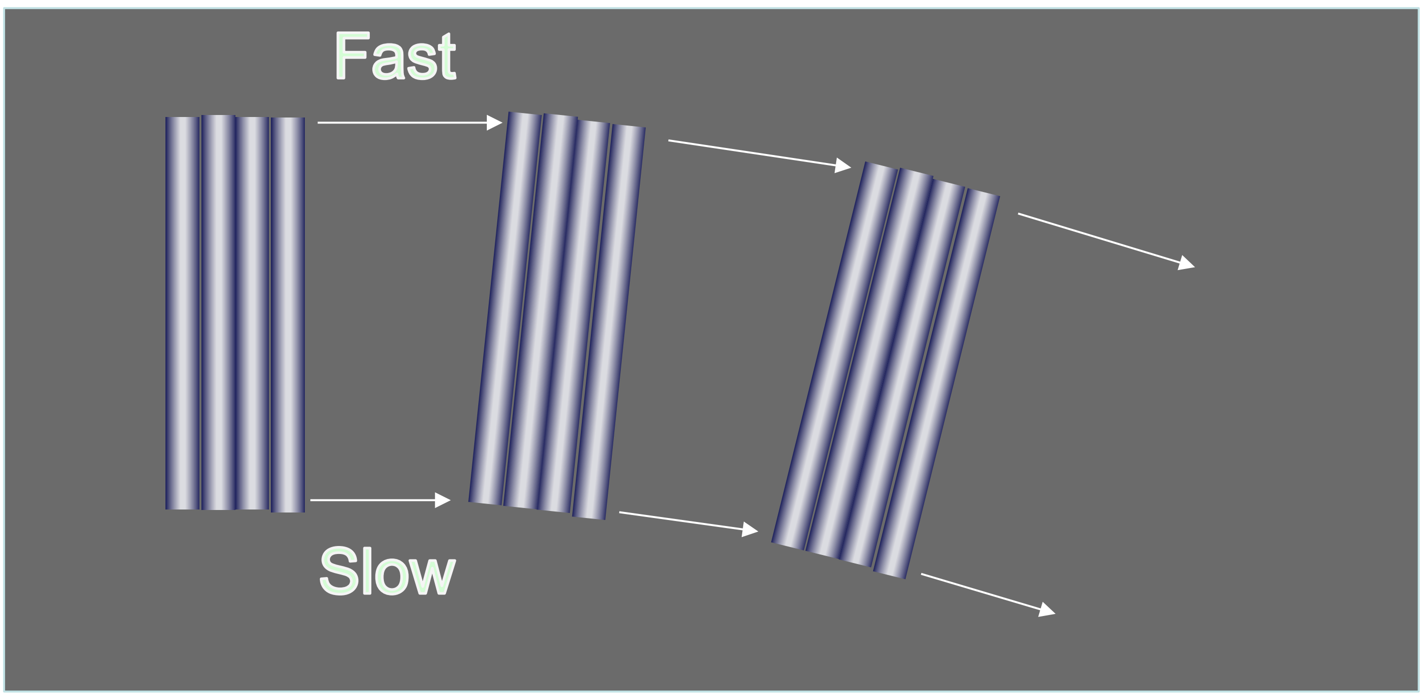
GRAVITY
1920

- Einstein's general theory of relativity confirms that the vacuum has physical properties.
- A gravitational field is equivalent to a variation in the speed of light such as would occur if the aether density is slightly increased in the presence of energy.

