Isaak Newton
Bringing Mathematics to Physics

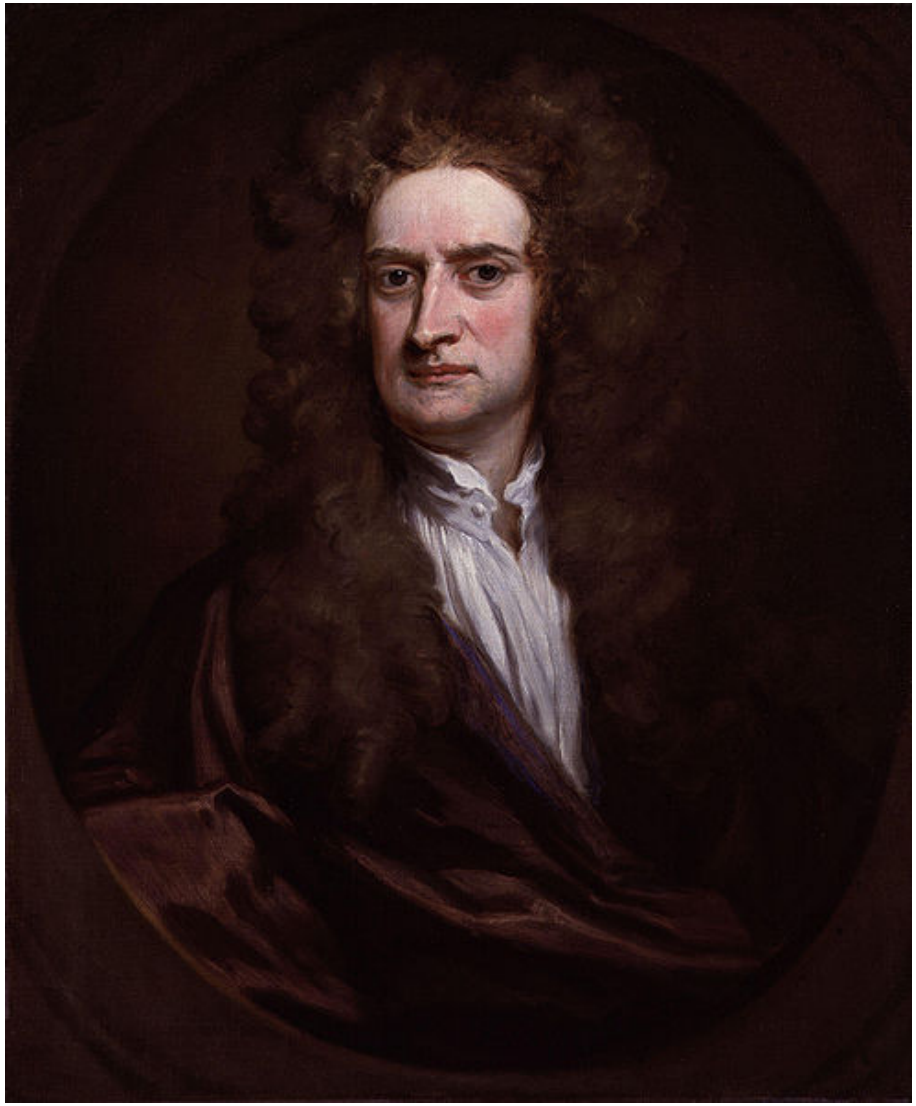
Peter Hertel

University of Osnabrück, Germany

Lecture presented at APS, Nankai University, China

`http://www.home.uni-osnabrueck.de/phertel`

Spring 2012



Isaak Newton, 1643–1727

His signature

Environment

- During Newton's lifetime (1643–1727) ...
- England, Scotland, Wales and Northern Ireland were united in personal union by James VI
- In 1707 the United Kingdom (Great Britain) was founded
- With a constitution and a common parliament
- The Anglican Church was the official church of the country
- The British Navy had won decisive battles over Spain
- ... Britannia rules the waves
- London then the most important city of the world
- Before: zero longitude fixed at Canarian Island El Hierro
- Later: at Royal Observatory at Greenwich (London)
- Outstanding universities at Oxford, Cambridge and Edinburgh

United Kingdom, as of Newton's later years

The Spanish armada repeatedly beaten in the Anglo-Spanish war 1585–1604

Britannia rules the waves.

Canary islands.

The Royal Observatory at Greenwich.

Mathematics and Physics in the UK

- Practical needs often drive scientific progress
- Henry Briggs: 1561–1630
- Arithmetica Logarithmica, 1624
- Tables of the logarithms of sines and tangents, 1631
- Robert Hooke: 1635–1703
- linear relation between stress and strain
- constructional mechanics
- spring-balance watch (Huygens?)
- urgently required for navigation
- Means of transportation were ships and coaches drawn by horses,
- or riding a horse
- Royal Mail since 1516

