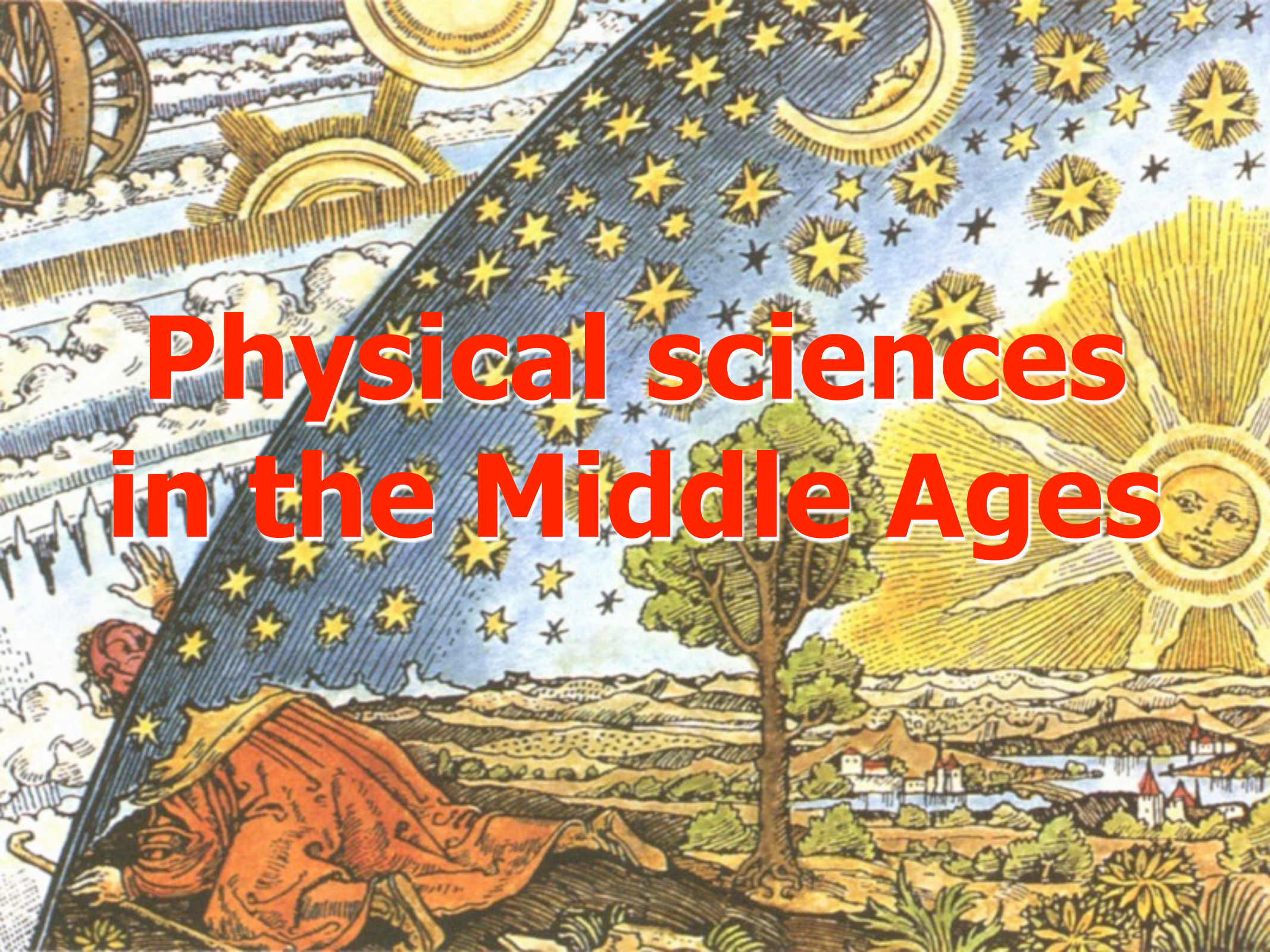


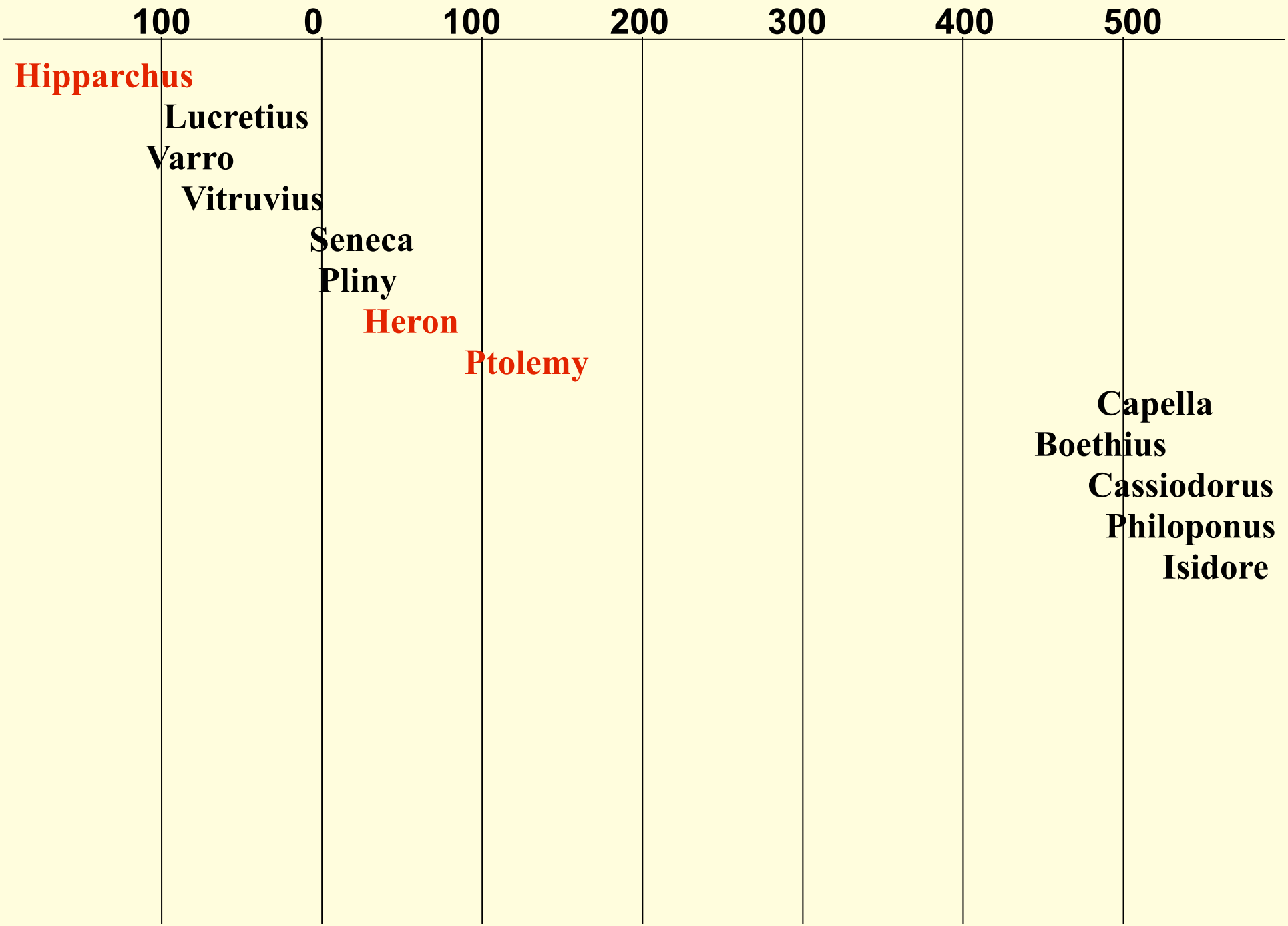
Physical sciences in the Middle Ages

Important dates of the decline and fall of the ancient world

268	Athens and Sparta plundered by the Goths
378	Battle of Adrianople, ”invincible” Roman legions defeated
395	Roman Empire divided into eastern and western states
410	Rome sacked by the Visigoths (Alaric I)
415	Symbolic end of the Alexandrian School (death of Hypatia)
455	Rome taken and destroyed by the Vandals (Genseric)
476	The last western Roman emperor Romulus Augustus deposed by Odoacer (Traditional date of the end of the Roman Empire)
529	Plato’s Academy closed by emperor Justinian the Great; Benedictine monastery founded at Monte Cassino
622	Hegira - migration of Muhammad from Mecca to Medina
732	Moslem army defeated by Charles Martel in the battle of Poitiers (Tours) – the end of Arab expansion in Europe

