Historical Timelines in the Development of Phase Space

David D Nolte
Historical Timelines of the Theory of Trajectories and Phase Space

David D. Nolte

Dynamics TimeLine (1500 - 2000)

More stories behind the development of phase space and its role in modern dynamics can be found at the WordPress Blog Site

https://galileo-unbound.blog/

Chapter 2: A New Scientist

1564  Galileo born
1581  Enters University of Pisa
1585  Leaves Pisa without a degree
1586  Invents hydrostatic balance
1588  Receives lecturship in mathematics at Pisa
1592 Chair of mathematics at University of Padua
1595 Theory of the tides
1595 Invents military and geometric compass
1596 *Le Meccaniche* and the principle of horizontal inertia

1600 Bruno Giordano burned at the stake
1601 Death of Tycho Brahe
1609 Constructs his first telescope, makes observations of the moon
1610 Discovers 4 moons of Jupiter, *Starry Messenger (Sidereus Nuncius)*, appointed chief philosopher and mathematician of the Duke of Tuscany, moves to Florence, observes Saturn, Venus goes through phases like the moon
1611 Travels to Rome, inducted into the Lyncean Academy, name “telescope” is first used (47 years old)
1611 Scheiner discovers sunspots
1611 Meets Barberini, a cardinal
1613 Letters on sunspots published by Lincean Academy in Rome
1614 Denounced from the pulpit
1615 (April) Bellarmine writes an essay against Copernicus
1615 Investigated by the Inquisition
1615 Writes Letter to Christina, but does not publish it
1615 (December) travels to Rome and stays at Tuscan embassy
1616 (January) Francesco Ingoli publishes essay against Copernicus
1616 (March) Decree against copernicanism
1616 Publishes theory of tides, Galileo meets with Pope Paul V, Copernicus’ book is banned, Galileo warned not to support the Copernican system, Galileo decides not to reply to Ingoli, Galileo proposes eclipses of Jupiter’s moons to determine longitude at sea
1618 Three comets appear, Grassi gives a lecture not hostile to Galileo
1618 Galileo, through Mario Guiducci, publishes scathing attack on Grassi
1619 Jesuit Grassi (Sarsi) publishes attack on Galileo concerning 3 comets
1619 Marina Gamba dies, Galileo legitimizes his son Vincenzio
1619 Kepler’s third law
1623 Barberini becomes Urban VIII, *The Assayer* published (response to Grassi)
1624 Galileo visits Rome and Urban VIII
1629 Birth of his grandson Galileo
1630 Death of Johannes Kepler
1632 Publication of the *Dialogue Concerning the Two Chief World Systems*, Galileo is indicted by the Inquisition (68 years old)
1633 (February) Travels to Rome
1633 Convicted, abjurs, house arrest in Rome, then Siena, then home to Arcetri
1638 Blind, publication of *Two New Sciences*
1642 Dies (77 years old)

Chapter 3: Galileo’s Trajectory
TRAJECTORY TIMELINES

1583  Galileo Notices isochronism of the pendulum
1588  Receives lecturship in mathematics at Pisa
1589 – 1592  Work on projectile motion in Pisa
1592  Chair of mathematics at University of Padua
1596  *Le Meccaniche* and the principle of horizontal inertia

1600  Guidobaldo shared technique of colored ball
1602  Discovered isochronism of the pendulum (experimentally)
1604  First experiments on uniformly accelerated motion
1604  Wrote to Scarpi about the law of fall (s \(\approx t^2\))
1607-1608  Identified trajectory as parabolic
1609  Velocity proportional to time
1632  Publication of the *Dialogue Concerning the Two Chief World Systems*, Galileo is indicted by the Inquisition (68 years old)
1636  *Letter to Christina* published in Augsburg in Latin and Italian
1638  Blind, publication of *Two New Sciences*
1641  Invented pendulum clock (in theory)
1642  Dies (77 years old)