Early life

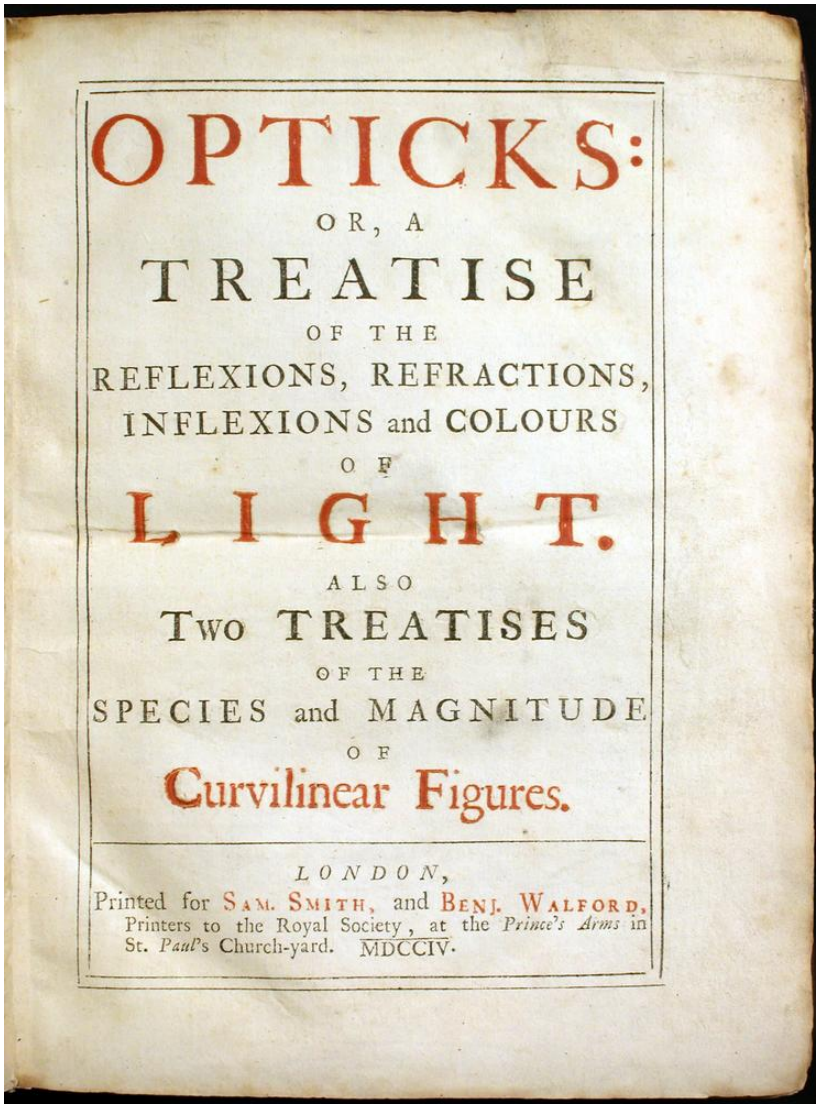
- Born at Christmas day 1642 (Julian Calender)
- January 1643 (Gregorian Calender)
- His father, a wealthy farmer, was already dead since three months
- Born prematurely, he was very tiny
- At the age of three, his mother re-married, and he was cared for by his grand-mother
- Went to school at King's College at Grantham
- Had to leave school with 16 because his newly widowed mother wanted him to become a farmer
- He hated farming,
- Was sent back to school to complete his education as pressured by the headmaster

University

- Newton, 18 years old, was admitted to Trinity College at Cambridge
- Studying Aristotle, Descartes, Copernicus, Kepler and Galilei
- Works on his theory of infinitesimal calculus
- Degree in 1665
- University closed for two years, precaution against the Great Plague
- Studying at home for the next two years
- Calculus
- Optics
- Gravitation
- Return to Trinity as a fellow (assistant professor)

Trinity college

The Great Plague, 1665-1666



OPTICKS:

OR, A

TREATISE

OF THE

REFLEXIONS, REFRACTIONS,

INFLEXIONS and COLOURS

OF

LIGHT.

