History of special relativity 11 01 Newton 04 Poincaré

History of special relativity 01 Newton

[Although] Isaac Newton ---based> his theory /on/ absolute space and time,

he ---also adhered to> the Principle of relativity of Galileo Galilei. []

This ---stated> all observers

L who ---move uniformly> relative /to/ each other

<are> equal

[and] no absolute state of motion <can be attributed---$ /to/ any observer. []

/During/ the 19th century

the ether Theory <was widely accepted---$,

/mostly in/ the form <given by--- James Clerk Maxwell. []

/According to/ Maxwell

all optical and electrical phenomena ---propagate> /in/ a medium. []

[Thus] it ---seemed> possible

/to/ $---determine> *absolute* motion <relative to> the aether

[and therefore] /to/ $--- disprove> Galileo's Principle. []

Those experiments and their failure ---lead to>

the development of the Maxwell-Lorentzian Electrodynamics

/by/ Hendrik Lorentz. []

Henri Poincaré ---formally completed> this

/by/ $---stating> the Relativity Principle

<as> a general law of nature,

$---including> Electrodynamics and Gravitation. []

Albert Einstein ---eventually devised> Special Relativity (SR)

/by/ $---completely re-interpreting> Lorentzian Electrodynamics

/by/ $---changing> the concepts of space and time

/and/ ---abolishing> the aether. []

This ---paved> the way /to/ General Relativity. []

Subsequent work of Hermann Minkowski

---laid> the foundations of Relativistic Field Theories. []

From aether to relativity principle

1816 — Augustin-Jean Fresnel ---developed> a Stationary Aether Theory

/in/ which light ---propagates> <as> a transverse wave

[and] aether <was partially dragged /with/ a certain coefficient by--- matter.[]

[Based on] this assumption,

Fresnel ---was able to explain> the Aberration of light

<and> many optical phenomena.[A 1] []

1845 — George Gabriel Stokes,

<contrary to> Fresnel,

---stated> that the aether <was *fully* dragged by--- matter. []

/In/ his model/ the aether <might be (by analogy with pine pitch) rigid---$

/at/ very high frequencies and fluid /at/ lower speeds. []

[Thus] the Earth ---could move through> it /fairly freely,

[but] it <would be> rigid /enough to/ $ ---support> light.[A 2] []

1851 — Both theories <were considered---$,

[but] Fresnel's theory <was favoured--- $

[because] his dragging coefficient <was confirmed by---

the experiments of Armand Hippolyte Louis Fizeau,

L who ---measured> the speed of light /in/ moving liquids.[A 3][B 1][B 2] []

1861–1864 — James Clerk Maxwell ---developed> a set of equations

/in/ electricity, magnetism and inductance, <named-- Maxwell's equations. []

He ---first proposed> that light <was> /in fact/

undulations (Electromagnetic radiation) /in/ the *same* aetherial medium

that <is> the cause of electric and magnetic phenomena.[A 4] []

History of special relativity 02 Michelson

1881 — Albert Abraham Michelson ---tried to measure>

the relative motion of earth and Aether (Aether-Wind),

<as> it <was expected---$ /in/ Fresnel's theory,

/by/ $ ---using> an interferometer. []

[However], he ---could not determine> any relative motion,

[so] he ---interpreted> the result <as> a confirmation of the thesis of Stokes.[A 5] []

1881 — J. J. Thomson ---recognized>,

/during/ his development of Maxwell's Theory,

that charged bodies <are> harder /to/ set /in/ motion

<than> uncharged bodies.[]

Electrostatic fields ---behave>

<as if> they ---add> an "electromagnetic mass"

/beside/ the mechanical mass /to/ the bodies. []

[I.e.], <according to> Thomson,

electromagnetic energy ---corresponds to> a certain mass.[A 6] []

1886 — Hendrik Lorentz ---showed>

Michelson's 1881 experiment calculations <were> wrong

[and therefore] the experiment <was> not conclusive. []

This <was admitted by--- Michelson himself.[A 7] []

Lorentz ---also showed> that a complete drag of the aether <as> in Stokes' Theory

<is> self-contradictory.[B 1][B 2] []

1886 — Michelson and Edward Morley ---performed> an experiment

/to/ $---check> Fizeau's experiment,

L which ---measured> Fresnel's dragging coefficient /in/ a moving liquid. []

Fresnel's theory <was confirmed---$ <very exact on> that occasion. []

