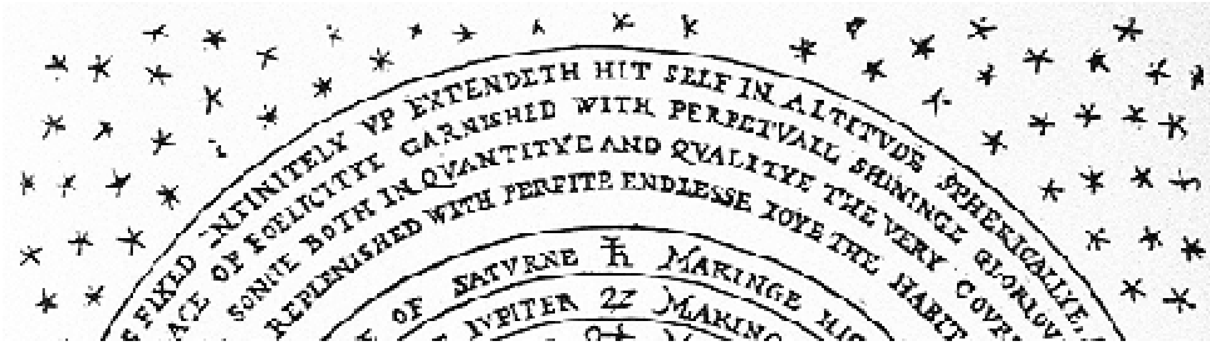


PHY1033C/HIS3931/IDH 3931 : Discovering Physics:

The Universe and Humanity's Place in It

Fall 2016

Prof. Peter Hirschfeld, Physics

Developments of and Challenges to Newton's Achievement

Last time

The legend of the apple
The problem of the moon's motion
Newton's strategy and his solution to the problem
Analysis of the strategy

Today

The controversy over vis viva
- Descartes's measure and Huygens addition
- Leibniz's critique of Descartes's measure
- 'sGravesande's experimental confirmation of Leibniz's vis viva

Challenges to Newton's Achievement
- The shape of the earth
- The three body problem
- The return of Halley's Comet
- The secular acceleration of the moon

By the 1720s 3 natural philosophical traditions had emerged: differed on "what is the nature of force"

Cartesians:

contact forces only, all agencies material

Leibnizians:

physical world is like clock run by God

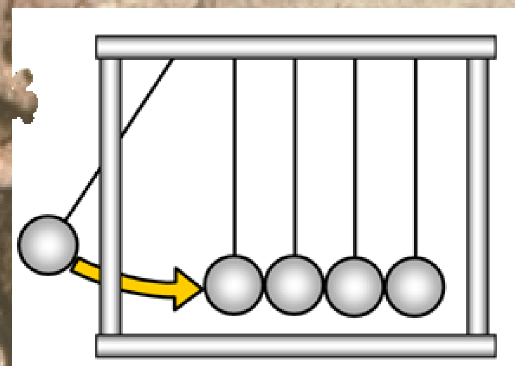
Both criticize Newton's "occult force"!

Newtonians:

Gravity was effect, not cause

The theological origin of the vis viva controversy

God “conserves the world in the same action with which he created it.”
Rene Descartes



The problem of measuring the force of motion: what are the factors?

Descartes’s candidate: mv

Problems with mv and Huygens addendum

Leibniz's critique of Descartes (and Huygens)

Actual motion can really be lost in Descartes and Huygens

Leibniz's candidate for the measure of force of motion

force of motion $= ½ mv^2$

He called it *viv viva*

Can never be negative, so no *vis viva* can be lost

Clearly we're not talking about just force, a push or pull

Said we should think of force of motion in terms of its ***effect***, or ***damage done*** by moving mass

Willem 's Gravesande

Showed that a mass m dropped from a height h made a certain size dent in clay

Mass ½ m (same size and shape) dropped from 2h made **same** dent

Descartes's formula does not work. It would say

Case 1 → mv

Case 2 → $\frac{1}{2} m \sqrt{2}\, v$

Leibniz gets same result in both cases

Questioning Newton in the 18th century

I The shape of the earth

II The inverse square law

III The return of Halley's Comet

IV The secular acceleration of the moon

I

Controversy over the shape of the earth

1718 extensive mapping of France showed longitudinal lines were unequal as one traveled north

"If the earth is an oblate spheroid, the length of a degree of longitude must increase from the equator to the poles; if it is prolate, that is, elongated, then a degree decreases near the poles."