ALSO

Two TREATISES

OF THE

SPECIES and MAGNITUDE

OF

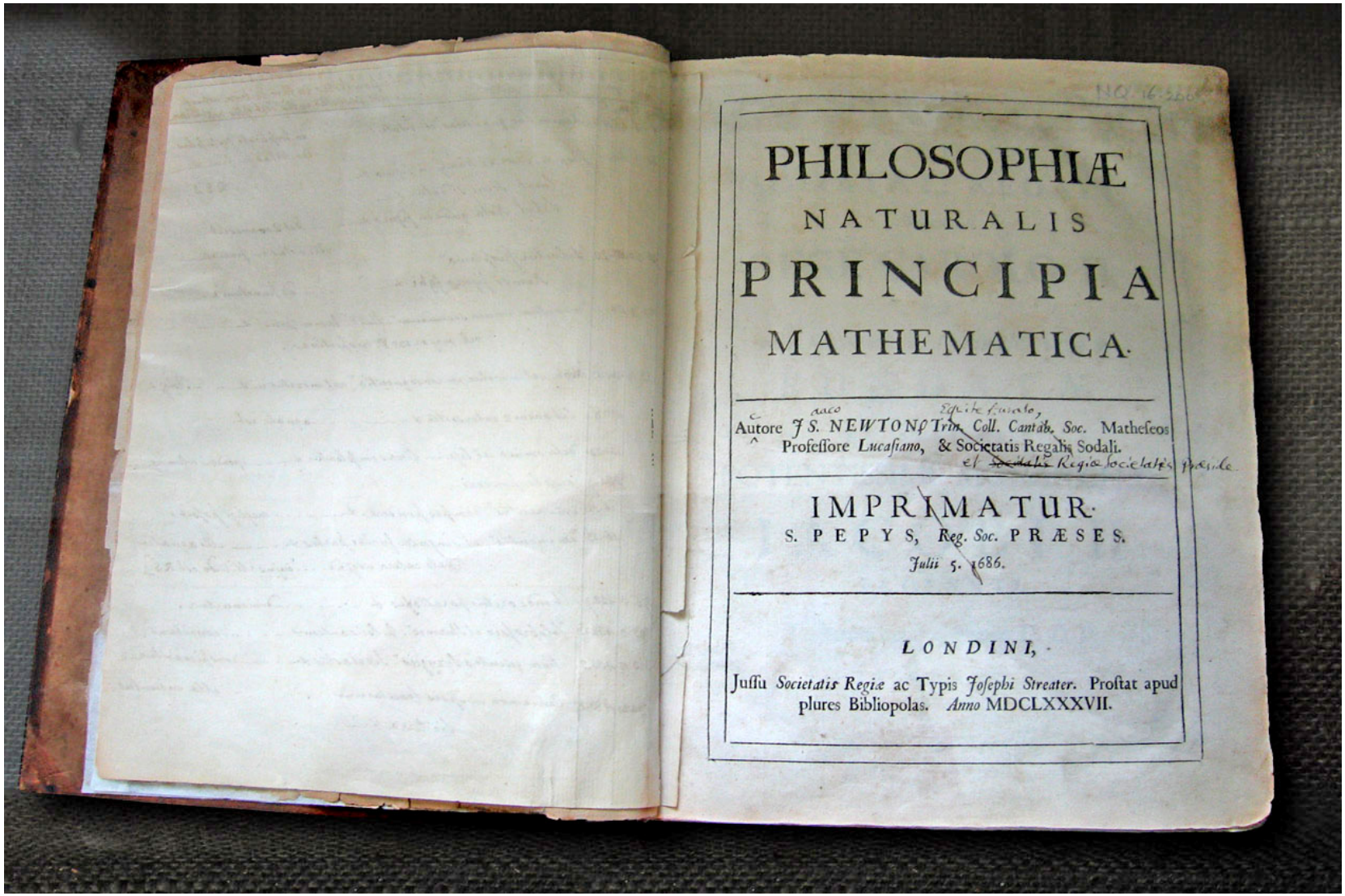
Curvilinear Figures.

LONDON,

Printed for SAM. SMITH, and BENJ. WALFORD,

Printers to the Royal Society, at the *Prince's Arms* in St. *Paul's* Church-yard. MDCCIV.

Opticks, printed in 1704, London



Newtons own copy with corrections

Leibniz or Newton?

- There was a bitter dispute on who had invented the differential calculus
- Today, most historians are convinced that Newton and Leibniz developed calculus independently
- However, Leibniz's notation lives up to now
- for $f = f(t)$ we write
  $$\dot{f}(t) = \frac{\mathrm{d}f(t)}{\mathrm{d}t}$$
- according to Newton (left) and Leibniz (right)
- Leibniz's infinitesimals $\mathrm{d}f$ make infinitesimal calculus simple, such as
  $$(f + \mathrm{d}f)(g + \mathrm{d}g) = fg + g\mathrm{d}f + f\mathrm{d}g + \ldots$$
- resulting in
  $$\frac{\mathrm{d}(fg)}{\mathrm{d}x} = g\frac{\mathrm{d}f}{\mathrm{d}x} + f\frac{\mathrm{d}g}{\mathrm{d}x}$$

Newton or Leibniz?

- Both interpreted the derivative as the slope of a tangent
- Both derived the laws for differentiating sums, products and fractions of functions
- The derivative of an inverse function is very easy to work out in Leibniz's notation
- Both knew the fundamental theorem of calculus:

  $$f(b) - f(a) = \int_a^b \mathrm{d}x \, \frac{\mathrm{d}f(x)}{\mathrm{d}x}$$

  and interpreted the integral as we do now
- Leibniz published in scholarly Latin, in French and in German
- the integral sign stands for "somme" in French, or sum

Gottfried Wilhelm Leibniz, 1646–1716

A calculation device invented by Leibniz.

Finding roots by iteration

- An invention by Newton
- Look for the zeros of a function $f = f(x)$
- Guess an initial value x_1
- Iterate

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

- Example $f(x) = x^2 - y$
- solution is $x = \sqrt{y}$
- iteration boils down to

$$x_{n+1} = \frac{x_n^2 - y}{2x_n}$$

- $x_0 = 1$, $y = 2$
- 1.500000000, 1.416666667, 1.414215868 ...
- 1.414213562 remains stable (10 digits)