$$U = \frac{c^2 - c_0^2}{4}$$

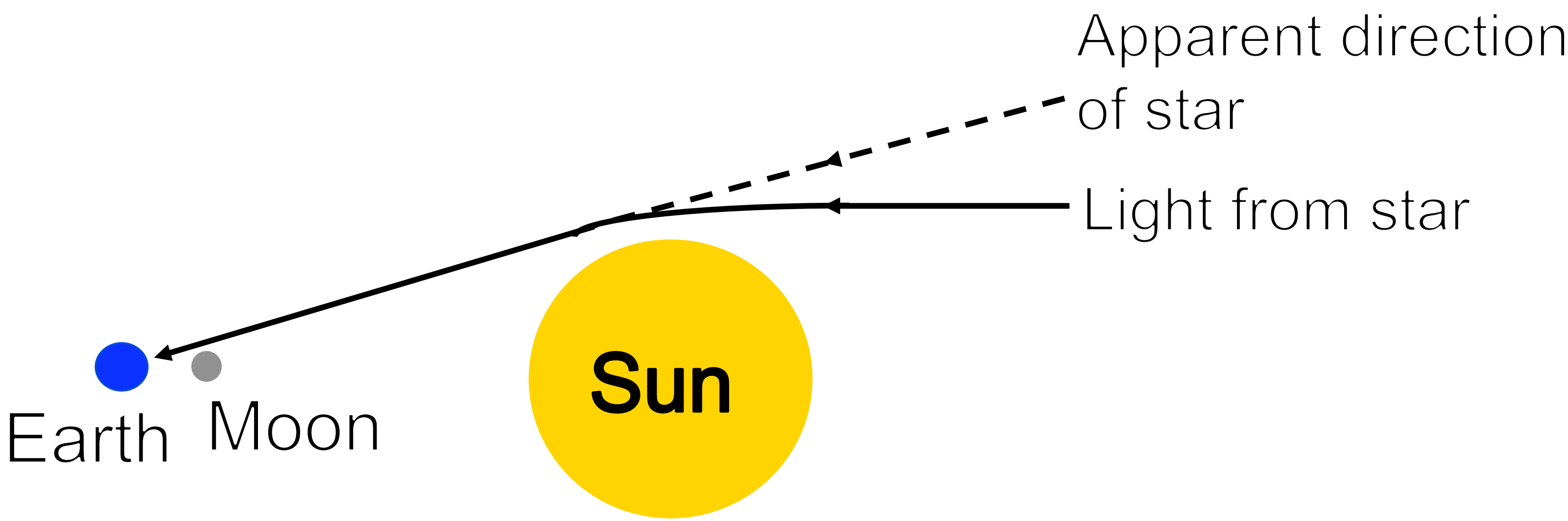
GRAVITY
1920

Waves refract (bend) toward regions of slower wave speed.

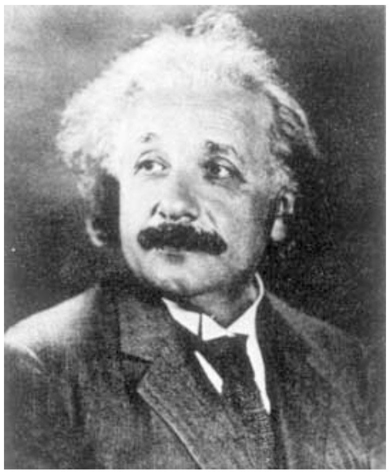


GRAVITY
1920

- During a solar eclipse, the positions of stars near the direction of the sun are observed to be shifted. This confirms that the light rays from those stars are bent as they pass near the sun.



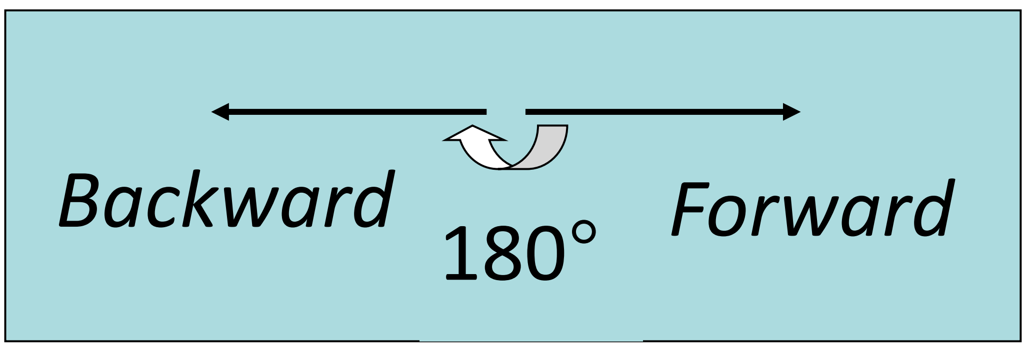
GRAVITY
1920



- Einstein writes, *“There is a weighty argument to be adduced in favour of the ether hypothesis. To deny the ether is ultimately to assume that empty space has no physical qualities whatever. The fundamental facts of mechanics do not harmonize with this view.”*

MATTER WAVES 2002

- Half-integer spin is a property of classical waves because solutions traveling forward and backward along a single axis are independent states separated by 180° rotation.
  (Close, "Torsion waves in three dimensions: quantum mechanics with a twist," Found. Phys. Lett.)