Michelson <was> now of the opinion

L that a nearly stationary aether <is confirmed---$.[A 8] []

1887 — Michelson and Morley

---published> the results of repeating Michelson's 1881-experiment. []

The now famous Michelson-Morley experiment

---didn't yield> the expected positive result,

[and] <was> /in/ sharp <contrast to> the 1886 Michelson and Morley experiment,

which ---spoke for> Fresnel's stationary aether. []

[However], Stokes's alternative of a fully-dragged aether

<was> hardly justifiable either,

[because of] Lorentz's 1886 arguments.[A 9] []

1887 — Woldemar Voigt ---investigated> the Doppler Effect

/for/ waves ---propagating> /in/ an incompressible elastic medium

[and] ----deduced> /for/ the first time/ relativistic transformation relations,

L which ---have> some similarity /to/ the 'Lorentz Transformation'. []

He ---started from> the corresponding partial differential equation. []

He ---assumed> a wave expression <as> a solution of it

[and] ---inserted> /in/ the argument

L◇ the most general form of the Galilean Transformation,

L which accounts /for/ <both> a rotation of coordinates <and> a shift /in/ time.[]

The Relativistic Transformation ---relations> /for/ some special cases

he ---deduced> then

/by/ $---subjecting> the Galilei transformed wave expression

/to/ the partial differential wave equation. []

Voigt ---distinguished strictly>

/between/ transformation relations <valid for> *longitudinal* waves

/and/ transformation relations <valid for> *transverse* waves

(<such as> electromagnetic waves). []

The Voigt-Transformation ---predicted>

the negative result of the following Michelson-Morley Experiment,

[but] the equations <were not> symmetrical. []

[However], Voigt's work <was completely ignored by--- his contemporaries.[A 10] []

1889 — Oliver Heaviside ---continued> the 1881 work of Thomson

[and] ---recognized> that the mass of a body <is increased---$,

[not only] when it <is charged---$,

[but] the electromagnetic mass <is also increased----$ /due to/ higher velocity.[]

[Additionally] he ---determined>

that the electrostatic fields <were contracted---$

/in/ the line of motion (Heaviside Ellipsoid),

which ---leads to>

$ ---physically undetermined> conditions /at/ the speed of light.[A 11] []

1889 — [Following] Heaviside,

George FitzGerald ----suggested>

that also material bodies ---contract>/in/ the line of motion (length contraction),

which ---could explain>

the negative result of the Michelson–Morley experiment.[A 12] []

1890 — [After] Heinrich Hertz /in/ 1887/

---had proven> the existence of electromagnetic waves,[B 1]

he (and, similar to him, Heaviside) /in/ 1890/

---further developed> Maxwell's theory.[A 13][A 14] []

The "Maxwell–Hertz" Equations ---subsequently formed>

an important basis /for/ the further development of electrodynamics. []

Hertz ---assumed>,

<like> Stokes,

that the aether <was completely carried along by--- the bodies

– which <was not in accordance with> experiments. []

/At/ the beginning of the 20th century

his theory <was also directly disproved by--- experiment

[and] <was replaced by--- the theory of Lorentz. []

Hertz <was> one of the last proponents of the "mechanical world–view",

[according to] which all electromagnetic processes <should be reduced--- $

/to/ mechanical impact <and> contact actions.[B 2] []

History of special relativity 03 Lorentz

1892 — Lorentz ---set> the foundations of Lorentz Aether/Electron Theory,

/by/ $ ---assuming> the existence of electrons

<as> the source of electromagnetic fields

[and] /by/ $---replacing> the "Maxwell-Hertz" Equations

/by/ the "Maxwell-Lorentz" Equations. []

/In/ his model,

the aether <is> completely motionless

[and],

<contrary to> Fresnel's theory,

<also is not partially dragged by--- matter. []

He ---gave> no statements /about/ the mechanical nature of the aether

<and> the electromagnetic processes,

[but],

/vice-versa/,

---tried to explain> the mechanical processes /by/ electromagnetic ones

[and therefore] ---created> an abstract Electromagnetic Aether. []

/In/ the framework of his theory,

Lorentz ---calculated>,

<like> Heaviside,

the contraction of the electrostatic fields.[A 15] []

/In/ the same year/ he ---proposed> length contraction

<independently from> Fitzgerald

/in order to/ $ ---explain> the Michelson-Morley experiment. □

/For/ plausibility reasons/,

Lorentz ---referred to> the analogy of the contraction of electrostatic fields.□

[However], even Lorentz ---admitted> that

◇ that <was not> a necessary reason

[and] length-contraction ---consequently remained>

<as> a purely *ad-hoc* hypothesis.[A 16] □

1895 — Lorentz ---introduced> the "Theorem of Corresponding States"