Gravitation

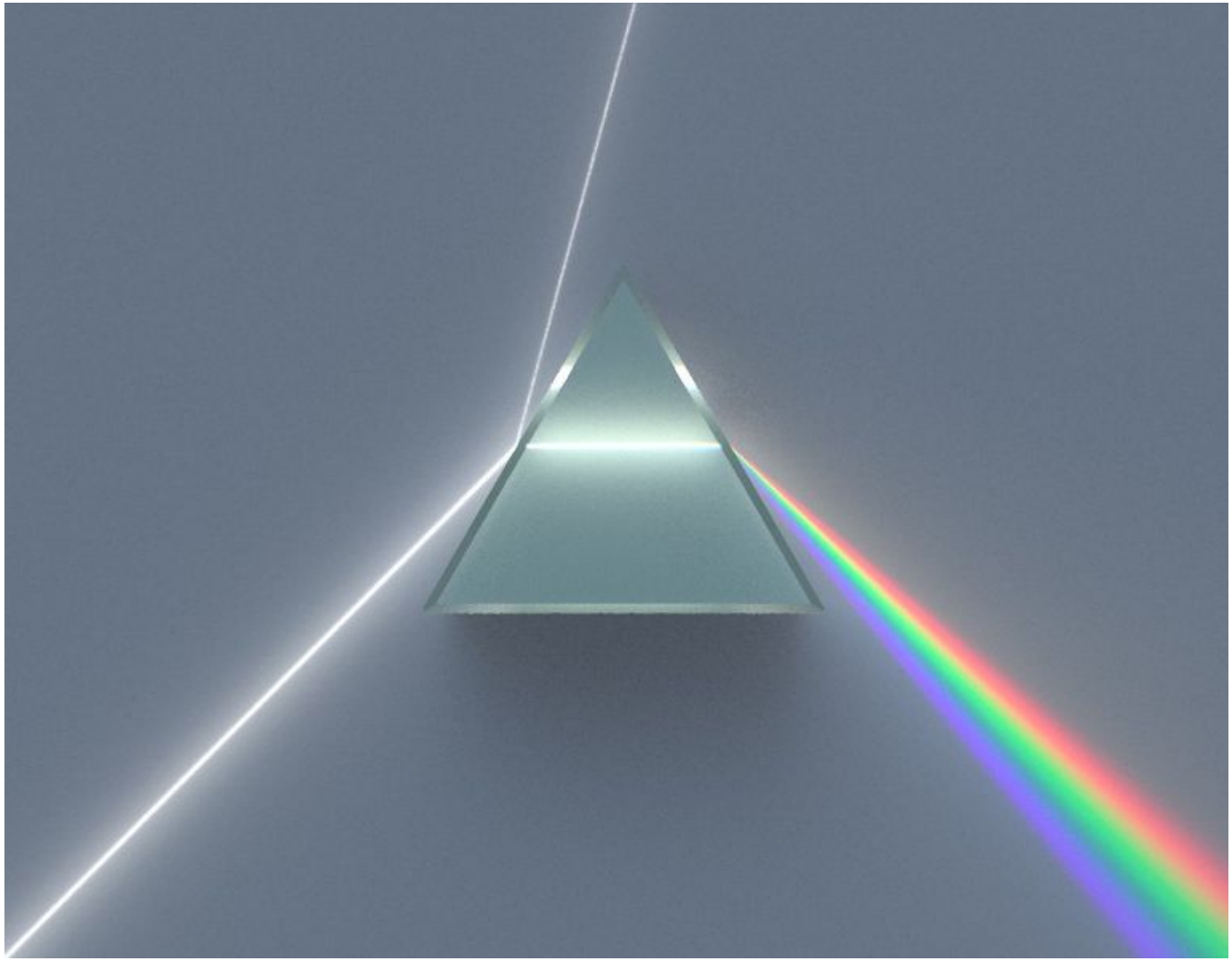
- Today it is simple
- Use frame of reference where $\ddot{\boldsymbol{x}} = 0$ if there are no forces (inertial frame)
- Momentum $\boldsymbol{p} = m\dot{\boldsymbol{x}}$ where m is the mass of the body
- $\dot{\boldsymbol{p}} = \boldsymbol{F}$ where F is a physical force
- The force exerted by a mass M at $\boldsymbol{X}$ on another mass m at $\boldsymbol{x}$ is
$$\boldsymbol{F} = -\frac{GMm(\boldsymbol{x} - \boldsymbol{X})}{|\boldsymbol{x} - \boldsymbol{X}|^3}$$
- attractive $1/r^2$ law, *actio=reactio*, proportionality to m and M highly plausible
- Newton could explain Keplers's findings.

The famous apple

- Gravitation is universal: masses attract each other
- The sun the planets
- The planets their moons
- The earth the apples on a tree
- Explanation of Kepler's law
- Spherical mass distribution acts
- as if all the mass were concentrated at its center
- hence
  $$g = \frac{GM}{R^2}$$
  where M and R are mass and radius of the earth
- g depends only weakly on height