Highligths of the development of science

- ◆ hostile attitude of the Church Fathers to Greek science (treated as pagan science)
- ◆ Greek science in Western Europe almost completely forgotten
- ◆ VII-IX cent. – assimilation of Greek science by the Arabs; House of Wisdom (*bayt-al-hikhmah*) in Baghdad, 830
- ◆ IX-XII cent. – original contributions of Moslem scientists to physics and astronomy
- ◆ XII-XIII cent. – rediscovery of Greek science in the West thanks to translations of books from Arabic to Latin
- ◆ end of the XIIth century - first universities
- ◆ beginning of the XIIIth century – ban on teaching Aristotelian physics in Paris
- ◆ 1277 - bishop Étienne Tempier of Paris - condemnation of 219 theses – increase of intelectual freedom
- ◆ XIVth century – acceptance of modified Aristotelelian science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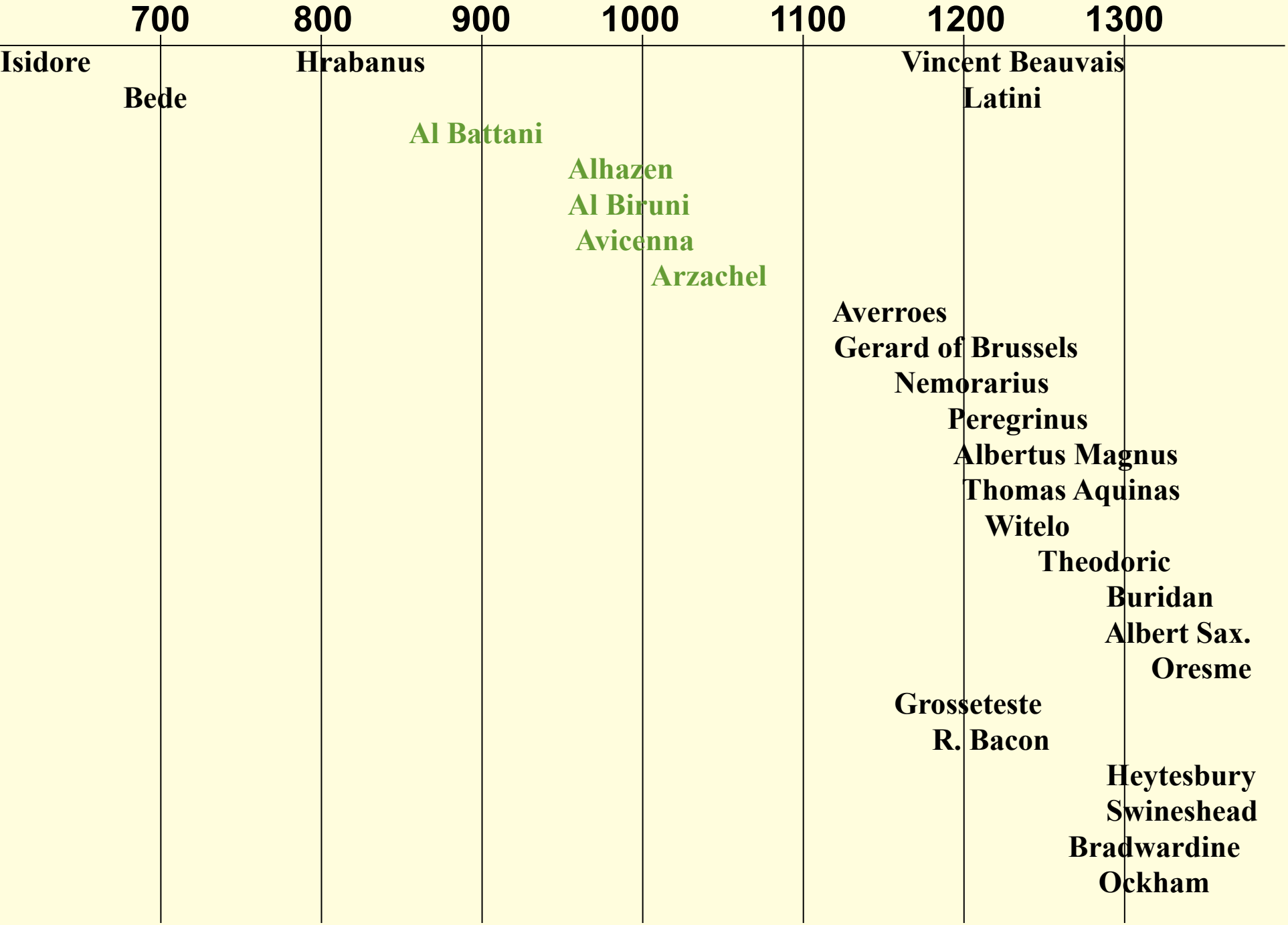
Hipparchus
Lucretius
Varro
Vitruvius
Seneca
Pliny
Heron
Ptolemy
Capella
Boethius
Cassiodorus
Philoponus
Isidore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Isidore
Bede
Hrabanus
Al Battani
Alhazen
Al Biruni
Avicenna
Arzachel
Vincent Beauvais
Latini
Averroes
Gerard of Brussels
Nemorarius
Peregrinus
Albertus Magnus
Thomas Aquinas
Witelo
Theodoric
Buridan
Albert Sax.
Oresme
Grosseteste
R. Bacon
Heytesbury
Swineshead
Bradwardine
Ockham

Boethius (Anicius Manlius Severinus Boethius)
(ca. 480-525)
A program of preserving Greek science

Capella (Martianus Felix Capella)
(ca. 490-580)
De nuptiis Mercurii et Filologiae
(grammar, dialectics, rethorics,
geometry, aritmetic, astronomy, music)


MARTIANI MINEI
CAPELLAE DE NVPTIIS PHILOLOGIAE ET MERCVRII, LIBRI II.
AD HAEC de septē artibus liberalibus libri eiusdē singuli, utpote de
GRAMMATICA
DIALECTICA
RHETORICA
GEOMETRIA
ARITHMETICA
ASTRONOMIA
MVSICA
LIBER
TERTIVS.
QVARTVS.
QVINTVS.
SEXTVS.
SEPTIMVS.
OCTAVVS.
NONVS.
BASILEAE EXCVDEBAT HENRICVS PETRVS, MENSE MARTIO, ANNO M. D. XXXII.