MATTER WAVES
2002

- In 1-D (scalar waves), 1st order bispinor equations represent 2nd order wave equations:

Bispinor	Scalar
$\partial_t\left[\psi_v^T\sigma\psi_v\right]+c\partial_z\left[\psi_v^T\gamma^5\sigma\psi_v\right]=0$	$\partial_t^2\Theta-c^2\partial_z^2\Theta=0$
$\partial_t\left[\psi_v^T\gamma^5\sigma\psi_v\right]+c\partial_z\left[\psi_v^T\sigma\psi_v\right]=0$	$\partial_t\left[-c\partial_z\Theta\right]+c\partial_z\left[\partial_t\Theta\right]=0$

Bispinors = Waves

MATTER WAVES
2010

- A Lagrangian density for finite-angle rotational waves in an ideal elastic solid is found:
- R. A. Close, "Exact Description of Rotational Waves in an Elastic Solid," **Advances in Applied Clifford Algebras**, DOI 10.1007/s00006-010-0249-1 (2010).

$$\mathscr{L} = \underbrace{\mathrm{Re}\left\{-\mathrm{i}\,\psi^{\dagger}\partial_t\psi\right\}}_{-\text{Total Energy}} + \underbrace{\mathrm{Re}\left\{\psi^{\dagger}\left[-\mathrm{i}\,c\beta_1\boldsymbol{\sigma}\cdot\nabla\right]\psi\right\}}_{\text{Potential Energy}}$$

$$\underbrace{+\frac{1}{2\rho}\left[\mathrm{Re}\left(-\psi^{\dagger}\,\mathrm{i}\nabla\psi\right)+\frac{1}{2}\nabla\times\psi^{\dagger}\frac{\boldsymbol{\sigma}}{2}\psi\right]^2}_{\text{Kinetic Energy}}$$

MATTER WAVES
2010

- Variation of Lagrange density determines the evolution of rotational waves:

$$\partial_t \psi + c\gamma^5 \boldsymbol{\sigma} \cdot \nabla \psi + \mathbf{u} \cdot \nabla \psi + \mathrm{i}\,\mathbf{w} \cdot \frac{\boldsymbol{\sigma}}{2} \psi = 0$$

where material velocity $\mathbf{u}$ may be computed from the conjugate momentum:

$$\mathbf{p}_\mathbf{r} = \frac{\partial \mathscr{L}}{\partial \mathbf{u}} = \mathrm{Re}\left(-\psi^\dagger \,\mathrm{i} \nabla \psi\right) + \frac{\nabla \times \mathbf{S}}{2} = \rho \mathbf{u}$$

And the vorticity is:

$$\mathbf{w} = \nabla \times \mathbf{u}/2$$

MATTER WAVES
2010

- The dynamical momentum is:

$$T_i^0 = P_i = -\mathrm{i}\,\psi^\dagger \partial_i \psi$$

- The angular momentum operator is:

$$\mathbf{J} = \frac{\partial \mathscr{L}}{\partial\left[\partial_t \boldsymbol{\phi}\right]} = \psi^\dagger \left\{ -\mathbf{r} \times \mathrm{i}\nabla + \frac{1}{2}\boldsymbol{\sigma} \right\} \psi = \mathbf{L} + \mathbf{S}$$

MATTER WAVES
2010

- The physical interpretation of the wave function utilizes an angular potential **Q** whose Laplacian is proportional to orientation angle **Θ**:

$$\nabla^2 \mathbf{Q} = -4\rho\Theta$$

$$\partial_t \mathbf{Q} \equiv \frac{1}{2}\left[\psi^\dagger \boldsymbol{\sigma} \psi\right] \;=\; \text{Spin Angular Momentum}$$

$$c^2\left[\nabla \cdot \mathbf{Q}\right] \equiv -\frac{1}{2} c\left[\psi^\dagger \beta_1 \psi\right]$$

$$c^2\left\{\nabla \times \nabla \times \mathbf{Q}\right\}_j \equiv -\frac{\mathrm{i}}{2} c\varepsilon_{ijk}\left\{\partial_i \psi^\dagger \beta_1 \sigma_k \psi - \psi^\dagger \beta_1 \sigma_k \partial_i \psi\right\}$$

MATTER WAVES
2010

- The first order bispinor equation is equivalent to a nonlinear second-order equation:

$$\partial_t^2 \mathbf{Q} - c^2 \nabla^2 \mathbf{Q} + \mathbf{u} \cdot \nabla \partial_t \mathbf{Q} - \mathbf{w} \times \partial_t \mathbf{Q} = 0$$

