

Math 710: Continuum Mechanics

A historical background
from the 1400s to the 21st century

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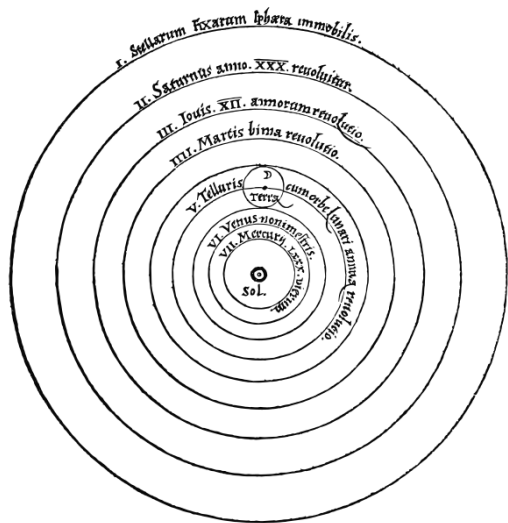
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Nicolaus Copernicus, Polish, 1473–1543

1532: *Dē revolutionibus orbium coelestium*



Tycho Brahe, Danish, 1546–1601

1572: *Astronomiae Instauratae Progygnasmata*
(Introduction to New Astronomy)

Tychonic system: The Sun orbits the Earth, planets orbit the Sun.

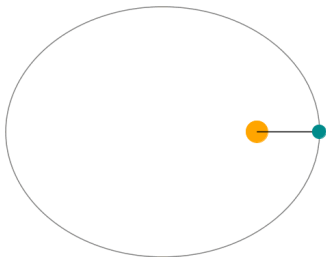


Johannes Kepler, German 1571–1630

Law of planetary motion:

1609: *Astronomia Nova*

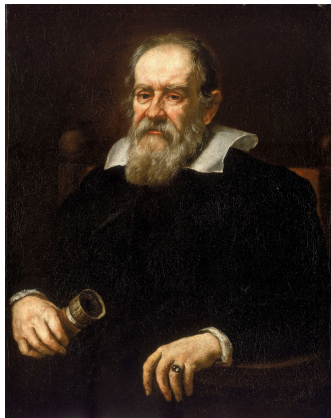
1619: *Harmonice Mundi*



Galileo Galilei, Italian, 1564–1642

Experiments on falling bodies

1610: Discovered moons of Jupiter



Christiaan Huygens, Dutch, 1629–1695

1657: Invented of the first mechanical clock

1662: Built his own telescope and discovered the rings of Saturn

1690: *Traité de la Lumière* (proposed a wave theory of light)



Isaac Newton, British, 1643–1727

1664–66: Invented integral and differential calculus

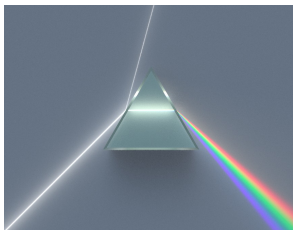
1665: Formulated his Laws of Motion ($F = ma$, etc.), first published in *Principia* (1687)

1666: Proposed the inverse-square law of gravity and derived Kepler's laws from it

1668: Invented and built his own *reflecting* telescope

1687: *Philosophiæ Naturalis Principia Mathematica*

1707: *Opticks* (proposed a corpuscular theory of light)



Ole Rømer, Danish, 1644–1710

1676: Based on the astronomical observations of the occultations of Jupiter's moon *Io*, determined that light would take 22 minutes of travel a distance equal to the diameter of Earth's orbit around the Sun. That's about 226,663 km/sec. The correct value is 299,792 km/s.

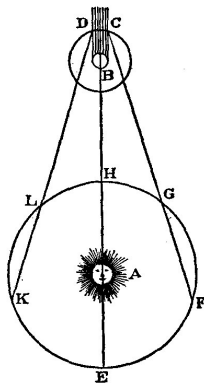


FIG. 70.



Leonhard Euler, Swiss/Russian, 1707–1783

Transitioned from Newton's particle dynamics to the motion of rigid bodies and fluids

The equations of motion of an ideal incompressible fluid, known as *Euler's equations of fluid dynamics*

$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{b}$$
$$\operatorname{div} \mathbf{v} = 0$$

$\mathbf{v}$: velocity

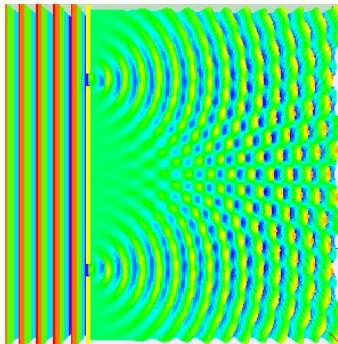
p : pressure

$\mathbf{b}$: force per unit mass



Thomas Young, British, 1773–1829

1801: The double-slit experiment



Experiment agreed with Huygens' wave theory of light and disagreed with Newton's corpuscular theory of light, and thus lead to the concept of *luminiferous ether*.