/for terms on/ the order of v/c. □

This theorem ---states>

that a moving observer (<relative to> the aether) /in/ his „fictitious" field

---makes> the same observations

<as> a resting observers /in/ his „real" field. □

An important part of it <was> local time $t' = t - vx/c^2$,

which ---paved> the way /to/ the Lorentz Transformation

[and] which he ---introduced independently of> Voigt. □

/With/ the help of this concept,

Lorentz ---could explain> the aberration of light,

the Doppler Effect <and> the measurements of the Fresnel drag coefficient

/by/ Hippolyte Fizeau /in/ moving and resting liquids /as well/. □

[However],

Lorentz's local time <was not> the time <measured by--- watches,

<but only> an auxiliary mathematical tool. []

[However] Lorentz ---recognized> the fact

that his theory ---violated> the principle of action and reaction,

[since] the aether ---acts on> matter,

[but] matter ---cannot act on> the immobile aether.[A 17] []

1895 — Henri Poincaré ---judged> that,

[despite] the violation of the Reaction Principle,

the theory of Lorentz <is> the least defective of all theories of electrodynamics. []

[Because], <contrary to> the other theories,

it ---can explain> the Fizeau experiment

<and> the Conservation of Electricity /and/ Magnetism. []

[Contrary to] Lorentz,

who ---only wanted to explain>

the negative (optical) aether ---drift> experiments of first order /to/ v/c,

Poincaré (<based on--- the Michelson-Morley experiment)

<was> of the opinion

that it <is> only possible /to/ $---observe> relative motions of matter,

[but not] absolute motion [nor] motion <relative to> the aether.[A 18]

1897 — Joseph Larmor ---created> a model <very similar to> Lorentz's. []

[However], he ---went> a step /further/

[and] ---extended> the Lorentz Transformation /for/ second order terms. []

[So] Larmor <was> the first /to/ $---put>

the Lorentz Transformation /in/ an algebraically equivalent form,

which ---is used to> this day. []

He ---noticed on> that occasion,

that [not only] $---can> length-contraction <be derived from--- it,

[but] he ---also calculated>

some sort of Time Dilation /for/ electron orbits.[A 19] []

Larmor ---specified> his considerations /in/ 1900.[A 20] []

/In/ 1899,

Lorentz ---extended> his transformation /for/ second order terms

[and] ---noted> a (mathematical) Time Dilation effect /as well/. []

The integration of the speed-dependence of masses <recognized by-- Thomson

<was especially> important /for/ his theory. []

He ---noticed> that the mass ---not only varied> /due to/ speed,

<but is also> dependent /on/ the direction,

[and] he ---introduced>

what Abraham ---later called> "longitudinal" and "transverse" mass. []

(The transversal mass ---corresponds to>

what later <was called---$ <> Relativistic Mass).[A 21] []

1898 — /In/ the second half of the 19th century

there <were> many attempts

/to/ $ ----develop> a world-wide clock network

<synchronized by--- electrical signals. []

/On/ that occasion,

the finite propagation speed of light <had to be considered----$ /as well/.[B 3] []

[So] Henri Poincaré ----drew> some important consequences of this process

[and] ---explained> that astronomers,

/in/ $----determining> the speed of light,

---simply assume>

that light ---has> a constant speed,

[and] that this speed <is> the same /in/ all directions. []

[Without] this postulate

it ---would be> impossible

/to/ $---infer> the speed of light /from/ astronomical observations,

[as] Ole Rømer ---did based on> observations of the moons of Jupiter. []

Poincaré ---also noted> that the propagation speed of light

<can be (and in practice often is) used---$

/to/ $---define> simultaneity

/between/ spatially separate events. []

He ---concluded> /by/ $---saying>,

that ″The simultaneity of two events,

<or> the order of their succession,

the equality of two durations,

<are to be so defined---$

that the enunciation of the natural laws ---may be> <as simple as> possible. []

[In other words], all these rules,

all these definitions

<are only> the fruit of an unconscious opportunism.″[A 22] []

History of special relativity 04 Poincaré

1900 — <Like in> 1895,

Poincaré ---argued> that experiments

<like> that of Michelson-Morley ---show>

the impossibility of $---detecting> the absolute motion of matter

/or/ the relative motion of matter

/in/ relation /to/ the aether. []