- Rotational solitons satisfy a three-dimensional Klein-Gordon equation involving as many as three different “masses”, e.g. :

$$\partial_t^2 Q_i - c^2 \nabla^2 Q_i + M_i^2 Q_i = 0$$

MATTER WAVES
2010

- The normalized correlation *C* between two rotational wave functions is:

$$C(\psi_A, \psi_B) = \frac{\left|\psi_A^\dagger \psi_B\right|^2}{\left|\psi_A^\dagger \psi_A\right|\left|\psi_B^\dagger \psi_B\right|}$$

- The normalized correlation between an initial state and a possible final rotational wave state is:

$$C\left(\psi_F \mid \psi(t_0)\right) = \left\langle \psi_F \middle| e^{-\mathrm{i}H(t-t_0)} \middle| \psi(t_0) \right\rangle$$

$$= \frac{\left|\int \psi_F^\dagger e^{-\mathrm{i}H(t-t_0)} \psi(t_0)\, d^3 r\right|^2}{\left|\int \psi_F^\dagger \psi_F\, d^3 r\right|\left|\int \psi^\dagger(t_0) \psi(t_0)\, d^3 r\right|}$$

MATTER WAVES
2010

- Interference of two spin eigenfunctions:

$$\left[\psi_A^\dagger + \psi_B^\dagger\right]\sigma_z\left[\psi_A + \psi_B\right] = \psi_A^\dagger \sigma_z \psi_A + \psi_B^\dagger \sigma_z \psi_B$$

$$+\psi_A^\dagger \sigma_z \psi_B + \psi_B^\dagger \sigma_z \psi_A$$

- Cancellation of interference terms yields exclusion principle:

$$\psi_A^\dagger \psi_B + \psi_B^\dagger \psi_A = 0$$

MATTER WAVES
2010

- Cancellation is achieved using phase shifts:

$$\psi'_B = \exp(i\chi)\psi_B$$

- Phase shifts produce <u>interaction potentials</u>, e.g. :

$$e\mathbf{A} \equiv -\frac{c}{2}\nabla\chi$$

$$e\Phi \equiv \frac{1}{2}\partial_t\chi - \mathbf{u}\cdot\frac{e}{c}\mathbf{A}$$

MATTER WAVES
1928

- Paul Dirac modifies the rotational wave equation by replacing the nonlinear operators with a constant matrix operator and mass eigenvalue. All other physical interpretations remain the same:

$$\partial_t \psi + c\gamma^5 \boldsymbol{\sigma} \cdot \nabla \psi + \mathrm{i}\gamma^0 M\psi = 0$$

1928-1973

- Since experiments typically involve detection of entire particles rather than local matter-wave field measurements, Dirac’s equation is interpreted statistically. This approach eventually leads to the Standard Model of Particle Physics.

MATTER WAVES 1951-1952

- Dirac states*, "If one examines the question in light of present-day knowledge, one finds that … good reasons can now be advanced for postulating an aether… It is necessary to set up an action principle and to get a Hamiltonian formulation of the equations suitable for quantization purposes, and for this the aether velocity is required."*

,

PARITY
1939

- A spatial inversion operator is derived for Dirac bispinors, assuming that all matter is mirror-symmetric, and electrical charge is a true scalar.
- "Unitary Representations of the Inhomogeneous Lorentz Group", E.P. Wigner, Ann. Math., 40, 149 (1939). "Intrinsic Parity of Elementary Particles", G.C. Wick, E.P. Wigner, and A.S. Wightman, Phys. Rev. 88, 101 (1952).
- It is claimed that spatial inversion cannot invert γ^0 because it is the temporal part of a 4-vector, evidently ignoring the fact that the 4-vector in question:

$$\left(\psi^\dagger\psi, \psi^\dagger\gamma^5\sigma_i\psi\right) = \left(\overline{\psi}\gamma^0\psi, \overline{\psi}\gamma^i\psi\right) \text{ is } \underline{\text{independent}} \text{ of } \gamma^0\,!$$

1956

- Lee and Yang suggest that this parity operator may not be consistent with parity conservation in weak interactions.

Lee TD and Yang CN 1956 Question of Parity Conservation in Weak Interactions, *Phys. Rev.* **104**, 254.