Cassiodorus (Flavius Magnus Aurelius Cassiodorus) (ca. 485-570)
De artibus ac disciplinis liberarium artium

Isidore of Seville (ca. 560-636)

Origines seu Etymologiae

(An encyclopaedia in 20 books)

Venerable Bede (673-735)

De natura rerum

Hrabanus Maur (ca. 780-856)

De Universo libri XXII, sive etymologiarum opus

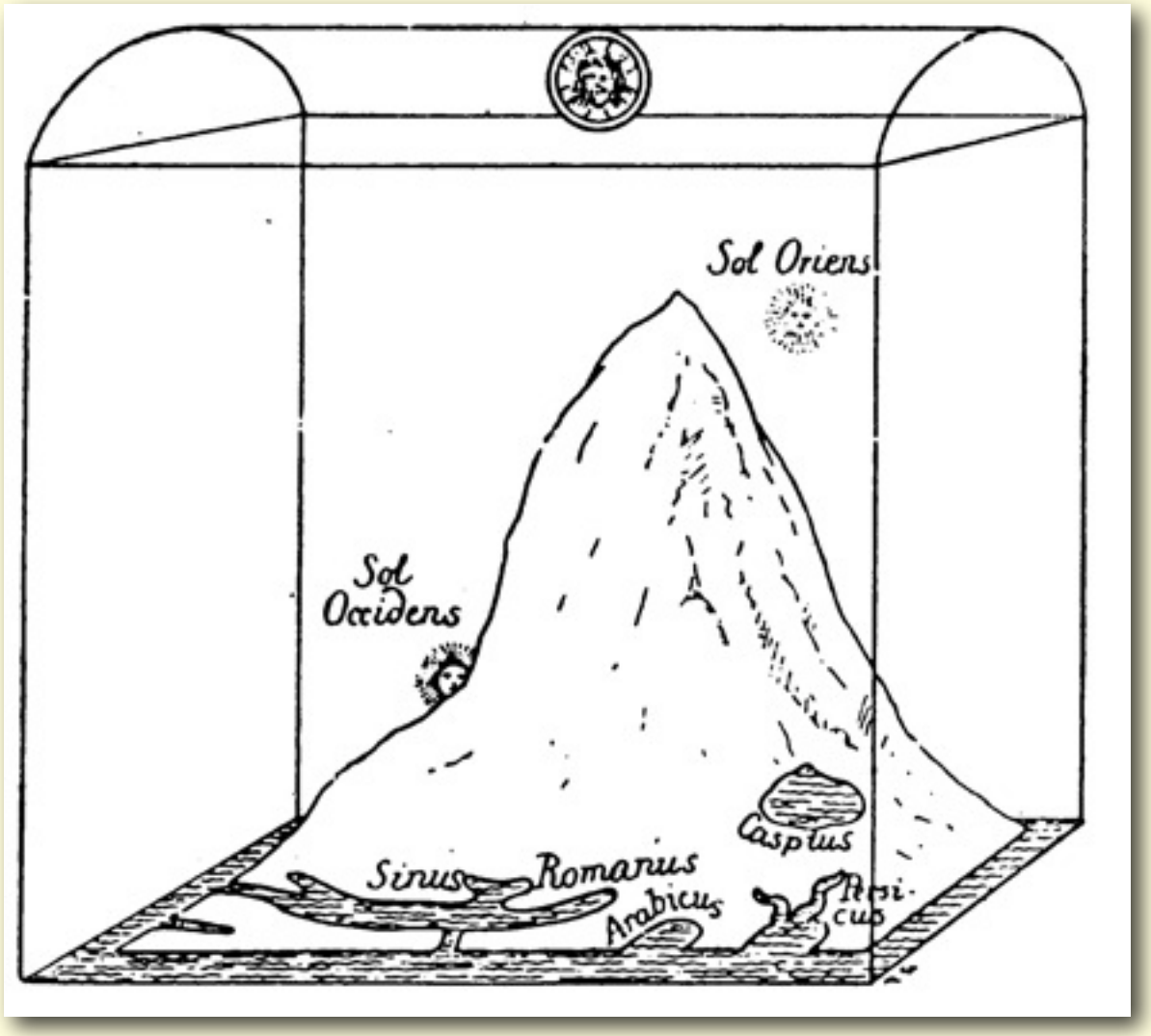
"How is it with those who imagine that there are antipodes opposite to our footsteps? Do they say anything to the purpose? Or is there any one so senseless as to believe that there are men whose footsteps are higher than their heads? or that the things which with us are in a recumbent position, with them hang in an inverted direction? that the crops and trees grow downwards? that the rains, and snow, and hail fall upwards to the earth?... Thus the rotundity of the earth leads, in addition, to the invention of those suspended antipodes. But if you inquire from those who defend these marvellous fictions, why all things do not fall into that lower part of the heaven, they reply that such is the nature of things..."

Lactantius, *Divine Institutions* (302-323),
Book III - Of the False Wisdom of Philosophers, Chapter 24

”...so poor is all the useful knowledge which is gathered from the books of the heathen when compared with the knowledge of Holy Scripture. For whatever man may have learnt from other sources,
if it is hurtful, it is there condemned; if it is useful, it is therein contained.”

St. Augustine, *On Christian Doctrine*, Book II, Chapter 42

Cosmas Indicopleustes - *Topographia Christiana* (ca. 540)



Isidore of Seville – *The Etymologies* in twenty books

I Grammar
II Rhetoric and dialectic
III Arithmetic, geometry, music, astronomy
IV Medicine
V Laws and times
VI Books and ecclesiastical offices
VII God, angels, and saints
VIII The Church and sects
IX Languages, nations, reigns, the military, citizens, family relationships
X Vocabulary
XI On human beings and monsters
XII Animals
XIII The cosmos and its parts
XIV The earth and its parts
XV Buildings and fields
XVI Stones and metals
XVII Agriculture
XVIII War and games
XIX Ships, buildings, and garments
XX Provisions and various utensils

Isidore of Seville - *Origines seu Etymologiae*
(excerpts from Book XI ”On man and monsters”, chapter 3)

”...in the whole human kind there are certain monstrous races, as the Gigantes, Cynocephali, Cyclopes, and the rest. The Cynocephali are so called because they have dogs' heads and their very barking betrays them as beasts rather than men. These are born in India. The Cyclopes, too, the same India gives birth to, and they are named Cyclopes because they are said to have a single eye in the midst of the forehead...

The Blemmyes, born in Libya, are believed to be headless trunks, having mouth and eyes in the breast; others are born without necks, with eyes in their shoulders... The race of the Sciopodes is said to live in Ethiopia. They have one leg apiece, and are of a marvelous swiftness, and the Greeks call them Sciopodes from this, that in summertime they lie on the ground on their backs and are shaded by the greatness of their feet. The Antipodes in Libya have feet turned backward and eight toes on each foot.

Other fabulous monstrosities of the human race are said to exist, but they do not; they are imaginary...”

English translation by Ernest Brehaut (1912)

Isidore of Seville - *Origines seu Etymologiae*
(excerpts from Book XIII)

”Water (*aqua*) is so named because its surface is ’even’ (*aequalis*)...

In Thessaly there are two rivers; sheep drinking from one of them become black, those drinking from the other white, and those drinking from both have mixed colours...

There is a lake in the country of the Troglodytes; three times a day it becomes bitter, and then, just as often, sweet again...

A flash of lightning is produced at the same time as the thunder, but it is seen sooner because it is bright; thunder reaches the ears later...”