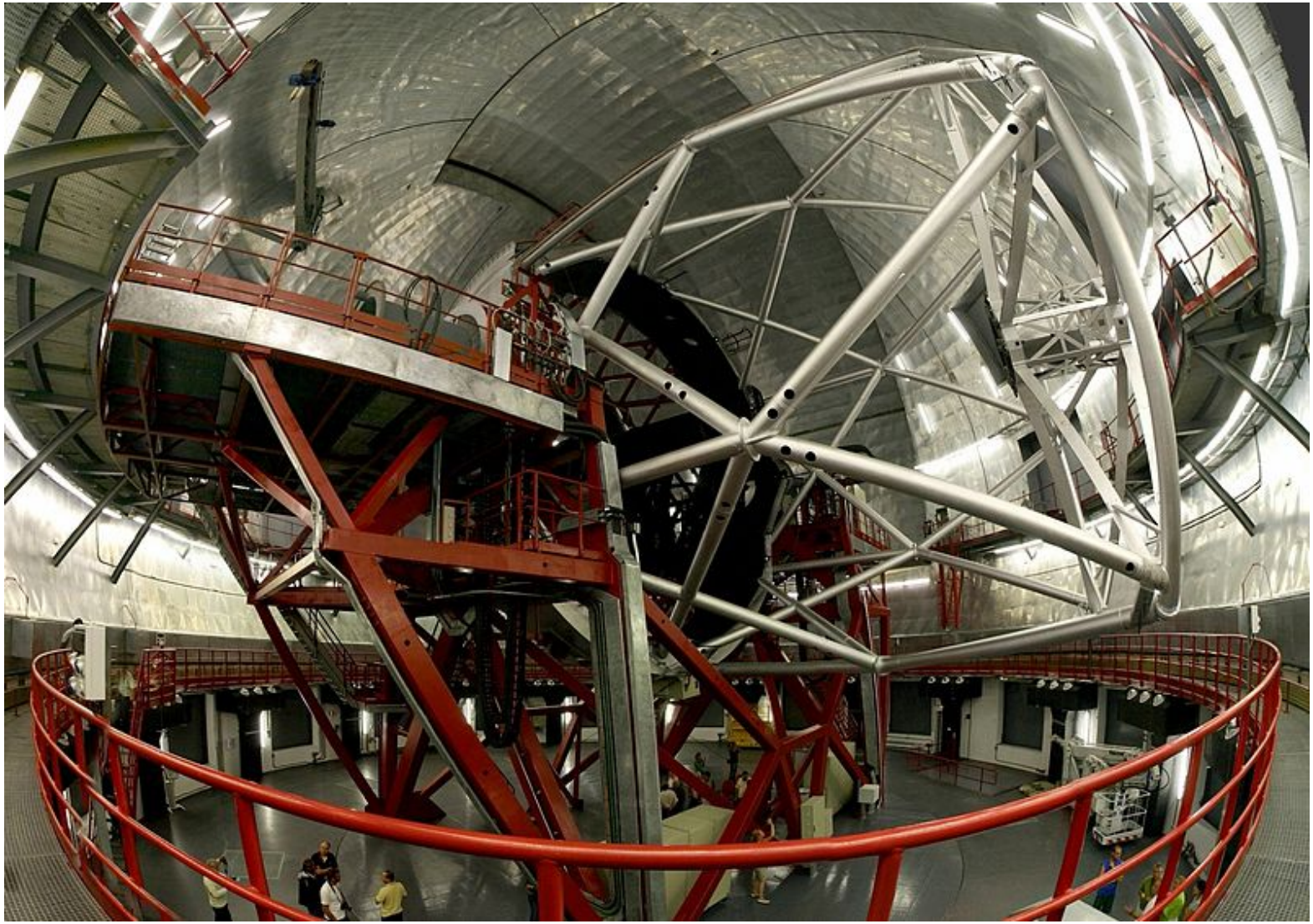
Optics

- 1670–1672 Lectures on optics
- Decomposition of white light into colors by a prism
- Composition of the colors into white light by another prism or a lense
- Color is a property of light, not of objects
- Refractor telescope suffers from dispersion
- Reflector telescope (Newton's telescope)
- Demonstration to the Royal Society
- Newton's rings