Augustin-Louis Cauchy, French, 1789–1857

Major innovations and advances in

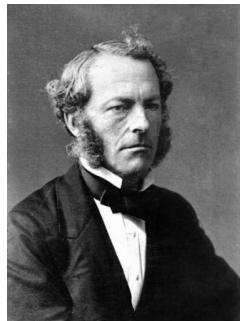
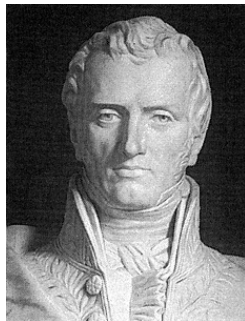
- ▶ Introduced the $\delta - \epsilon$ analysis of limits
- ▶ Real and Complex Analysis
- ▶ Number Theory
- ▶ Continuum Mechanics
- ▶ Propagation of light through luminiferous ether



Lamé, Navier and Stokes

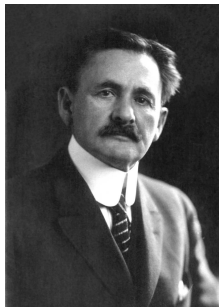
By the mid-1800s many of the immediate questions in continuum mechanics were answered. Major players in the area were

- ▶ *Gabriel Lamé*, French, 1795–1880
- ▶ *Claude-Louis Navier*, French, 1785–1836
- ▶ *George Gabriel Stokes*, French, 1819–1903



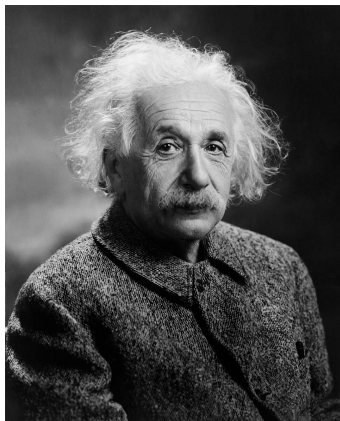
Albert Michelson, Polish/American, 1852–1931

- 1879 Experiment at USNA set the speed of light at $299,910 \pm 50$ km/s, improving the 298,000 km/s found by *Léon Foucault* in 1862.
- 1887 The Michelson–Morley experiment at *Case School of Applied Science* in Cleveland failed to detect evidence of luminiferous ether.



Albert Einstein, German/American, 1879–1955

- 1905 Special Theory of Relativity: no need for the luminiferous ether
- 1916 General Theory of Relativity: extensive use of tensor



Ronald Rivlin, British/American, 1915–2005

Series of articles during 1947–1955 established the mathematical foundations of modern continuum mechanics

- ▶ Finite strain theory
- ▶ Neo-Hookean solids
- ▶ Mooney–Rivlin solid
- ▶ Rivlin–Ericksen tensor
- ▶ Hyperelasticity



Clifford Truesdell, American, 1919–2000

Prolific writer, historian of science, and the torch-bearer of the modern continuum mechanics

1952 *The mechanical foundations of elasticity and fluid dynamics*

1960 *Classical Field Theories of Mechanics*

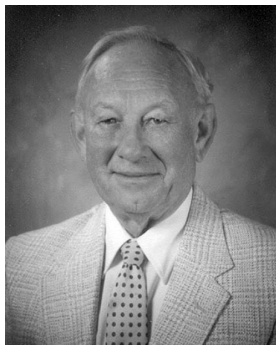
1965 *Non-linear Field Theories of Mechanics*



Jerald Ericksen, American, 1924–2021

Major contributor to modern continuum mechanics. Known for

- ▶ Rivlin–Ericksen tensor
- ▶ Rivlin–Ericksen representation
- ▶ Rivlin–Ericksen model of viscoelasticity
- ▶ Theory of liquid crystals

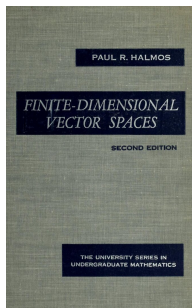
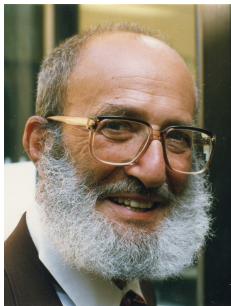


Paul Halmos, Hungarian/American, 1916–2006

Functional analysis, probability, measure theory, ergodic theory

1958: *Finite-Dimensional Vector Spaces*

“My purpose in this book is to treat linear transformations on finite-dimensional vector spaces by the methods of more general theories.”



The classical equations of continuum mechanics

Euler's equations of motion of an ideal incompressible fluid

$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = -\frac{1}{\rho} \nabla p + \mathbf{b}$$

$$\operatorname{div} \mathbf{v} = 0$$

The Navier–Stokes equations of motion of a viscous incompressible fluid

$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = \nu \Delta \mathbf{v} - \frac{1}{\rho} \nabla p + \mathbf{b}$$

$$\operatorname{div} \mathbf{v} = 0$$

The equations of motion of a viscous compressible fluid

$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = \mu \Delta \mathbf{v} + (\mu + \lambda) \nabla \operatorname{div} \mathbf{v} - \nabla p + \rho \mathbf{b}$$

$$\frac{\partial \rho}{\partial t} + \operatorname{div}(\rho \mathbf{v}) = 0$$

The Lamé equations of linear isotropic elasticity ($\mathbf{u}$ = displacement)

$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \mu \Delta \mathbf{u} + (\mu + \lambda) \nabla \operatorname{div} \mathbf{u} + \rho \mathbf{b}$$