Chapter 4: On the Shoulders of Giants

1644  Descartes’ vortex theory of gravitation
1662  Fermat’s principle
1669 – 1690  Huygens expands on Descartes’ vortex theory
1698  Maupertuis born

1729  Maupertuis entered University in Basel. Studied under Johann Bernoulli
1736  Euler publishes *Mechanica sive motus scientia analytice exposita*
1745  Maupertuis becomes president of Berlin Academy. Paris Academy cancels his membership after a campaign against him by Cassini.
1746  Principle of Least Action for mass
1749  du Chatelet dies
1751  Samuel König disputes Maupertuis’ priority
1756  Cassini dies. Maupertuis reinstated in the French Academy
1759  Maupertuis dies
1759  du Chatelet’s French translation of Newton’s *Principia* published posthumously
1760  Euler 3-body problem (two fixed centers and coplanar third body)
1760-1761 Lagrange, Variational calculus published in Miscellanea Taurinensia
1762  Beginning of the reign of Catherine the Great of Russia
1763  Euler colinear 3-body problem
1765  Euler publishes *Theoria motus corporum solidorum* on rotational mechanics
1766  Euler returns to St. Petersburg
1766  Lagrange arrives in Berlin
1772  Lagrange equilateral 3-body problem, Essai sur le problème des trois corps, 1772, Oeuvres tome 6
1775  Beginning of the American War of Independence
1776  Adam Smith *Wealth of Nations*
1781  William Herschel discovers Uranus
1783  Euler dies in St. Petersburg
1787  United States Constitution written
1787  Lagrange moves from Berlin to Paris
1788  Lagrange, *Méchanique analytique*
1789  Beginning of the French Revolution
1799  Pierre-Simon Laplace *Mécanique Céleste* (1799-1825)

**Chapter 5: Geometry on My Mind**

1629  Fermat described higher-dim loci
1637  Descarte’s *Geometry*
1649  van Schooten’s commentary on Descartes *Geometry*
1694  Leibniz uses word “coordinate” in its modern usage
1697  Johann Bernoulli shortest distance between two points on convex surface
1732  Euler geodesic equations for implicit surfaces
1748  Euler defines modern usage of function
1801  Gauss calculates orbit of Ceres
1807  Fourier analysis
1807  Gauss arrives in Göttingen
1827  Karl Gauss establishes differential geometry of curved surfaces, *Disquisitiones generales circa superficies curvas*
1830  Bolyai and Lobachevsky publish on hyperbolic geometry
1834  Jacobi n-fold integrals and volumes of n-dim spheres
1836  Liouville-Sturm theorem
1838  Liouville’s theorem
1841  Jacobi determinants
1843  Arthur Cayley systems of n-variables
1843  Hamilton discovers quaternions
1844  Hermann Grassman n-dim vector spaces, *Die Lineale Ausdehnungslehre*
1846  Julius Plücker *System der Geometrie des Raumes in neuer analytischer Behandlungsweise*
1848  “Vector” coined by Hamilton
1854  Riemann’s habilitation lecture
1861  Riemann n-dim solution of heat conduction
1868  Publication of Riemann’s Habilitation
1868  Boltzmann distribution in momentum space
1869  Christoffel and Lipschitz work on multiple dimensional analysis
1871  Betti refers to the n-ply of numbers as a “space”.

1871 Klein publishes on non-euclidean geometry
1872 Jordan “Essay on the geometry of n-dimensions”
1872 Felix Klein’s “Erlangen Programme”
1872 Weierstrass’ Monster
1872 Dedekind cut
1872 Cantor paper on irrational numbers
1872 Cantor meets Dedekind
1874 Cantor beginning of set theory
1877 Cantor one-to-one correspondence between the line and n-dimensional space
1881 Gibbs codifies vector analysis
1883 Cantor set and staircase Grundlagen einer allgemeinen Mannigfaltigkeitslehre
1884 Abbott publishes Flatland
1887 Peano vector methods in differential geometry
1890 Peano space filling curve
1891 Hilbert space filling curve
1888 Darboux discusses least action as geodesic
1889 Darboux vol. 2 treats dynamics as a point in d-dimensional space. Applies concepts of geodesics for trajectories.
1898 Ricci-Curbastro Lesons on the Theory of Surfaces