Joseph Konvitz, *Cartography in France,1660-1848*, p. 10

Oblate spheroid

Newton (and Huygens) had argued that the earth was flattened at the poles

The French measurements meant that the earth was a prolate spheroid

Prolate spheroid

Belonged to the Newton party in France in 1730s

Styled the question of earth’s shape as a contest between Newtonians and Cartesians (when it wasn’t)

Headed an expedition to Lapland 1736-1737 to measure degree of longitudinal ar

Announced result as victory for Newton

Pierre-Louis Moreau de Maupertuis

II

Correcting the Inverse Square Law

Alexis Claude Clairaut
1713-1765

1747: Clairaut to French Academy
Newton ignored the Sun
in solving the moon's motion

Taking it into account might
help solve some irregularities
in the moon's motion

The three body problem - requires
approximating a solution

When approximations were made
the results put the moon in positions
it was not observed to be

Inverse square law needs correcting

$$\frac{1}{r^2} + \frac{1}{r^4}$$

A year later Clairaut realized that a what he thought was a harmless assumption he'd made when making the approximation was actually not so (others working on the approximation had made the same allegedly harmless assumption as well).

When he corrected his error the approximation turned out to put the Moon right where it was supposed to be and no correction of Newton's inverse square law was needed after all

III

The return of Halley's Comet

Back in the 17th century Edmund Halley argued that a comet that had come by in 1682 had appeared four times before and would return again in the late 1750s

He refused to be precise because this time the comet would pass close to Jupiter and Saturn and its orbit would be affected by the gravitational pull of those masses

Based on the periods of the earlier sightings it was assumed that the comet would appear sometime in 1758.

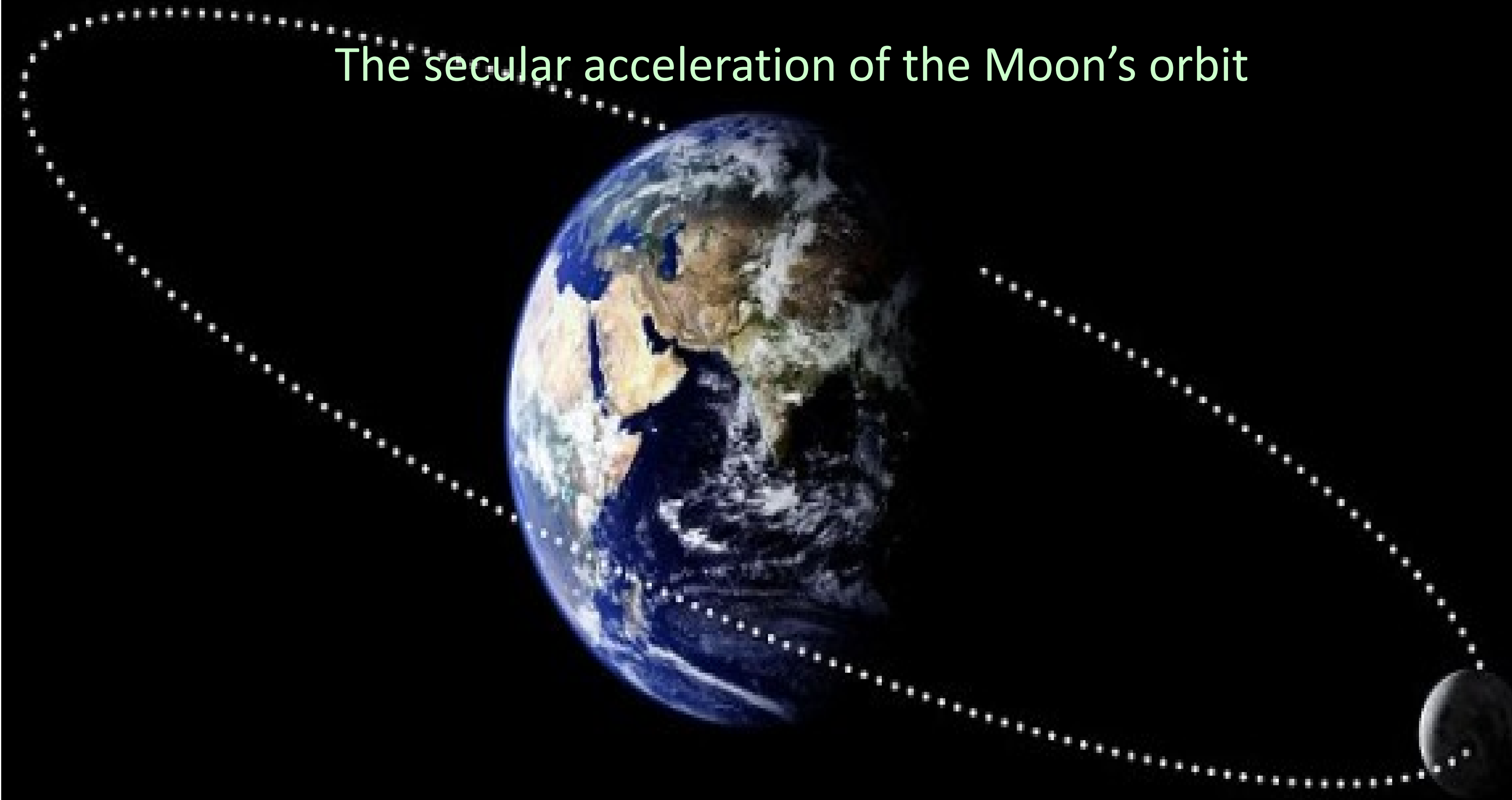
Clairaut, an expert on the three-body problem, took the masses of Jupiter and Saturn into account and announced in the fall of 1758 that the comet would not appear near the Sun until the spring of 1759 – within 30 days of April 15.