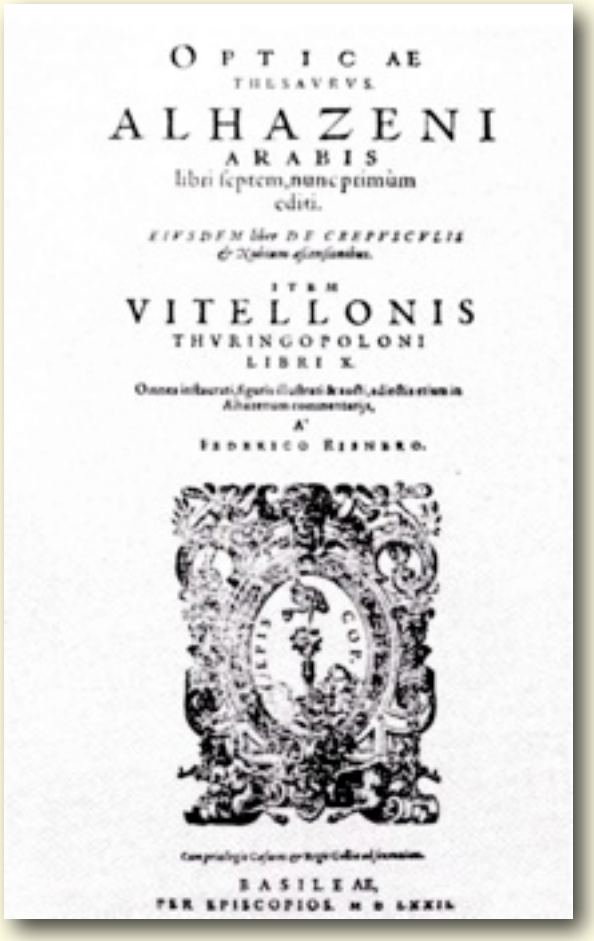
Monasteries developed scriptoria where books were produced by copyists

Greek science was absorbed, preserved and developed by Moslem scientists

Their most important contributions were in astronomy, mathematics, optics, and mechanics

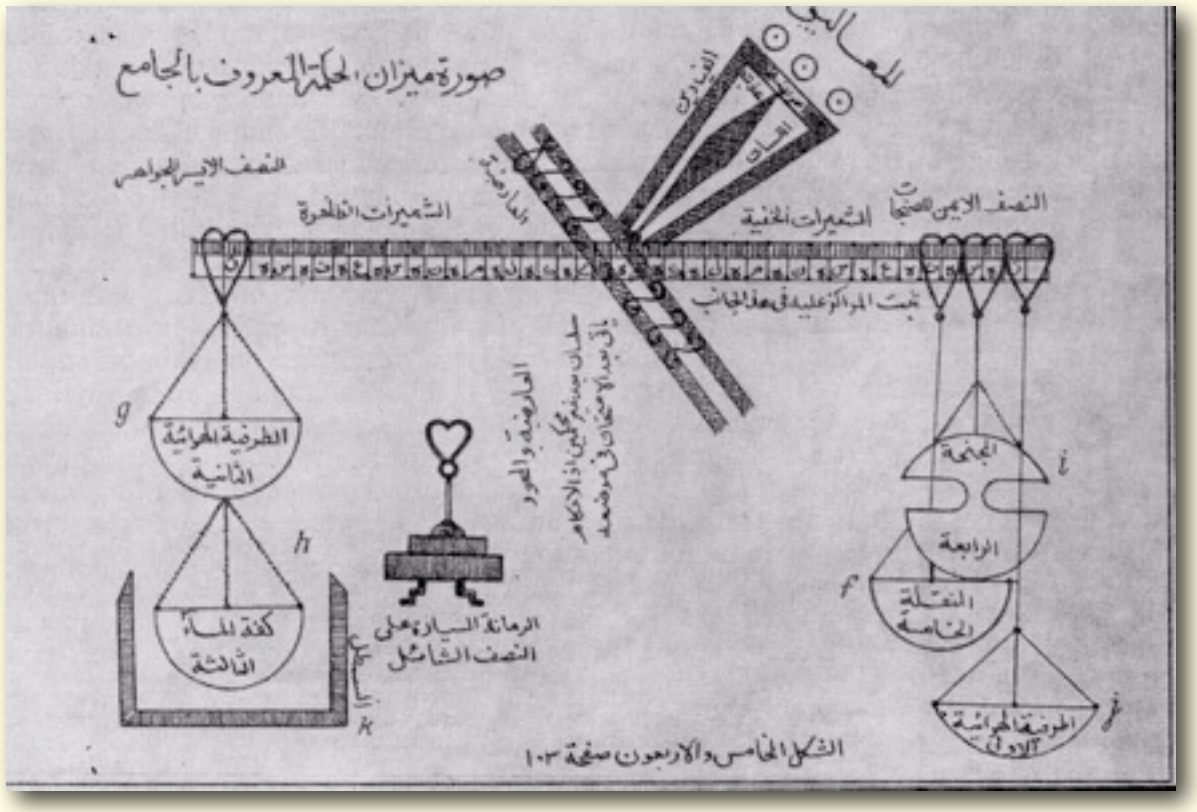
Unfortunately the progress of Moslem science was soon slowed down and practically stopped by religious fundamentalists

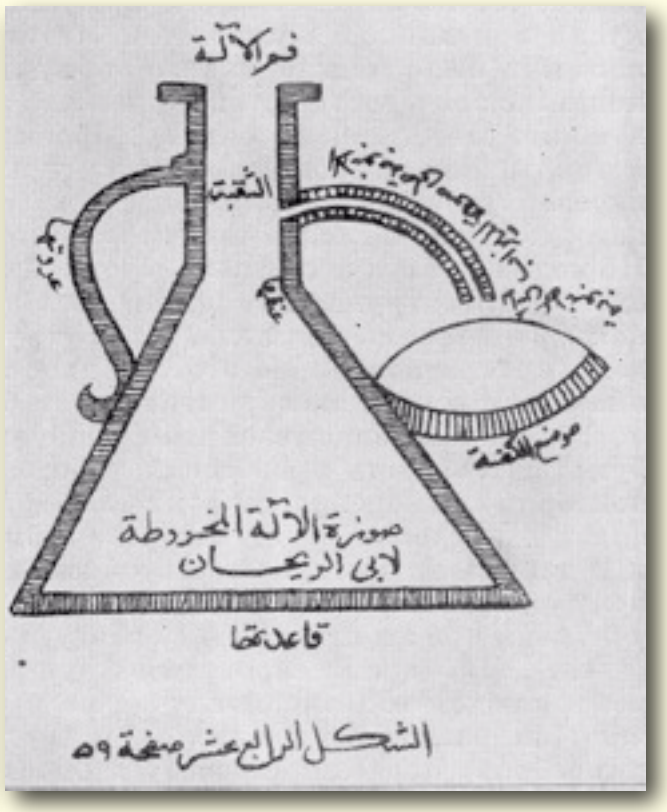
Ibn-Sina (Avicenna)
(980-1037)



Ibn-al-Haitham
(Alhazen)
(ca. 965-1039)

Al-Khazini - *The Book on the Balance of Wisdom* (1121)





The rise of universities

The original name of a university was *studium generale*

universitas magistrorum et scholarium -

A corporation of lecturers and students

First universities were formed spontaneously:

Of 14 universities which existed in 1300
only 3(2) were founded by the monarchs (popes)

The oldest: Bologna, Paris (XII century)
Oxford (1214), Padua (1222), Naples (1224),
Cambridge (1231), Toulouse (1233), Montpellier, Siena,
Salamanca, Piacenza, Seville, Lisbon, Lerida

Two types of university administration

Bologna type
(administered by the students)