1902 Lebesgue integral
1904 Hilbert studies integral equations
1904 von Koch snowflake
1906 Frechet thesis on square summable sequences as infinite dimensional space
1908 Schmidt Geometry in a Function Space
1910 Brouwer proof of dimensional invariance
1913 Hilbert space named by Riesz
1914 Hilbert space used by Hausdorff
1915 Sierpinski fractal triangle
1918 Hausdorff non-integer dimensions
1918 Weyl’s book Space, Time, Matter
1918 Fatou and Julia fractals
1920 Banach space
1927 von Neumann axiomatic form of Hilbert Space
1935 Frechet full form of Hilbert Space
1967 Mandelbrot coast of Britain
1982 Mandelbrot’s book The Fractal Geometry of Nature

Chapter 6: The Tangled Tale of Phase Space
1804 Jacobi born (1904 – 1851) in Potsdam
1804 Napoleon I Emperor of France
1806 William Rowan Hamilton born (1805 – 1865)
1807 Thomas Young describes “Energy” in his lecture notes on physics
1808 Beethoven performs his Fifth Symphony
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1809</td>
<td>Joseph Liouville born (1809 – 1882)</td>
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<tr>
<td>1821</td>
<td>Hermann Ludwig Ferdinand von Helmholtz born (1821 – 1894)</td>
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<tr>
<td>1824</td>
<td>Carnot published <em>Reflections on the Motive Power of Fire</em></td>
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<tr>
<td>1834</td>
<td>Jacobi n-fold integrals and volumes of n-dim spheres</td>
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<td>1834-1835</td>
<td>Hamilton publishes his principle.</td>
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<tr>
<td>1836</td>
<td>Liouville-Sturm theorem</td>
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<td>1837</td>
<td>Queen Victoria begins her reign as Queen of England</td>
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<tr>
<td>1838</td>
<td>Liouville develops his theorem on products of n differentials satisfying certain first-order differential equations. This becomes the classic reference to <em>Liouville’s Theorem</em>.</td>
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<tr>
<td>1847</td>
<td>Helmholz Conservation of Energy (force)</td>
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<tr>
<td>1849</td>
<td>Thomson makes first use of “Energy” (From reading Thomas Young’s lecture notes)</td>
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<tr>
<td>1850</td>
<td>Clausius establishes First law of Thermodynamics: Internal energy. Second law: Heat cannot flow unaided from cold to hot. Not explicitly stated as first and second laws</td>
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<tr>
<td>1851</td>
<td>Thomson names Clausius’ First and Second laws of Thermodynamics</td>
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<tr>
<td>1852</td>
<td>Thomson describes general dissipation of the universe (“energy” used in title)</td>
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<td>1854</td>
<td>Thomson defined absolute temperature. First mathematical statement of 2nd law. Restricted to reversible processes</td>
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<tr>
<td>1854</td>
<td>Clausius stated Second Law of Thermodynamics as inequality</td>
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<tr>
<td>1857</td>
<td>Clausius constructs kinetic theory, Mean molecular speeds</td>
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<tr>
<td>1858</td>
<td>Clausius defines mean free path, Molecules have finite size. Clausius assumed that all molecules had the same speed</td>
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<tr>
<td>1860</td>
<td>Maxwell publishes first paper on kinetic theory. Distribution of speeds. Derivation of gas transport properties</td>
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<tr>
<td>1865</td>
<td>Loschmidt size of molecules</td>
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<tr>
<td>1865</td>
<td>Clausius names entropy</td>
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<tr>
<td>1868</td>
<td>Boltzmann adds (Boltzmann) factor to Maxwell distribution</td>
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<tr>
<td>1872</td>
<td>Boltzmann transport equation and H-theorem</td>
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<tr>
<td>1876</td>
<td>Loschmidt reversibility paradox</td>
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<tr>
<td>1877</td>
<td>Boltzmann ( S = k \log W )</td>
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<tr>
<td>1890</td>
<td>Poincare: Recurrence Theorem. Recurrence paradox with Second Law (1893)</td>
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<tr>
<td>1896</td>
<td>Zermelo criticizes Boltzmann</td>
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<tr>
<td>1896</td>
<td>Boltzmann posits direction of time to save his H-theorem</td>
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<tr>
<td>1898</td>
<td>Boltzmann <em>Vorlesungen über Gas Theorie</em></td>
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<tr>
<td>1905</td>
<td>Boltzmann kinetic theory of matter in <em>Encyklopädie der mathematischen Wissenschaften</em></td>
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<tr>
<td>1906</td>
<td>Boltzmann dies</td>
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<tr>
<td>1910</td>
<td>Paul Hertz uses “Phase Space” (Phasenraum)</td>
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<tr>
<td>1911</td>
<td>Ehrenfest’s article in <em>Encyklopädie der mathematischen Wissenschaften</em></td>
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Chapter 7: The Lens of Gravity