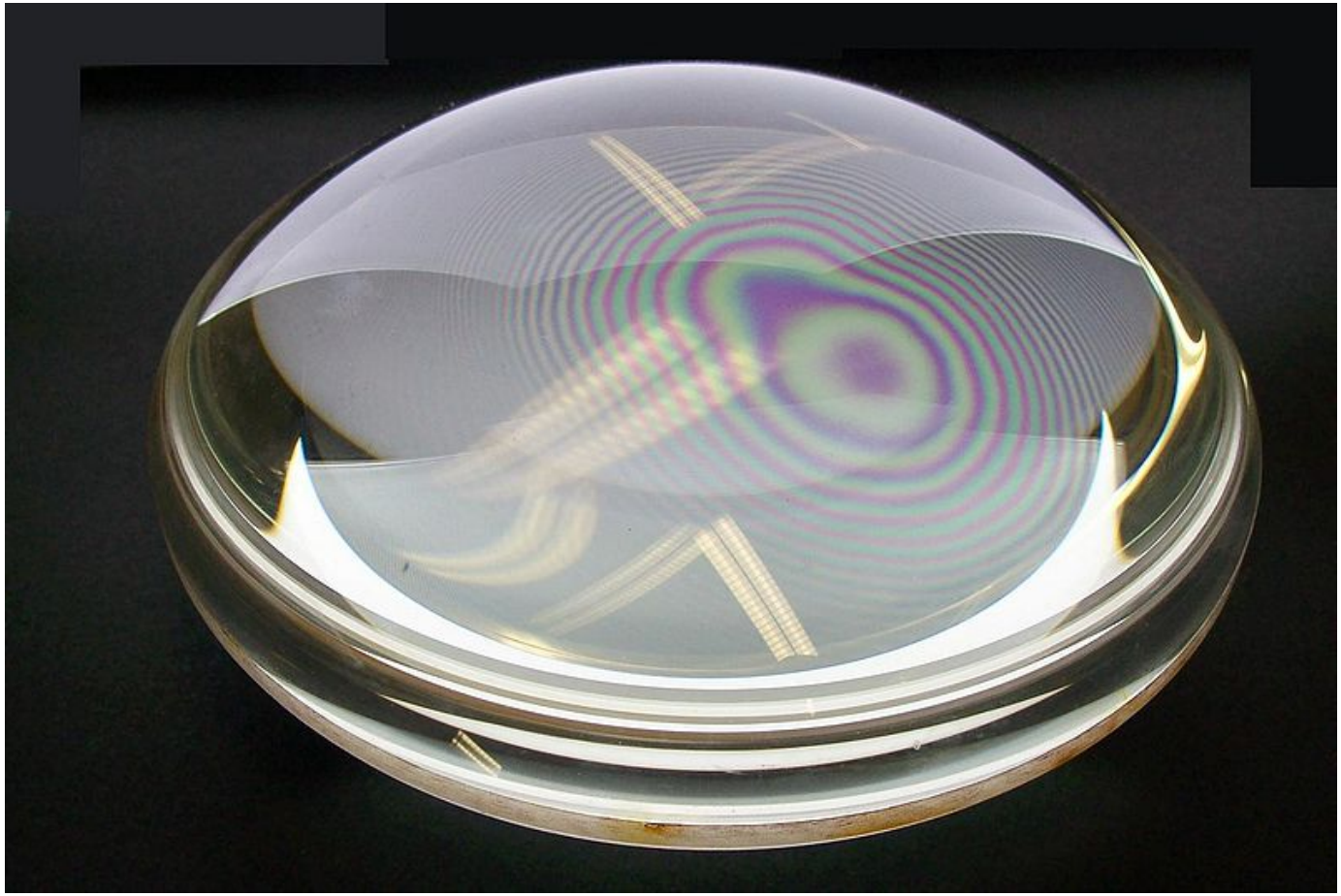


Newton discovered that white light is composed of colored light.

Telescope shown to the Royal Society (replica)



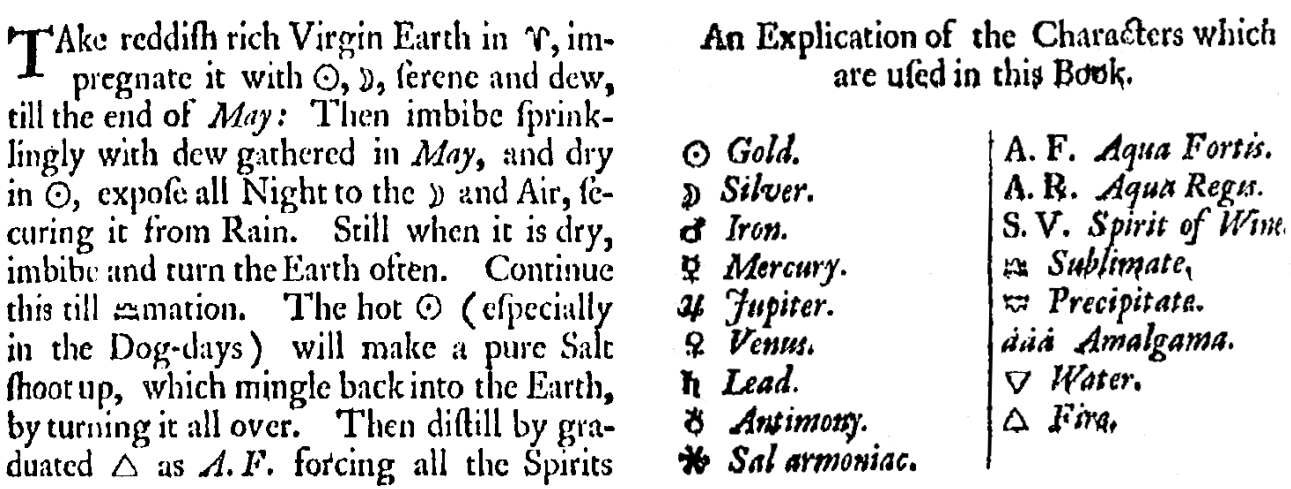
Largest telescope GTC as of 2010 at La Palma, Canary islands. The mirror has a diameter of 10.4 m. It consists of 36 segments which are adjusted individually.



Newton's rings

Later life

- Religious tracts
- Alchemy
- Elected to represent Cambridge University in Parliament of England (1689–90, 1701)
- mentioned only once in the records ...
- demanding to close the window because of draught
- was appointed as Master of the Mint (1696)
- Although a *sinecure* (paid job without duty)
- Newton took the job serious, retiring from Cambridge and moving to London
- fighting counterfeiting
- changed the pound Sterling from silver to gold standard



TAke reddiſh rich Virgin Earth in ♈, impregnate it with ☉, ☽, ſerene and dew, till the end of *May:* Then imbibe ſprinklingly with dew gathered in *May*, and dry in ☉, expoſe all Night to the ☽ and Air, ſecuring it from Rain. Still when it is dry, imbibe and turn the Earth often. Continue this till ♎mation. The hot ☉ (eſpecially in the Dog-days) will make a pure Salt ſhoot up, which mingle back into the Earth, by turning it all over. Then diſtill by graduated △ as *A. F.* forcing all the Spirits

An Explication of the Characters which are uſed in this Book.