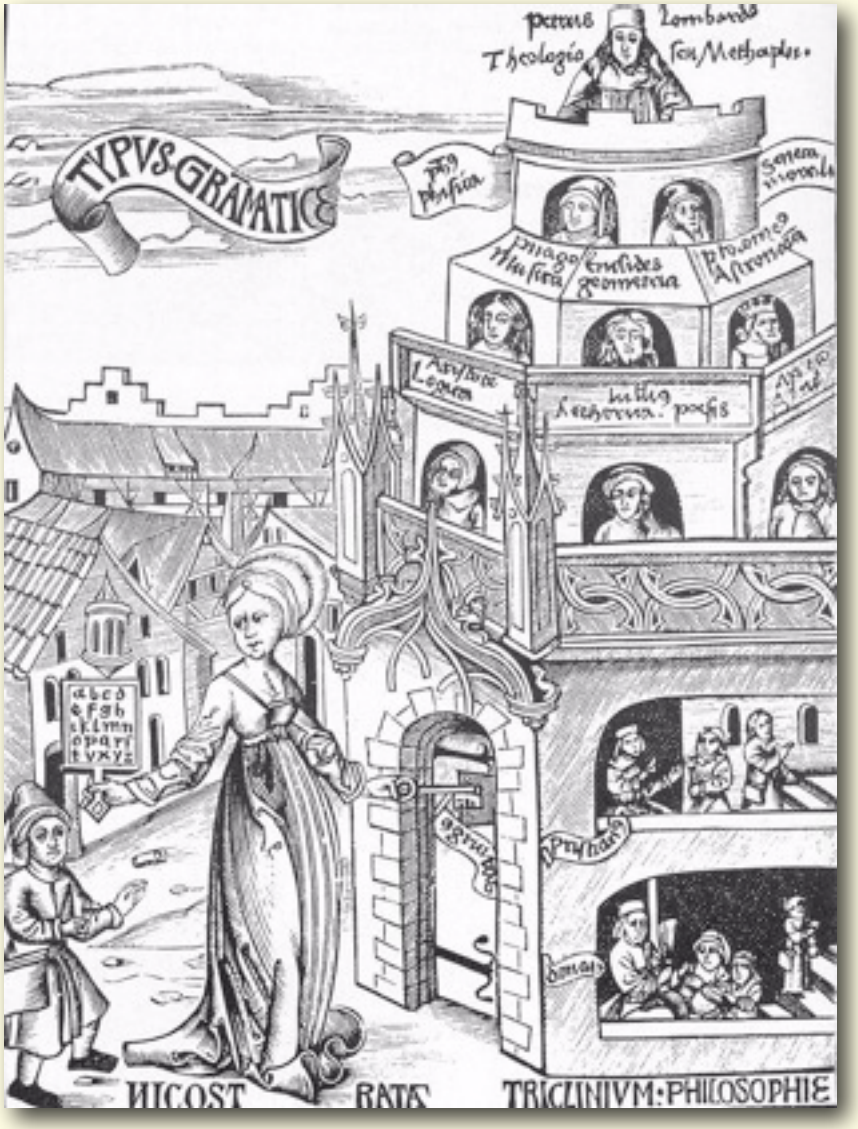
Paris type
(administered by the professors)

King’s College, Oxford

Trinity College, Cambridge

Sorbonne

Padua



Liberal arts
(*artes liberales*):

Trivium:
grammar, rhetoric, dialectics
Quadrivium:
arithmetic, geometry, music, astronomy

Master's (doctor's)
degree of liberal arts
necessary for the studies of
law, medicine and theology

University lectures (Bologna)

University debates:

ordinary,
extraordinary
and
quodlibet

A debate
(Paris University)

Examples of articles from the *Condemnation* of 1277

(articles considered to place limitations on God's absolute power)

21. That nothing happens by chance, but all things occur from necessity and that all future things that will be will be of necessity
34. That the first cause [that is, God] could not make several worlds
48. That God cannot be the cause of a new act, nor can He produce something anew
49. That God could not move the heavens [or world] with a rectilinear motion and the reason is that a vacuum would arise

The number of students in medieval universities was small

XIV cent.	Paris	ca. **6000**
	Bologna	ca. **15000**
	Touluse	< **2000**
	Vienna	< **2000**
	Leipzig	< **2000**
1426	Louvain	**1450**
End XIVth cent.	Praha	**1373** (incl. the masters)

University lecture (second half of the XIVth century)

The number of students in medieval universities was small

Cracow Academy

1400-1409	963
1427-1449	3084
1449-1471	4161
1490-1499	2889
1500-1509	3215
1510-1519	2816
1520-1529	1710
1530-1539	1715

(about 18,000 students in the period 1400-1499)

Only a small number of students obtained degrees

	Bachelors	Masters
Cracow Academy		
1427-1449	19.2%	4.8%
1449-1471	24.7%	6.6%
1471-1491	26.0%	4.7%
1491-1510	21.5%	3.6%
1518-1540	14.8%	4.1%
Leipzig university		
1429-1432	20.4%	3.8%
1439-1442	27.8%	6.9%
1459-1462	38.6%	5.6%
1469-1472	36.0%	5.4%
1479-1482	39.4%	4.2%
1509-1512	26.1%	3.4%

A note on the problem of ”nations” in medieval universities

Cracow: university without nations

Praha: 4 nations: Polish, Bavarian, Saxon, Czech;
the Polish nation included also Lithuanians, Saxons, Turingians, and Prussians

Bologna: the German nation included also students from Hungary, Flanders, Sweden, England, Scotland, and Poland

Paris: the English nation included Poles, Hungarians, and Italians

Cologne: the English nation included Czechs, Germans, Hungarians, and Poles

Vienna: Poles belonged to the Hungarian nation together with the Czechs and other Slavs

Leipzig: the Polish nation included Prussians and Russians, the Bavarian nation included Italians, French and Spanish

Note: Latin. *natio* – tribe, generation, class
Latin. *populus* – nation, people

”All the students, who directly or through their servants and supporters interfere with realization of our statutes, by making noise, stamping, throwing stones or by any other means, will by this law be excluded from our community for the whole year.”

[From the statutes of the Paris university]

There were no laboratories in medieval universities. Experiments were not performed. University scholars were doing research
of **texts**, and not **phenomena of nature**

The freedom of scientific debates in medieval universities contributed to the progress of science

Islamic schools, *madrases,* were dominated by fundamentalists – it was impossible to cross the limits fixed by the text of the Quran. Islamic science ceased to produce original results already several centuries ago

Medieval mechanics

Some new results of medieval mechanics

- theory of *impetus* (Jean Buridan)
- alternative laws of dynamics (Joannes Philoponus, Avempace, Thomas Bradwardine)
- introduction of graphic representation of relation between two variables (Nicole Oresme, Giovanni di Casali)
- mean velocity theorem for uniformly accelerated motion $v_{av} = (1/2)(v_{in} + v_{fin})$ (William Heytesbury, Richard Swineshead, Thomas Bradwardine, Nicole Oresme)
- consideration of the instantaneous velocity - *velocitas instantanea* (William Heytesbury, Richard Swineshead)
- acceleration (*velocitatio*) considered as intensity of the velocity (Nicole Oresme)

”If you let fall from the same height two weights of which one is many times as heavy as the other, you will see that the ratio of the times required for the motion does not depend on the ratio of the weights, but that the difference in time is a very small one. And so, if the difference in the weights is not considerable, that is, if one is, let us say, double the other, there will be no difference, or else an imperceptible difference, in time, though the difference in weight is by no means negligible, with one body weighing twice as much as the other.”

Joannes Philoponus, VIth century

Ιωάννης Φύλοπονης

”As for the case where there is [violent motion with the] separation of the moved [from the motor] like the projectile or that which is rolled, the scientists disagree in their opinions. There are some who hold that the cause lies in the tendency of the air which has been pushed to get behind the projectile and to unite there with a force which presses against that which is in front of it. There are others who say that the pusher pushes the air and the projectile together but the air is more receptive to pushing and so it is pushed more swiftly and thus pulls that which has been placed in it”

Avicenna, *Kitāb al-Shifā* (*Book of the Healing of the Soul*)

”And there are those who hold that the cause is in that force which the moved acquires from the mover and which persists in it for a time until it is abolished by the opposing force of that [medium] which touches it and is displaced by it. And just as the force is weakened in the projectile, so the natural inclination (*mayl*) and the action of friction becomes dominant over it, and thus the force is abolished and consequently the projectile passes in the direction of its natural inclination...”

Avicenna, *Kitāb al-Shifā* (*Book of the Healing of the Soul*)

Ibn-Sina (Avicenna) (980-1037)

”...But when we have verified the matter we have found the most valid opinion to be that of those who hold that the moved received the inclination (*mayl*) from the mover. The inclination is that which is perceived by the senses to be resisting a forceful effort to bring the natural motion to rest or to change one violent motion into another.”