PARITY
1957

- In geometric algebra, there are two unit imaginaries: a scalar imaginary (product of three axial vectors) and a pseudoscalar imaginary (product of three polar vectors).
- The matrices γ^0, i$\gamma^0\gamma^5$, and γ^5 have the same algebra as the Pauli matrices except for a pseudoscalar imaginary. All should change sign under correct spatial inversion.

PARITY
2010

- An alternative spatial inversion operator is derived for Dirac bispinors, predicting that matter and antimatter are related by spatial inversion, and electrical charge is a pseudoscalar. (R. A. Close, "The Mirror Symmetry of Matter and Antimatter," Adv. Appl. Clifford Algebras, 2010)

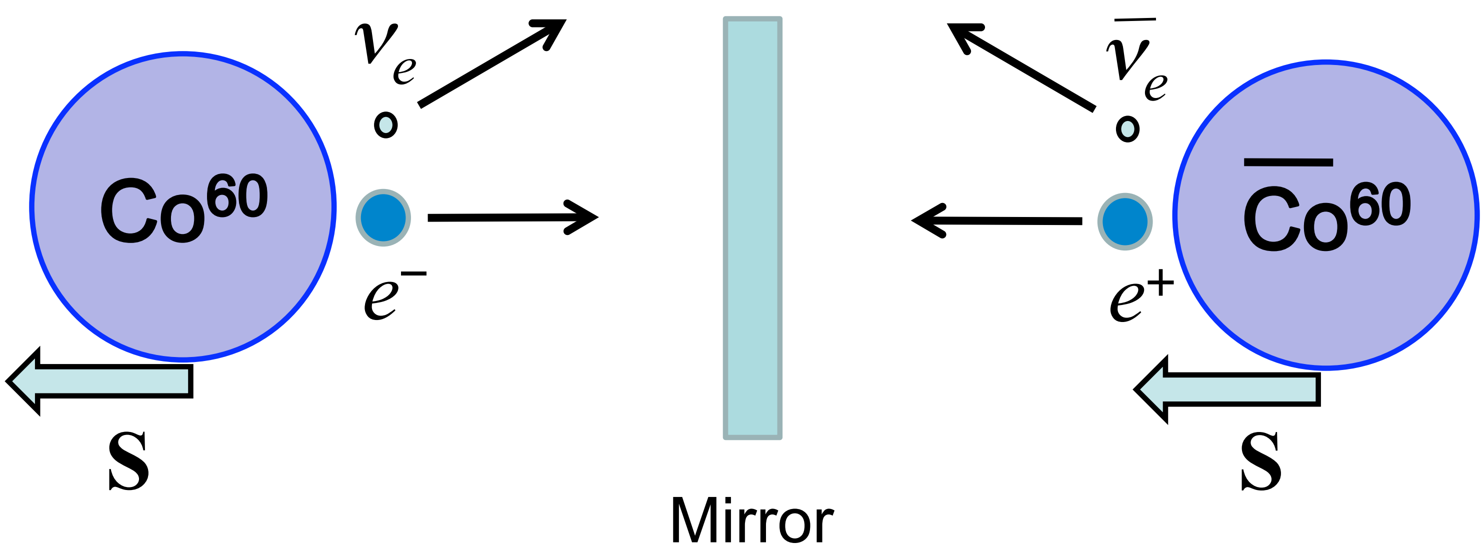
$$\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}, \begin{pmatrix} 0 & -\bar{\mathrm{i}} & 0 & 0 \\ \bar{\mathrm{i}} & 0 & 0 & 0 \\ 0 & 0 & 0 & -\bar{\mathrm{i}} \\ 0 & 0 & \bar{\mathrm{i}} & 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \quad \text{form an axial vector (spin)}$$

$$\begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 0 & -\tilde{\mathrm{i}} & 0 \\ 0 & 0 & 0 & -\tilde{\mathrm{i}} \\ \tilde{\mathrm{i}} & 0 & 0 & 0 \\ 0 & \tilde{\mathrm{i}} & 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \quad \text{form a polar vector (relative to velocity)}$$

- Both sets of matrices above obey the same algebra and each forms an orthogonal basis.

PARITY
1957

- Chien-Shiung Wu's beta decay experiment demonstrates that spatial inversion does indeed exchange matter and antimatter, and electrical charge is a pseudoscalar. Otherwise the mirror process never occurs in nature.