The comet appeared on March 13, 2 days outside the predicted time.

Clairaut’s prediction, which was based on Newton’s mechanics, raised Newton’s stature even higher than it already was.

IV

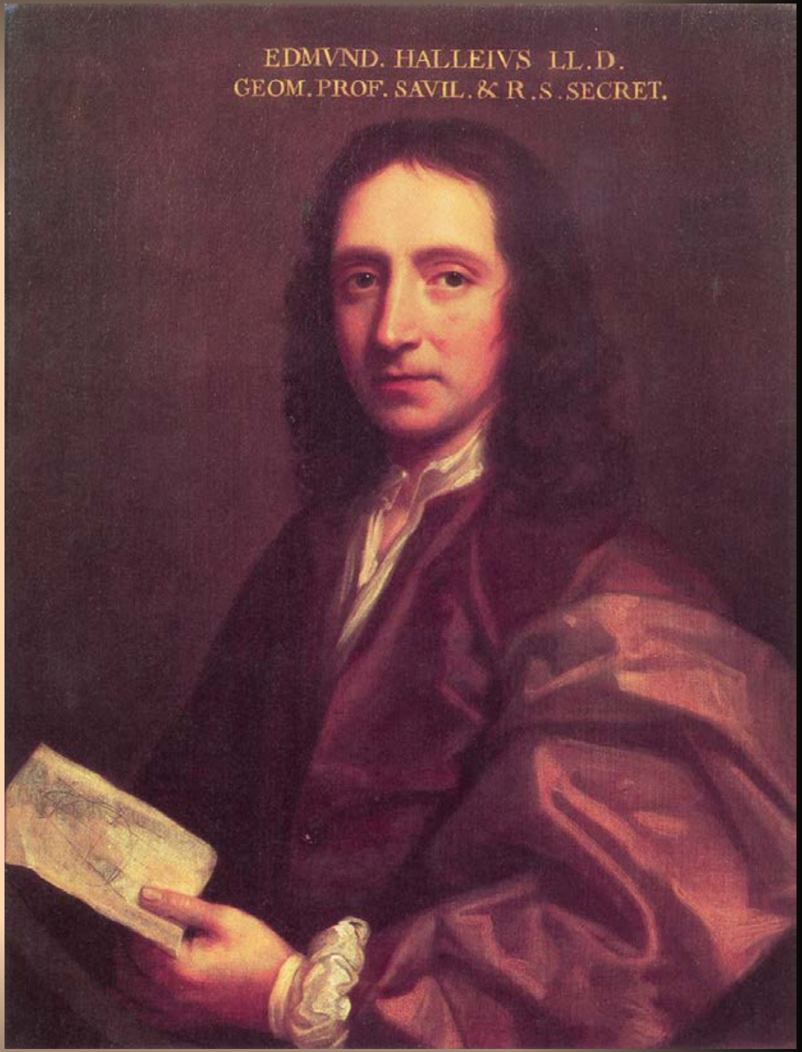
The secular acceleration of the Moon’s orbit



Halley's study of ancient eclipses revealed that if the Newtonian machinery was run backward, it would put ancient eclipses at a different time than when they were recorded to have occurred

Should we mistrust Newton's mechanics or the ancient datings?