Avicenna, *Kitāb al-Shifā* (*Book of the Healing of the Soul*)

Theory of *impetus*

”...we must conclude that a mover, in moving a body, impresses on it a certain ***impetus***, a certain power capable of moving this body to the direction in which the mover set it going, whether upwards, downwards, sideways or in a circle. By the same amount that the mover moves the same body swiftly, by that amount is the ***impetus*** that is impressed on it more powerful. It is by this ***impetus*** that the stone is moved after the thrower ceases to move it; but because of the resistance of the air and also because of the gravity of the stone, which inclines it to move in a direction opposite to that towards which the ***impetus*** tends to move it, this ***impetus*** is continually weakened. Therefore the movement of the stone will become continually slower, and at length the ***impetus*** is so diminished or destroyed that the gravity of the stone prevails over it and moves the stone down towards its natural place.”

Jean Buridan (1300-1358)
Quaestiones super octo libros Physicorum Aristotelis

”For if it is asked why I can throw a stone farther than a feather and a piece of iron or lead suited to the hand farther than a piece of wood, I say that the cause of this is that the reception of all forms and natural dispositions is in matter and by reason of matter. Hence the greater quantity of matter a body contains, the more ***impetus*** it can receive and the greater the intensity with which it can receive it. Now in a dense, heavy body there is, other things being equal, more *materia prima*, than in a rare, light body. Therefore a dense, heavy body receives more of this ***impetus*** and receives it with more intensity [than a rare, light body]. In the same way a certain quantity of iron can receive more heat than an equal quantity of wood or water.”

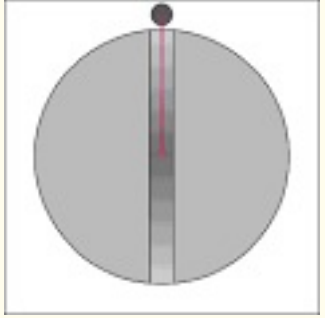
Jean Buridan, ***Quaestiones super octo libros Physicorum Aristotelis***

”A feather receives so feeble an ***impetus*** that it is soon destroyed by the resistance of the air and, similarly, if one projects with equal velocity a light piece of wood and a heavy piece of iron of the same size and shape, the piece of iron will go further because the ***impetus*** impressed on it is more intense, and this does not decay as fast as the weaker ***impetus***. It is for the same cause that it is more difficult to stop a big mill wheel, moved rapidly, than a smaller wheel; there is in the big wheel, other things being equal, more ***impetus*** than in the small. In virtue of the same cause you can throw a stone of one pound or half a pound farther than a thousandth part of this stone; in this thousandth part the ***impetus*** is so small that it is all soon overcome by the resistance of the air.”

Jean Buridan, *Quaestiones super octo libros Physicorum Aristotelis*

”However, it ought not to be thought that the force of the violent motor impresses in the stone which is moved by violence some force (*virtus*), by means of which it is moved, as the force of a generating agent impresses in that which is generated the form which natural motion follows. For [if] so, violent motion would arise from an intrinsic source which is contrary to the nature (*ratio*) of violent motion. It would also follow that a stone would be altered by being violently moved in local motion, which is contrary to sense. Therefore, the violent motion impresses in the stone only motion and only as long as it touches it...”

Thomas Aquinas, *In libros Aristotelis de coelo et mundo expositio*



”...if the earth were completely perforated, and through that hole a heavy body were descending quite rapidly toward the centre, that when the centre of gravity of the descending body was at the centre of the world, that body would be moved on still further (beyond the centre) in the other direction,
i.e. toward the heavens, because of the ***impetus*** in it not yet corrupted. And in so ascending, when the ***impetus*** would be spent, it would conversely descend. And in such a descent it would again acquire unto itself a certain small ***impetus*** by which it would be moved again past the centre. When this ***impetus*** was spent, it would descend again. And so it would be moved, oscillating about the centre until there no longer would be any ***impetus*** in it, and then it would come to rest.”

Albert of Saxony (1316-1390)
Quaestiones super quattuor libros de caelo et mundo Aristotelis

”And this quality can be called ‘*impetuosity’.* And it is not weight properly [speaking] because if a passage were pierced from here to the centre of the earth or still further, and something heavy were to descend in this passage or hole, when it arrived at the centre it would pass on further and ascend by means of this accidental and acquired quality, and then it would descend again, going and coming several times in the way that a weight which hangs from
a beam by a long cord [swings back and forth].”

Nicola Oresme, *Quaestiones super de caelo*

An example of earlier opinions:

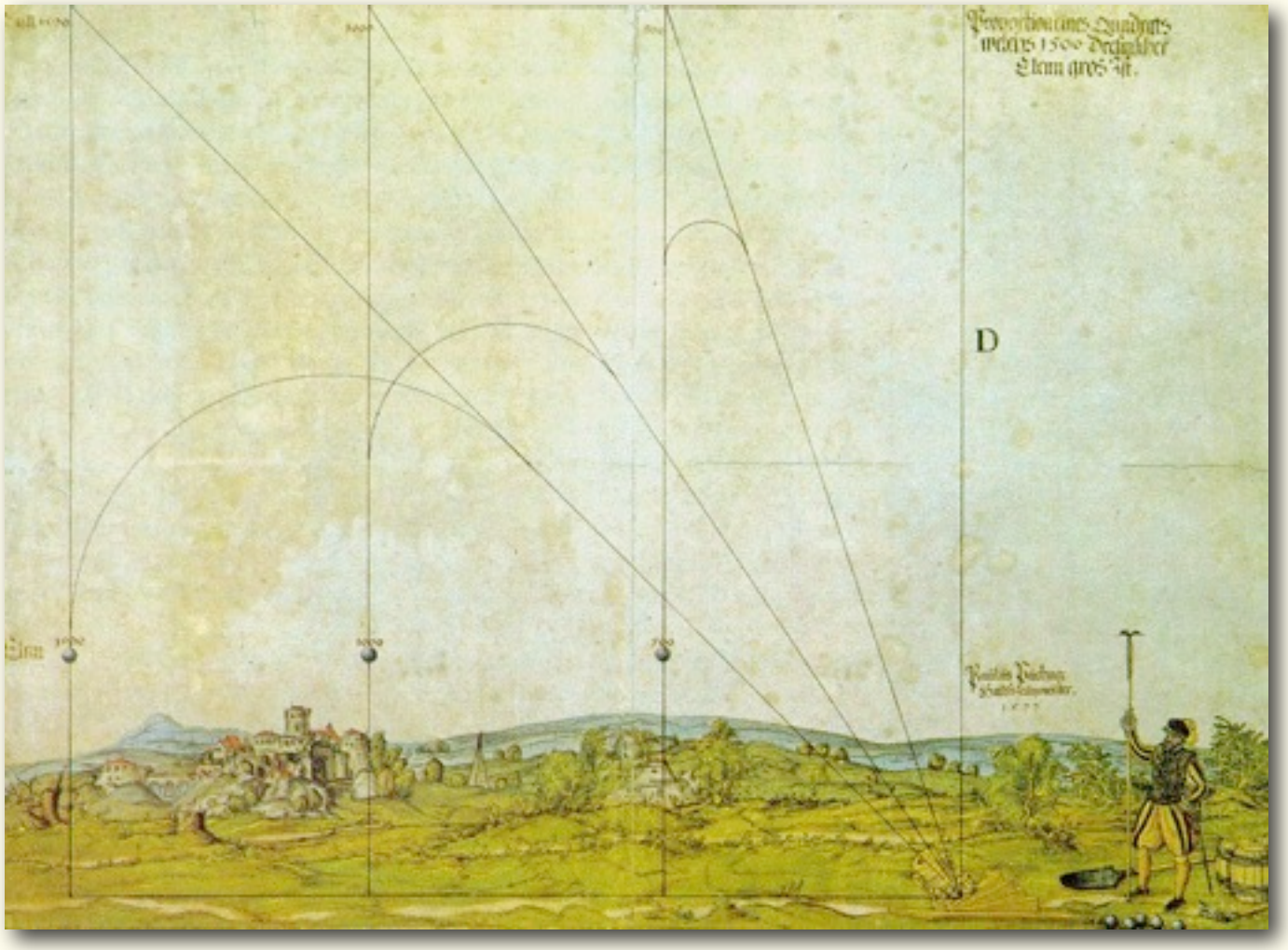
Brunetto Latini, *Li Livres du Trésor* (ca. 1265)

”...if the earth were completely perforated, and through that passage a heavy body, for example a large stone were descending quite rapidly toward the centre, then when the centre of gravity of the descending body reached the centre of the world, it would stop and not move any further... The stone would not move back nor forth because of the air surrounding the earth which entered the passage from both ends and made the stone immobile...
In general all things tend to the lowest point, and the lowest point in the world is the centre of the earth called an abyss in which the hell is situated...”