He ---called> this <> the ″principle of relative motion.″[A 23] []

/In the same year/

he ---interpreted> Lorentz's local time

<as> the result of a synchronization procedure <based on--- light signals. []

He ---assumed> that 2 observers <> A and B,

which ---are moving> /in/ the aether,

---synchronize> their clocks /by/ optical signals. []

[Since] they ---believe> themselves /to/ <be> at rest,

they ---must consider> only the transmission time of the signals

<and then> cross-reference their observations

/to/ $---examine> ◇whether their clocks <are> synchronous. []

[However], /from/ the point of view of an observer <> at rest /in/ the aether,

the clocks <are not> synchronous

[and] ---indicate> the local time $t' = t - vx/c^2$. []

[But because]

the moving observers ---do not know> anything /about/ their movement,

they ---do not recognize> this. []

[So], <contrary to> Lorentz,

Poincaré-defined local time <can be measured---$

[and] <indicated by--- clocks.[B 4] []

/In the same work/

Poincaré ---recognized>

that electromagnetic energy ---behaves like> a fictitious fluid

/with/ mass density of $m = E/c^2$ (or $E = mc^2$)

[and] ---defined> a fictitious electromagnetic momentum /as well/. []

[However], he ---arrived at> a radiation paradox

which <was fully explained by--- Einstein in 1905.[A 24]

1900 — Wilhelm Wien ---assumed>

([following] the works of Thomson <and> George Frederick Charles Searle)

that the *entire* mass <is> of electromagnetic origin

[and] the formula /for/ the mass-energy-relationship <is> $m = (4/3)E/c^2$. []

This <was formulated in--- the context

that all forces of nature <are> electromagnetic ones

(the Electromagnetic World View). []

Wien ---stated> that,

[if] it <is assumed-- that gravitation <is> an electromagnetic effect /too/,

[then] there ---has to be> a proportionality

/between/ electromagnetic energy, inertial mass

/and/ gravitational mass.[A 25] []

1900 — Emil Cohn ---created> an alternative Electrodynamics

/in/ which he,

<as> one of the first,

---discarded> the existence of the aether

(at least in the previous form)

[and] ---would use>,

<like> Ernst Mach,

the fixed stars <as> a reference frame instead.[A 26] []

[Due to] internal failures (<like> different light speeds /in/ different directions)

his theory <was superseded by--- Lorentz's and Einstein's. []

1901 — Menyhért Palágyi ---presented> a philosophical model,

[according to] which space and time

<were> only two sides of some sort of "spacetime". []

He ---used> time <as> a imaginary fourth dimension,

which he ---already gave> the form it (where $i = \sqrt{-1}$). []

[However],

there ---exists> no connection

/between/ his philosophy /and/ Lorentz's Electrodynamics,

[because], <contrary to> Lorentz's local time,

Palagyi's time coordinate <is not connected to--- the speed of light. []

He ---also rejected> any connection

/with/ the already-existing constructions of n-dimensional spaces

/and/ non-Euclidean geometry. []

(/Characteristically/, Palágyi ---later rejected>

also the spacetime constructions of Minkowski and Einstein,

which <were developed---$ /in/ the spirit of non-Euclidean geometry).[A 27][]

1901-1903 — Walter Kaufmann <was> the first

/to/ $---confirm> the velocity dependence of mass.[A 28] []

1902 — Max Abraham ---submitted> an explanation /for/ Kaufmann's experiments

[and], <following> Lorentz,

he ---coined> the names <> Longitudinal and Transverse Mass. []

/In/ <contrast to> Lorentz,

he ---didn't believe in> the Contraction Hypothesis,

[and therefore] his mass terms <differed from> those of Lorentz. []

Kaufmann's experiments <were>,

[however],

<not> precise /enough to/ $---distinguish>

/between/ the theories of Lorentz /and/ Abraham. []

[Following] Poincaré,

Abraham ---introduced> the concept of "Electromagnetic Momentum",

which,

/in/ <contrast to> Poincaré,

he ---considered> <as> a *real* physical entity

which <is proportional to> E/c^2.[A 29][A 30] []

1902 — Poincaré ---published> the philosophical /and/ popular-scientific book

<>"Science and Hypothesis",

which ---included> {◇#} [:][A 31] []

◇# philosophical assessments /on/ the relativity of space, time, and simultaneity

◇# the opinion that a violation of the Relativity Principle

<can never be detected---$

◇# the possible non-existence of the aether

◇# many remarks /on/ the non-Euclidean geometry.