☉ *Gold.*
☽ *Silver.*
♂ *Iron.*
☿ *Mercury.*
♃ *Jupiter.*
♀ *Venus.*
♄ *Lead.*
♁ *Antimony.*
✱ *Sal armoniac.*

A. F. *Aqua Fortis.*
A. R. *Aqua Regis.*
S. V. *Spirit of Wine.*
♎ *Sublimate,*
♍ *Precipitate.*
♃♀ *Amalgama.*
▽ *Water.*
△ *Fire.*

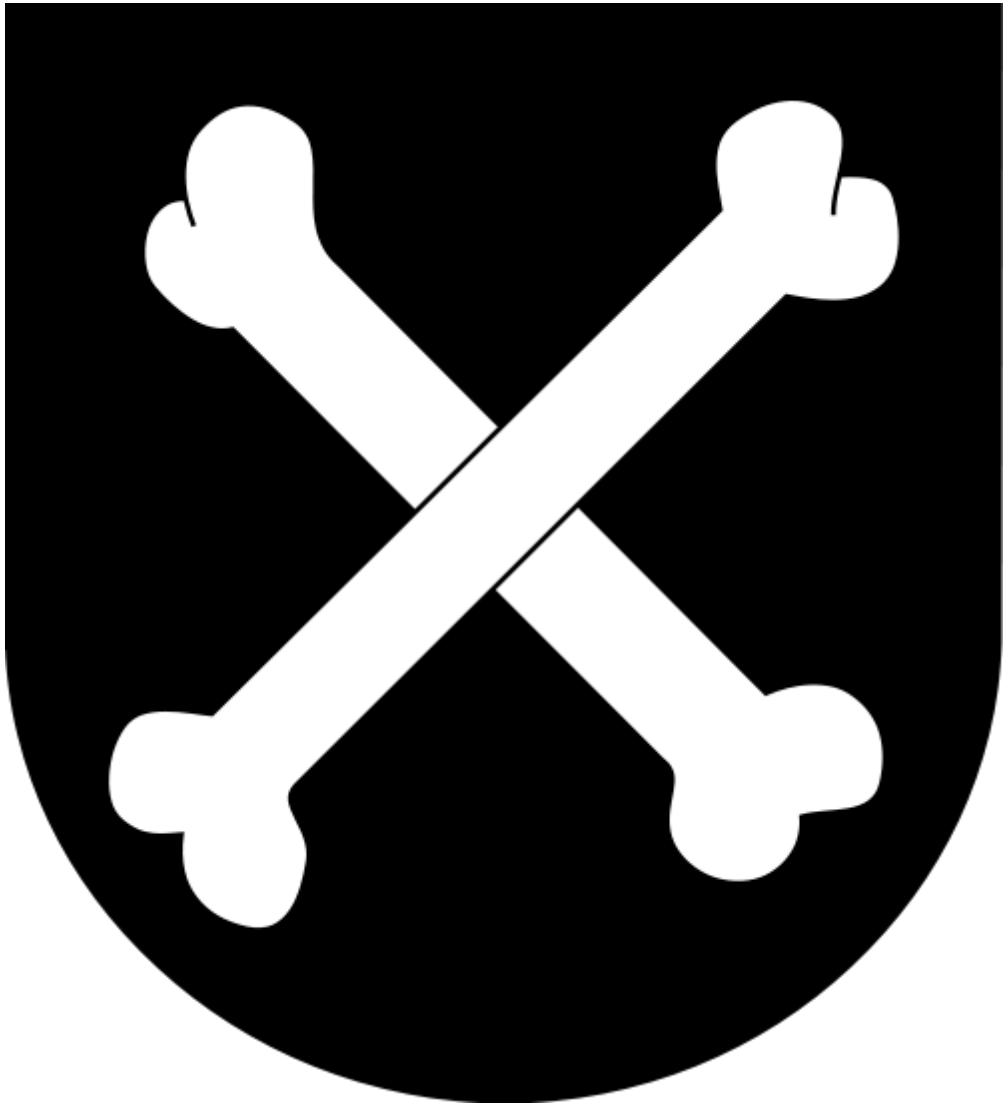
Alchemy recipies

British Parliament

The Tower of London, also seat of the mint.