[Similar considerations in other XIIIth century writings,
e.g. *Speculum Naturale* by Vincent of Beauvois]

Formal similarity of our momentum and *impetus* measured by a product of mass and speed, is misleading because:

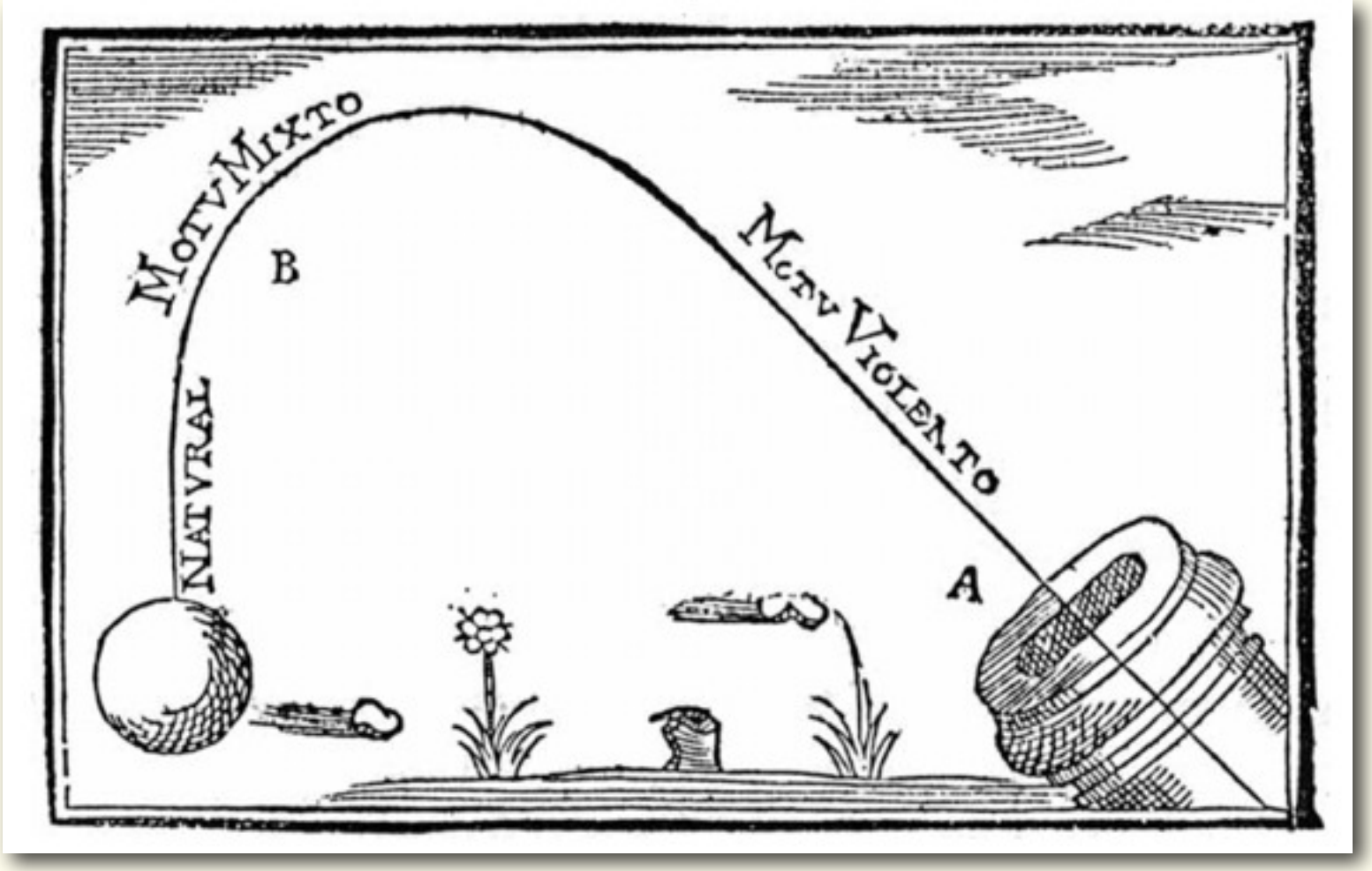
- *impetus* was treated as the cause of motion, whereas our momentum is a measure of motion
- Buridan introduced also circular *impetus* (for celestial bodies)
- momentum is a vector quantity, whereas *impetus* is a scalar quantity



Gradual modification of Aristotelian rules for motion of projectiles

An analysis of the trajectory of a cannon ball in the 16th century:

violent motion, mixed motion, and natural motion



Ancient and medieval dynamics

(Beware: presentation with the use of formulae is anachronistic !)

Aristotle: $v \sim F/R$ for $F > R$

$v = 0$ for $F \leq R$

$F = 0 \rightarrow v = 0$ (principle of inertia)

Philoponus: $v \sim (F - R)$ for $F \geq R$

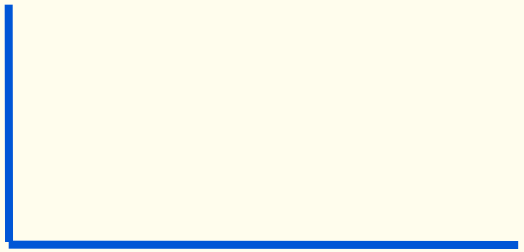
$v = 0$ for $F < R$

Bradwardine: $n \bullet v = \theta [(F/R)^n]$

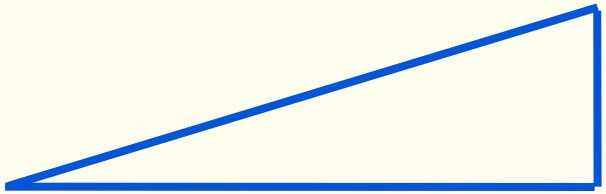
$v \sim \log (F/R)$

Nicole Oresme
(ca. 1320-1382)

Latitudo (Intensio)