Halley: If the Moon's orbit was slowly shrinking, it would correct the machinery to be consistent with the datings



Edmund Halley

Pierre Simon Laplace

The Frenchman Pierre Simon Laplace took up the problem In the late 1780s

He showed that a gravitational effect of the planets resulted in a change of the earth's orbit that in turn produced a *slow acting* (secular) effect from the sun on the Moon's orbit, shrinking it

This result seemed to threaten the stability of the solar system

But Laplace showed that after a very long time the orbit would begin expanding again – the stability of the solar system was assured

By the end of the 18th century Newton’s reputation had risen to heroic proportions and his system of the heavens was seen as a testimony to human genius

Flammarion engraving 1888

We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

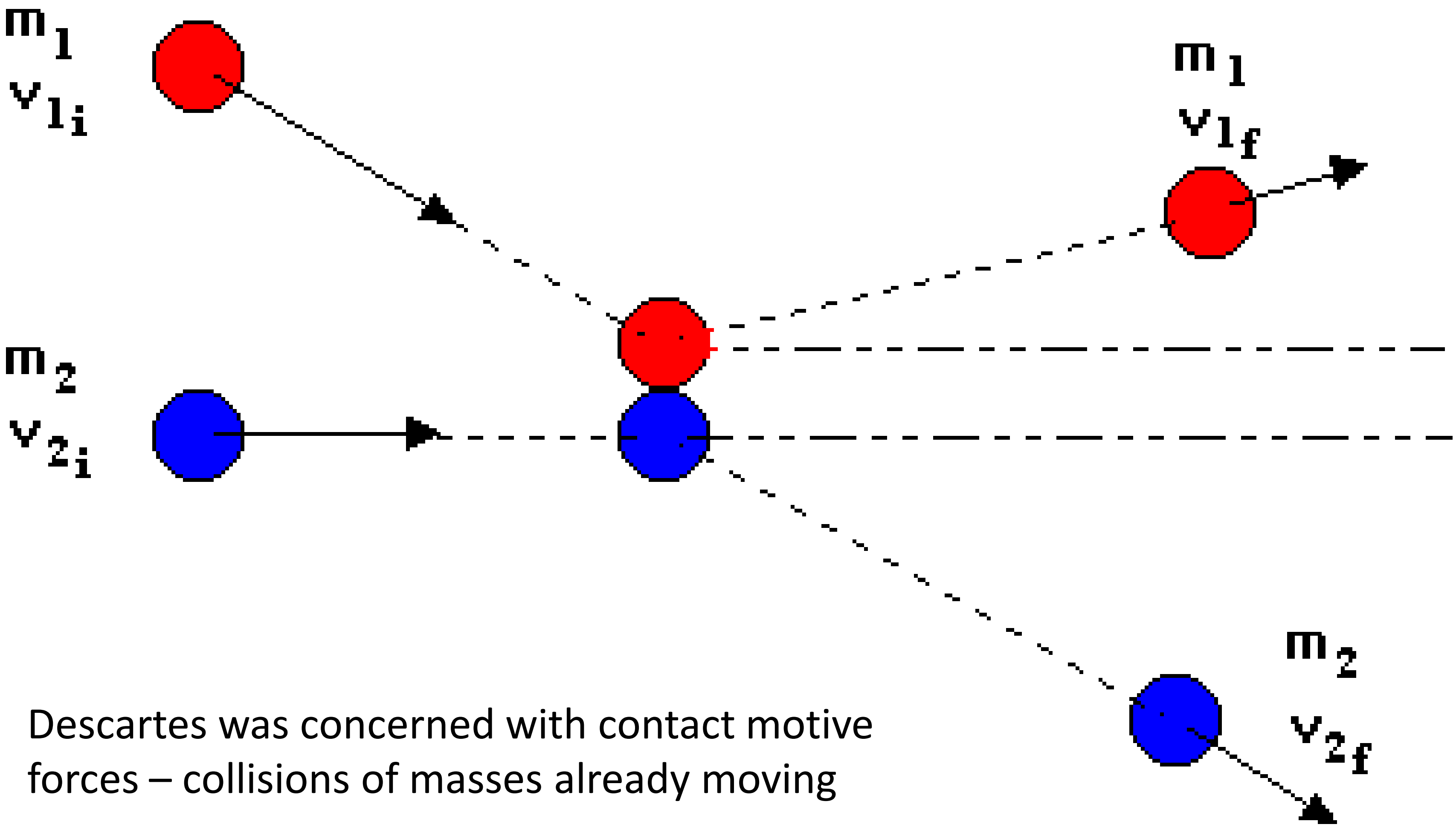
— *Pierre Simon Laplace, A Philosophical Essay on Probabilities*

The infinite universe that Laplace showed was stable and eternal

It was a mechanical clockwork universe that had and would continue to tick along

As Halley had shown in the problem sof the shrinking of the Moon's orbit and the prediction of his comet's reappearance, you could run the Newtonian mechanism of the heaven backwards as well as forwards