1697 Johann Bernoulli was first to find solution to shortest path between two points on a curved surface (1697).

1728 Euler found the geodesic equation.
1783 The pair 40 Eridani B/C was discovered by William Herschel on 31 January
1783 John Michell explains infalling object would travel faster than speed of light
1796 Laplace describes “dark stars” in Exposition du system du Monde

1827 The first orbit of a binary star computed by Félix Savary for the orbit of Xi Ursae Majoris.
1827 Gauss curvature Theoriem Egregum
1844 Bessel notices periodic displacement of Sirius with period of half a century
1844 The name “geodesic line” is attributed to Liouville.
1845 Buys Ballot used musicians with absolute pitch for the first experimental verification of the Doppler effect
1854 Riemann’s habilitationsschrift
1862 Discovery of Sirius B (a white dwarf)
1868 Darboux suggested motions in n-dimensions
1872 Lipshitz first to apply Riemannian geometry to the principle of least action.
1895 Hilbert arrives in Göttingen

1902 Minkowski arrives in Göttingen
1905 Einstein’s miracle year
1906 Poincaré describes Lorentz transformations as rotations in 4D
1907 Einstein has “happiest thought” in November
1907 Einstein’s relativity review in Jahrbuch
1908 Minkowski’s Space and Time lecture
1908 Einstein appointed to unpaid position at University of Bern
1909 Minkowski dies
1909 Einstein appointed associate professor of theoretical physics at U of Zürich
1910 40 Eridani B was discovered to be of spectral type A (white dwarf)
1910 Size and mass of Sirius B determined (heavy and small)
1911 Laue publishes first textbook on relativity theory
1911 Einstein accepts position at Prague
1911 Einstein goes to the limits of special relativity applied to gravitational fields
1912 Einstein’s two papers establish a scalar field theory of gravitation
1912 Einstein moves from Prague to ETH in Zürich in fall. Begins collaboration with Grossmann.
1913 Einstein EG paper
1914 Adams publishes spectrum of 40 Eridani B


1915  Sirius B determined to be also a low-luminosity type A white dwarf
1915  Einstein Completes paper
1916  Density of 40 Eridani B by Ernst Öpik
1916  Schwarzschild paper
1919  Eddington expedition to Principe
1920  Eddington paper on deflection of light by the sun
1922  Willem Luyten coins phrase “white dwarf”
1924  Eddington found a set of coordinates that eliminated the singularity at the Schwarzschild radius
1926  R. H. Fowler publishes paper on degenerate matter and composition of white dwarfs
1931  Chandrasekhar calculated the limit for collapse to white dwarf stars at 1.4MS
1933  Georges Lemaitre states the coordinate singularity was an artefact
1934  Walter Baade and Fritz Zwicky proposed the existence of the neutron star only a year after the discovery of the neutron by Sir James Chadwick.
1939  Oppenheimer and Snyder showed ultimate collapse of a 3Ms “frozen star”
1958  David Finkelstein paper
1965  Antony Hewish and Samuel Okoye discovered "an unusual source of high radio brightness temperature in the Crab Nebula". This source turned out to be the Crab Nebula neutron star that resulted from the great supernova of 1054.
1967  Jocelyn Bell and Antony Hewish discovered regular radio pulses from CP 1919. This pulsar was later interpreted as an isolated, rotating neutron star.
1967  Wheeler’s “black hole” talk
1974  Joseph Taylor and Russell Hulse discovered the first binary pulsar, PSR B1913+16, which consists of two neutron stars (one seen as a pulsar) orbiting around their center of mass.