PARITY
2010

Original	Spatially Inverted
electron (e^-)	positron (e^+)
proton	anti-proton
neutrino	anti-neutrino
photon	photon
E	+**E**
B	−**B**
Φ	$-\Phi$
A	+**A**
$\mathbf{J}_e$	$+\mathbf{J}_e$

- Sources:

- http://www.encyclopedianomadica.org/English/aether.php
- http://www.newworldencyclopedia.org/entry/Light
- http://home.clara.net/rod.beavon/robert_hooke.htm
- http://en.wikipedia.org/wiki/Patrick_Maynard_Stuart_Blackett
- Whittaker E 1954 A History of the Theories of Aether and Electricity, vols. 1 & 2 (Edinburgh: Thomas Nelson and Sons Ltd.)

Publications

- R. A. Close, "Torsion Waves in Three Dimensions: Quantum Mechanics With a Twist," **Foundations of Physics Letters** 15(1):71-83, Feb. 2002.
- R. A. Close, "A Classical Dirac Bispinor Equation," in *Ether Space-time & Cosmology*, vol. 3. M. C. Duffy and J. Levy, eds. (Apeiron 2009).
- R. A. Close, "Exact Description of Rotational Waves in an Elastic Solid," **Advances in Applied Clifford Algebras**, DOI 10.1007/s00006-010-0249-1 (2010).
- R. A. Close, "The Mirror Symmetry of Matter and Antimatter," **Advances in Applied Clifford Algebras**, DOI 10.1007/s00006-010-0245-5 (2010).

More at: www.ClassicalMatter.org

Bibliography

- de Broglie LV 1924 *Recherches sur la Theorie des Quanta*, PhD Thesis, (Paris: University of Sorbonne).
- Davisson C and Germer LH 1927 Diffraction of Electrons by a Crystal of Nickel, *Phys. Rev.* **30** 705–40.
- Dmitriyev VP 1992 The Elastic Model of Physical Vacuum, *Mechanics of Solids (N.Y.)* **26**(6) 60-71.
- Einstein A 1956 *The Meaning of Relativity* (Princeton: Princeton Univ. Press) Fifth Edition, pp 84-89.
- Gu YQ 1998 Some Properties of the Spinor Soliton, *Advances in Applied Clifford Algebras* **8**(1) 17-29.
- Hestenes D 1967 Real Spinor Fields, *J. Math. Phys.* **8**(4) 798-808.
- Hestenes D 1973 Local observables in the Dirac theory, *J. Math. Phys.* **14**(7) 893-905.
- Hestenes D 1990 The Zitterbewegung Interpretation of Quantum Mechanics, *Found. Phys.* **20**(10) 1213-32.
- Karlsen BU 1998 Sketch of a Matter Model in an Elastic Universe (http://home.online.no/ ~ukarlsen).
- Kleinert H 1989 *Gauge Fields in Condensed Matter* vol II (Singapore: World Scientific) pp 1259
- Lee TD and Yang CN 1956 Question of Parity Conservation in Weak Interactions, *Phys. Rev.* **104**, 254.
- Morse PM and Feshbach H 1953a *Methods of Theoretical Physics* vol I (New York: McGraw-Hill Book Co.) pp 304-6.
- Rowlands P 1998 The physical consequences of a new version of the Dirac equation *Causality and Locality in Modern Physics and Astronomy: Open Questions and Possible Solutions* (Fundamental Theories of Physics, vol 97) eds G. Hunter, S. Jeffers, and J-P. Vigier (Dordrecht: Kluwer Academic Publishers) pp 397-402
- Rowlands P and Cullerne J P 2001 The connection between the Han-Nambu quark theory, the Dirac equation and fundamental symmetries *Nuclear Phys. A* **684** 713-5
- Rowlands P 2005 Removing redundancy in relativistic quantum mechanics *Preprint* arXiv:physics/0507188
- Takabayashi Y 1957 Relativistic hydrodynamics of the Dirac matter, *Suppl. Prog. Theor. Phys.* **4**(1) 1-80.
- Thomson GP and Reid A 1927 Diffraction of cathode rays by a thin film, *Nature* **119** 890-5.
- Whittaker E 1951 *A History of the Theories of Aether and Electricity*, (Edinburgh: Thomas Nelson and Sons Ltd.).
- C. S. Wu et al., *Experimental test of parity conservation in beta decay. Phys. Rev.* **105 (1957), 1413-1415.**