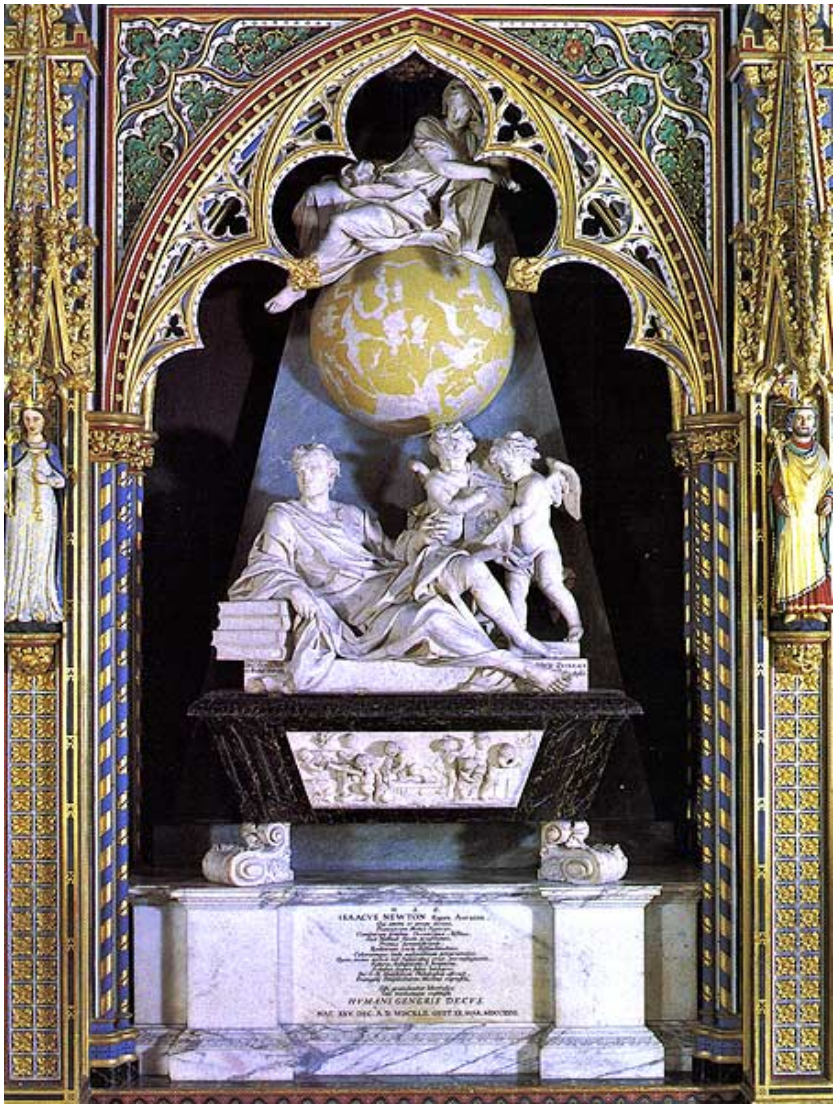
Honors

- Was elected President of the Royal Society, 1703–1727
- Associated member of the French Académie des Sciences
- Queen Anne knighted him in 1705
- probably not for his merits, but for political reasons
- shortly before parliamentary elections
- Sir Isaak Newton was the second scientist (after Sir Francis Bacon)
- Died in sleep, 1727
- Considerable amount of mercury found in his hair (alchemy?)
- Buried at Westminster Abbey
- Later Charles Darwin was buried there close by



Sir Isaak Newton, coat of arms.

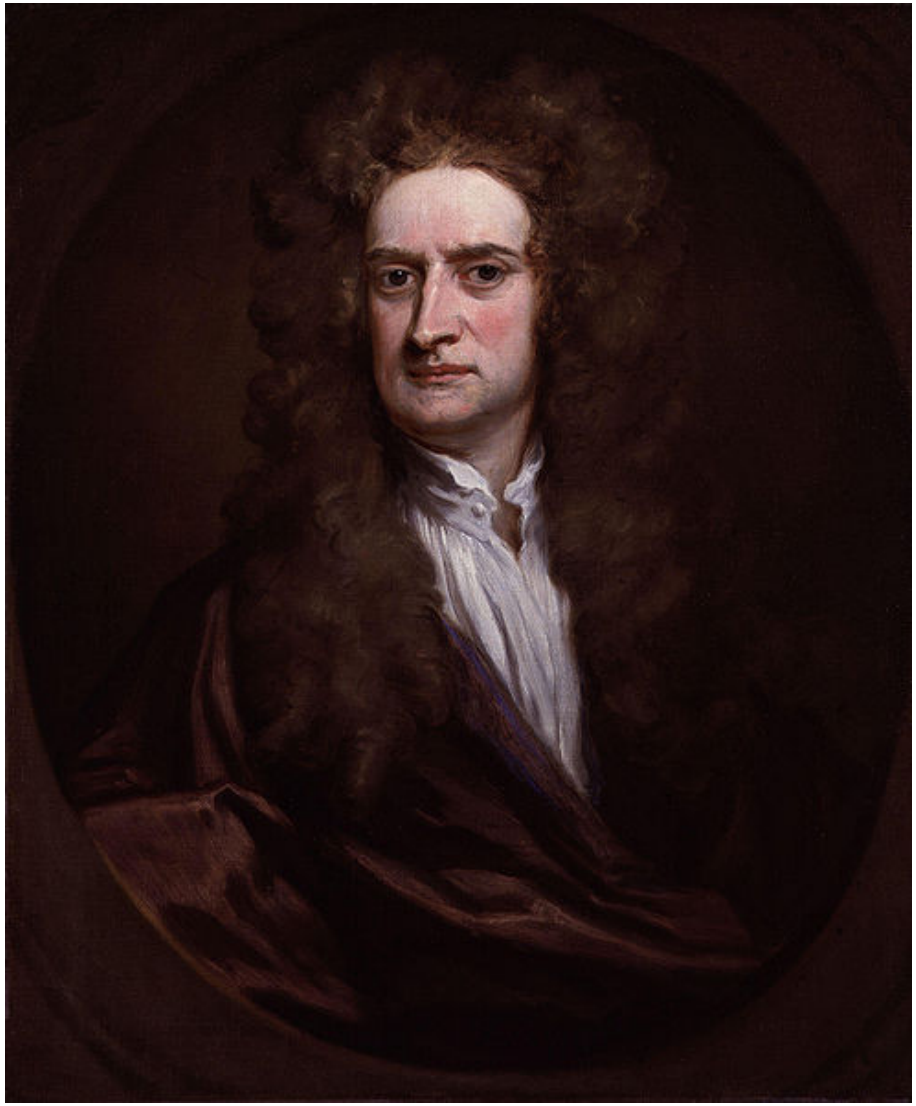
Westminser Abbey



Newton's tomb in Westminster Abbey

I could see further because I was standing on the shoulders of giants.

Galileo Galilei, 1564–1642



Isaak Newton, 1643–1727