2015  LIGO detects gravitational waves on Sept. 14 from the merger of two black holes
2017  LIGO detects the merger of two neutron stars

Chapter 8: On the Quantum Footpath

1885  Balmer Theory: \( \frac{1}{\lambda} = R_H \left( \frac{1}{4} - \frac{1}{n^2} \right) \)
1897  J. J. Thomson discovered the electron
1904  Thomson plum pudding model of the atom
1911  Rutherford nuclear model
1911  First Solvay conference
1911  “ultraviolet catastrophe” coined by Ehrenfest
1913  Bohr combined Rutherford’s nuclear atom with Planck’s quantum hypothesis: 1913 Bohr model
1913  Ehrenfest adiabatic hypothesis
1914-1916  Bohr at Manchester with Rutherford
1916 Bohr appointed Chair of Theoretical Physics at University of Copenhagen: a position that was made just for him
1916 Schwarzschild and Epstein introduce action-angle coordinates into quantum theory
1920 Heisenberg enters University of Munich to obtain his doctorate
1920 Bohr’s Correspondence principle: Classical physics for large quantum numbers
1921 Bohr Founded Institute of Theoretical Physics (Copenhagen)
1922-1923 Heisenberg studies with Born, Franck and Hilbert at Göttingen while Sommerfeld is in the US on sabbatical.
1923 Heisenberg Doctorate. The exam does not go well. Unable to derive the resolving power of a microscope in response to question by Wien. Becomes Born’s assistant at Göttingen.
1924 Heisenberg visits Niels Bohr in Copenhagen (and met Einstein?)
1924 Heisenberg Habilitation at Göttingen on anomalous Zeeman
1924 – 1925 Heisenberg worked with Bohr in Copenhagen, returned summer of 1925 to Göttingen
1924 Pauli exclusion principle and state occupancy
1924 de Broglie hypothesis extended wave-particle duality to matter
1924 Bohr Predicted Halfnium (72)
1924 Kronig’s proposal for electron self spin
1924 Bose (Einstein)
1925 Heisenberg paper on quantum mechanics
1925 Dirac, reading proof from Heisenberg, recognized the analogy of noncommutativity with Poisson brackets and the correspondence with Hamiltonian mechanics.
1925 Uhlenbeck and Goudschmidt: spin
1926 Born, Heisenberg, Kramers: virtual oscillators at transition frequencies: Matrix mechanics (alternative to Bohr-Kramers-Slater 1924 model of orbits). Heisenberg was Born’s student at Göttingen.
1926 Schrödinger wave mechanics
1927 de Broglie hypothesis confirmed by Davisson and Germer
1927 Complementarity by Bohr: wave-particle duality “Evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects.”
1927 Heisenberg uncertainty principle (Heisenberg was in Copenhagen 1926 – 1927)
1927 Solvay Conference in Brussels
1928 Heisenberg to University of Leipzig
1928 Dirac relativistic QM equation
1929 de Broglie Nobel Prize
1930 Solvay Conference
1932 Heisenberg Nobel Prize
1932 von Neumann operator algebra
1933 Dirac Lagrangian form of QM (basis of Feynman path integral)
1933 Schrödinger and Dirac Nobel Prize
1935 EPR paper and Bohr’s response.
1935  Schrodinger’s cat
1939  Feynman graduates from MIT
1941  Heisenberg (head of German atomic project) visits Bohr in Copenhagen
1942  Feynman PhD at Princeton, "The Principle of Least Action in Quantum Mechanics"
1942 – 1945  Manhattan Project, Bethe-Feynman equation for fission yield
1943  Bohr escapes to Sweden in a fishing boat. Went on to England secretly.
1945  Pauli Nobel Prize
1945  Death of Feynman’s wife Arline (married 4 years)
1945  Fall, Feynman arrives at Cornell ahead of Hans Bethe
1947  Shelter Island conference: Lamb Shift, did Kramer’s give a talk suggesting that
infinities could be subtracted?
1947  Fall, Dyson arrives at Cornell
1948  Pocono Manor, Pennsylvania, troubled unveiling of path integral formulation and
Feynman diagrams, Schwinger’s master presentation
1948  Feynman and Dirac. Summer drive across the US with Dyson
1949  Dyson joins IAS as a postdoc, trains a cohort of theorists in Feynman’s technique
1949  Karplus and Kroll first g-factor calculation
1950  Feynman moves to Cal Tech
1965  Schwinger, Tomonaga and Feynman Nobel Prize
1967  Hans Bethe Nobel Prize