1904 — /In/ May,

Lorentz ---came very near to>

$---creating> a Lorentz-covariant formulation of Electrodynamics

([although] he ---didn't succeeded completely>). []

[Like] Wien and Abraham,

he ---argued>

that there ---exists> only electromagnetic mass, <not> mechanical mass. []

Another important step <was> the postulate

that the Lorentz Transformation ---has to be> valid

/for/ non-electrical forces /as well/.[A 32] []

1904 — Cohn,

[following] the work of Lorentz,

(<like> Poincaré)

---noticed> that local time <was not only> a mathematical construct,

<but was> the result of $---synchronizing>

moving clocks /by/ light signals. []

Cohn ---believed> that this <is only> valid /for/ optical phenomena,

<but> mechanical clocks ---would indicate>

the "real" time.[A 33] []

[Also] Abraham ---criticized>

that Lorentz's theory of the contracted electrons

<is not compatible with> the electromagnetic conception of the world,

[since] non-electric forces <are needed---$

/in order to/ $---guarantee> the stability of matter. []

[Thus] the question ---arose>

/whether/ the Electromagnetic conception of the world

(<> compatible /with/ Abraham's theory)

/or/ the Relativity Principle

(<> compatible /with/ Lorentz's Theory)

<was> correct.[A 34] []

1904 — /In/ a September lecture /in/ St. Louis,

Poincaré ---defined>

(/in/ modification of Galileo's Relativity Principle

<and> Lorentz's Theorem of Corresponding States)

the following principle

<:> "The Principle of Relativity,

<according to> which the laws of physical phenomena

<must be> the same /for/ a stationary observer

<as for> one ---carried along>

/in/ a uniform motion of translation,

[so that] we ---have> no means,

[and] ---can have> none,

of $---determining>

/whether or not/

we <are> <being carried along---$ /in/ such a motion." []

He ---also specified> his clock synchronization method

[and] ---explained> the possibility of a "new method" <or> "new mechanics",

/in/ which no velocity ---can surpass> that of light /for/ *all* observers.[]

[However],

he ---critically noted> that the Relativity Principle,

Newton's action and reaction,

the Conservation of Mass

/and/ the Conservation of Energy

<are not fully established---$

[and] <are even threatened by--- some experiments.[A 35] []

1904 — Friedrich Hasenöhrl ---suggested> that part of the mass of a body

(which he ---called> apparent mass)

<can be thought of---$ <as> radiation ---bouncing> /around/ a cavity.[]

The apparent mass of radiation ---depends on> the temperature

([because] every heated body ---emits> radiation)

[and] <is proportional to> its energy,

[and] he ---first concluded> that $m = (8/3)E/c^2$. []

[However], Abraham and Hasenöhrl himself /in/ 1905/

---changed> the result /to/ $m = (4/3)E/c^2$,

the same value /for/ the electromagnetic mass /for/ a body /at/ rest.[]

[However], Hasenöhrl ---stated>

that this energy-apparent-mass relation ---only holds>

<as long> a body ---radiates>,

[i.e.], [if] the temperature of a body <is> greater than 0 K.[A 36][A 37] []

1905 — /On/ 5 June,

Henri Poincaré ---submitted> the summary of a work

which ---closed> the existing gaps of Lorentz's work. []

(This short paper ---contained> the results of a more complete work

which <was published---$ /in/ January 1906). []

He ---showed> that Lorentz's equations of electrodynamics

<were not fully> Lorentz-covariant. []

[So] he ---pointed out> the group characteristics of the transformation,

[and] he ---corrected> Lorentz's formulae

/for/ the transformations of charge density

/and/ current density

(which ---implicitly contained> the relativistic velocity-addition formula,

which he ---elaborated> /in/ May /in/ a letter /to/ Lorentz). []

Poincaré ---used> /for/ the first time/ the term <> "Lorentz transformation",

[and] he ---gave> them > the symmetrical form

which <is used to---$ /this day/. []

He ---introduced> a non-electrical binding force

/to/ $---ensure> the stability of the electrons

[and] /to/ $---explain> length contraction. []

He ---also sketched> a Lorentz-invariant model of gravitation

(---including> gravitational waves)

/by/ $---extending> the validity of Lorentz-invariance

/to/ non-electrical forces.[A 38] []