Newtonian celestial mechanics was, in other words, reversible



Descartes was concerned with contact motive forces – collisions of masses already moving

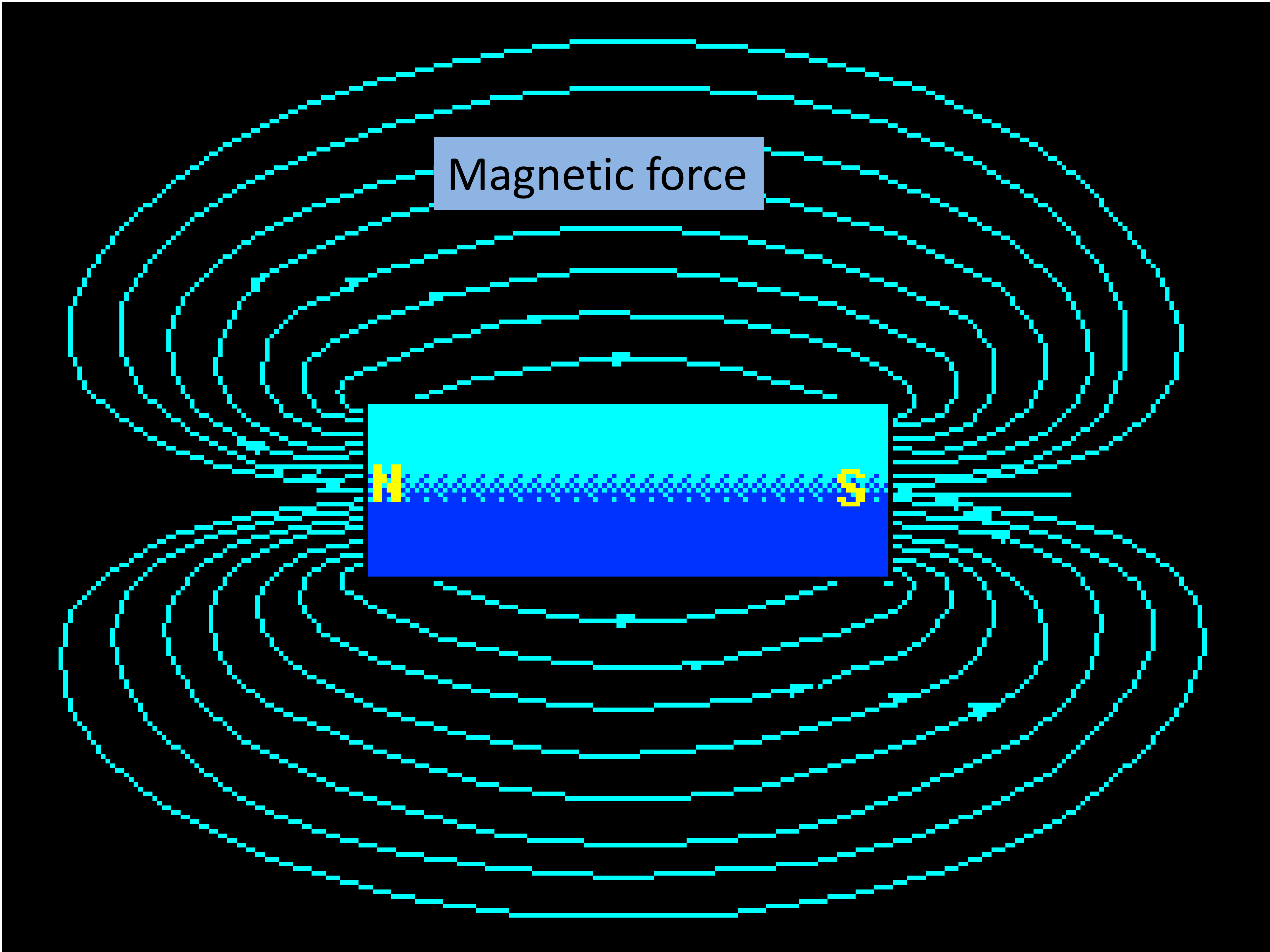
In the wake of debates about *vis viva*, natural philosophers became interested in other forces that were a counterpart to "living forces"

These "dead" forces were exerted on matter but did not result in the motion of matter unless they were converted into motive force

As they investigated these forces they discovered that there were numerous ways in which they were interconvertible

What were these forces?

Electrical force


Magnetic force
N
S


Chemical force
Thermal force

Optical force