Chapter 9: From Butterflies to Hurricanes

1760  Euler 3-body problem (two fixed centers and coplanar third body)
1763  Euler colinear 3-body problem
1772  Lagrange equilateral 3-body problem
1881-1886  Poincare memoires “Sur les courbes de finies par une equation
differentielle”
1890  Poincare “Sur le probleme des trois corps et les equations de la dynamique”. First-
return map, Poincare recurrence theorem, stable and unstable manifolds
1892 – 1899  Poincare Celestial Mechanics
1892  Lyapunov The General Problem of the Stability of Motion
1899  Poincare homoclinic trajectory

1913  Birkhoff proves Poincaré’s last geometric theorem, a special case of the three-
body problem.
1927  van der Pol and van der Mark
1937  Coarse systems, Andronov and Pontryagin
1938  Morse theory
1942  Hopf bifurcation
1945  Cartwright and Littlewood study the van der Pol equation (Radar during WWII)
1954  Kolmogorov A. N., On conservation of conditionally periodic motions for a small
change in Hamilton's function.
1960  Lorenz: 12 equations
1962  Moser On Invariant Curves of Area-Preserving Mappings of an Annulus.


1963  Arnold Small denominators and problems of the stability of motion in classical and celestial mechanics
1963  Lorenz: 3 equations
1964  Arnold diffusion
1965  Smale’s horseshoe
1969  Chirikov standard map
1971  Ruelle-Takens (Ruelle coins phrase “strange attractor”)
1972  “Butterfly Effect” given for Lorenz’ talk (by Philip Merilees)
1975  Gollub-Swinney observe route to turbulence along lines of Ruelle
1975  Yorke coins “chaos theory”
1976  Robert May writes review article of the logistic map
1977  New York conference on bifurcation theory
1987  James Gleick Chaos: Making a New Science

Chapter 10: Darwin in the Clockworks

1202  Fibonacci

1766  Thomas Robert Malthus born
1776  Adam Smith The Wealth of Nations

1817  Ricardo Principles of Political Economy and Taxation
1838  Cournot early equilibrium theory in duopoly
1848  John Stuart Mill
1848  Karl Marx Communist Manifesto
1859  Darwin Origin of Species
1867  Karl Marx Das Kapital
1871  Darwin Descent of Man, and Selection in Relation to Sex
1871  Jevons Theory of Political Economy
1871  Menger Principles of Economics
1874  Walrus Éléments d’économie politique pure, or Elements of Pure Economics (1954)
1890  Marshall Principles of Economics

1908  Hardy constant genetic variance
1910  Brouwer fixed point theorem
1910  Alfred J. Lotka autocatalytic chemical reactions
1913  Zermelo determinancy in chess
1922  Fisher dominance ratio
1922  Fisher mutations
1925  Lotka predator-prey in biomathematics
1926  Vita Volterra published same equations independently
1927  JBS Haldane (1892—1964) mutations
1928  von Neumann proves the minimax theorem
1930  Fisher ratio of sexes
1932  Wright Adaptive Landscape
1932  Haldane *The Causes of Evolution*
1933  Kolmogorov *Foundations of the Theory of Probability*
1934  Rudolph Carnap *The Logical Syntax of Language*
1936  John Maynard Keynes, *The General Theory of Employment, Interest and Money*
1936  Kolmogorov generalized predator-prey systems
1938  Borel symmetric payoff matrix
1942  Sewall Wright *Statistical Genetics and Evolution*
1943  McCulloch and Pitts *A Logical Calculus of Ideas Immanent in Nervous Activity*
1944  von Neumann and Morgenstern *Theory of Games and Economic Behavior*
1950  Prisoner’s Dilemma simulated at Rand Corporation
1950  John Nash *Equilibrium points in n-person games and The Bargaining Problem*
1951  John Nash *Non-cooperative Games*
1952  McKinsey *Introduction to the Theory of Games* (first textbook)
1953  John Nash *Two-Person Cooperative Games*
1953  Watson and Crick DNA
1955  Braithwaite’s *Theory of Games as a Tool for the Moral Philosopher*
1961  Lewontin *Evolution and the Theory of Games*
1962  Patrick Moran *The Statistical Processes of Evolutionary Theory*
1962  Linus Pauling molecular clock
1968  Motoo Kimura neutral theory of molecular evolution
1972  Maynard Smith introduces the evolutionary stable solution (ESS)
1972  Gould and Eldridge Punctuated equilibrium
1973  Maynard Smith and Price *The Logic of Animal Conflict*
1973  Black Scholes
1977  Eigen and Schuster *The Hypercycle*
1978  Replicator equation (Taylor and Jonker)
1982  Hopfield network
1982  John Maynard Smith *Evolution and the Theory of Games*
1984  R. Axelrod *The Evolution of Cooperation*

**Chapter 11: The Measure of Life**

1642  Galileo dies
1649  Vincenzo Gamba dies
1656  Huygens invents pendulum clock
1665  Huygens observes “odd kind of sympathy” in synchronized clocks
1673  Huygens publishes *Horologium Oscillatorium sive de motu pendulorum*

1736  Euler Seven Bridges of Königsberg

1845  Kirchhoff’s circuit laws
1852  Guthrie four color problem
1857  Cayley trees
1858  Hamiltonian cycles

D. D. Nolte, Galileo Unbound: A Path Across Life, the Universe and Everything (Oxford, 2018) 12
1887  Cajal neural staining microscopy

1913  Michaelis Menten dynamics of enzymes

1924  Berger, Hans: neural oscillations (Berger invented the EEG)

1926  van der Pol dimensioness form of equation

1927  van der Pol periodic forcing

1943  McCulloch and Pits mathematical model of neural nets

1948  Wiener cybernetics

1952  Hodgkin and Huxley action potential model

1952  Turing instability model

1956  Sutherland cyclic AMP

1957  Broadbent and Hammersley bond percolation

1958  Rosenblatt perceptron

1959  Erdös and Renyi random graphs

1962  Cohen EGF discovered

1965  Sebeok coined zoosemiotics

1966  Mesarovich systems biology

1967  Winfree biological rythms and coupled oscillators

1969  Glass Moire patterns in perception

1970  Rodbell G-protein

1971  phase “strange attractor” coined (Ruelle)

1972  phase “signal transduction” coined (Rensing)

1975  phase “chaos theory” coined (Yorke)

1975  Werbos backpropagation

1975  Kuramoto transition

1976  Robert May logistic map

1977  Mackey-Glass equation and dynamical disease

1982  Hopfield network

1990  Strogatz and Murillo pulse-coupled oscillators

1997  Tomita systems biology of a cell

1998  Strogatz and Watts Small World network

1999  Barabasi Scale Free networks

2000  Sequencing of the human genome