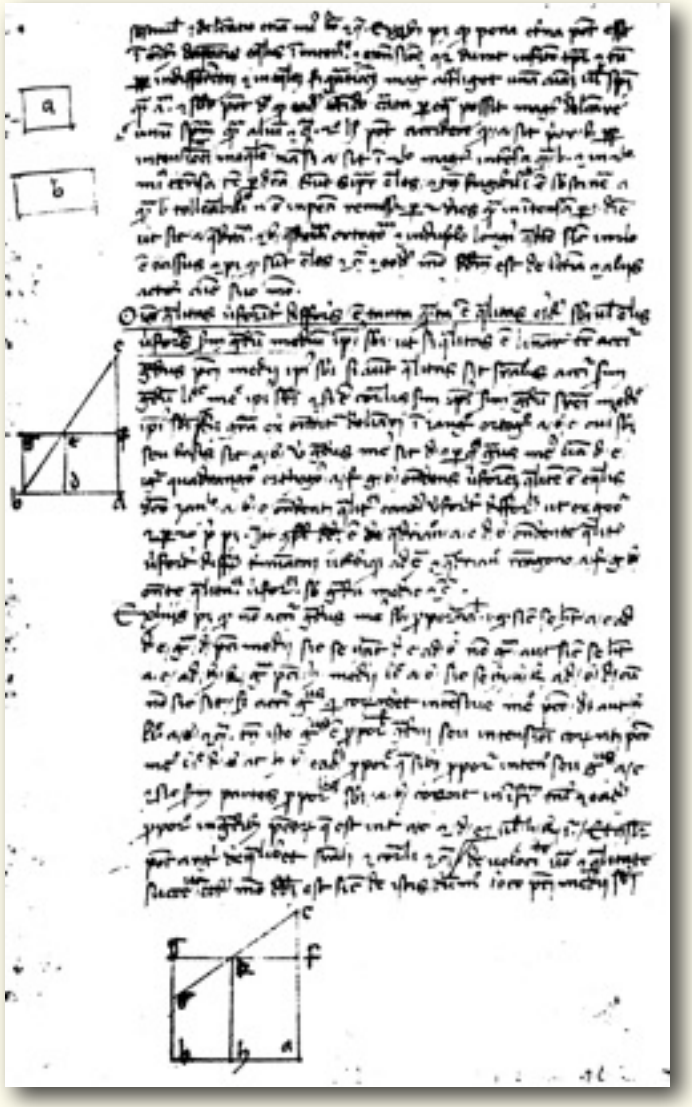
Longitudo (Extensio)



"motus uniformiter difformis"

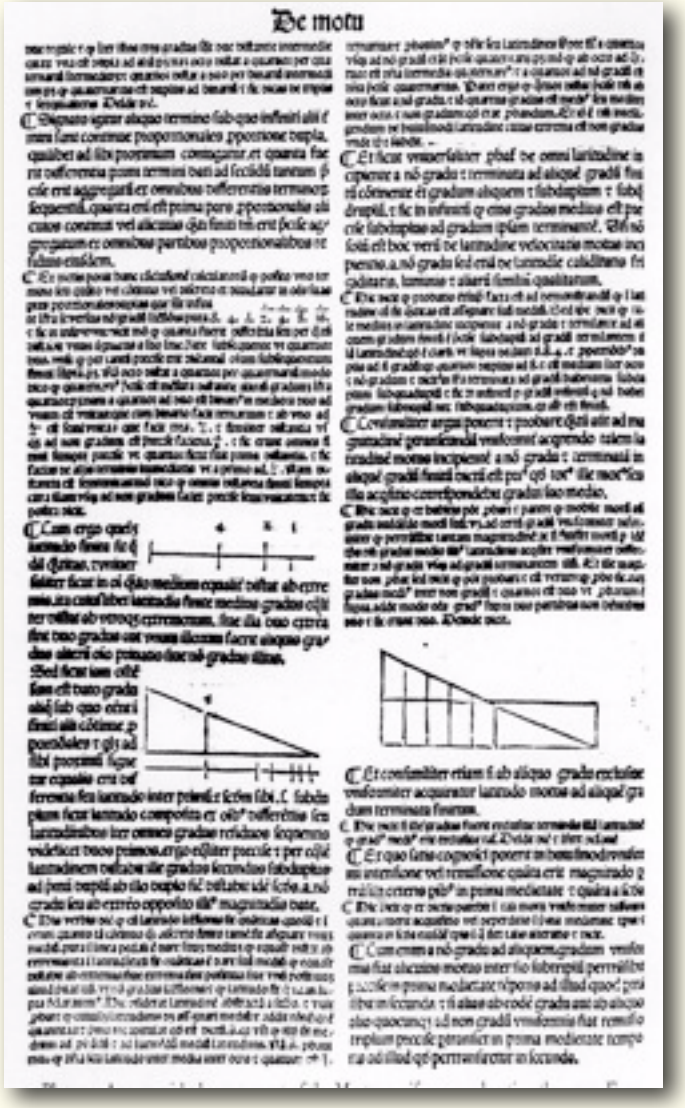
"motus uniformis"

[Similar methods of analysis of two variables were given by Giovanni di Casali (1346)]



Nicole Oresme

De configuratione qualitatum



William Heytesbury

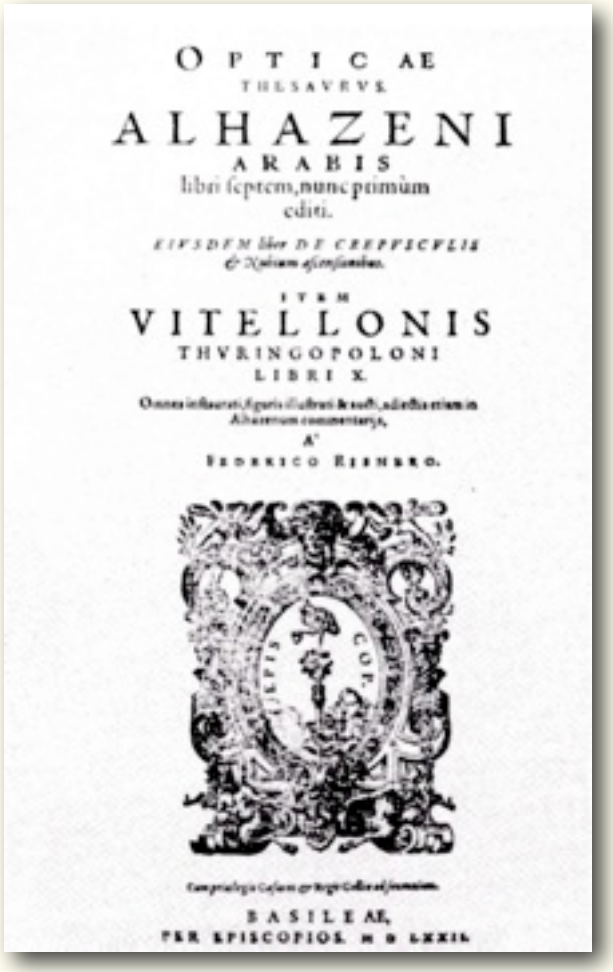
Regule solvendi sophismata

Medieval optics

Ibn-al-Haitham
(Alhazen)
(ca. 965-1039)

Optical treatise in seven books *Kitāb al-Manābir*, translated into Latin in 1270 as *Opticae Thesaurus Alhazeni*.

Comprised physiological optics, structure of the eye, *camera obscura*, reflection and refraction of light


OPTICAE
THESAVRVS
ALHAZENI
ARABIS
libri septem, nunc primùm
editi.
EIVSDEM liber DE CREPVSCVLIS
& Nubium ascensionibus.
A
VITELLONE
THVRINGOPOLONO
LIBRI X.
Omnes instaurati, figuris illustrati & multis additionibus in
Alhazenum commentarijs,
A
FRIDERICO RISNERO.
BASILEAE,
PER EPISCOPIOS M D LXXII.

Experimental facts concerning light

(known since Antiquity)

propagation in straight lines

reflection

refraction

rainbow/colours

geometrical optics → practical applications
- mirrors
- burning glasses
- spectacles
- physiological optics/vision

These observations, mostly qualitative, did not allow any detailed theory of light

Medieval optics (*perspectiva*), differed much from the present branch of physics; it comprised theory of vision, structure of the eye, propagation of light, properties of mirrors and refracting surfaces, origin of images with reflection and refraction of light and luminous meteorological phenomena (eg. the rainbow). Three competing theories of vision in antiquity were those of ”intramission”, ”extramission”, and Aristotle’s ”mediumistic”

a) ”Intramission” theory: thin films of atoms depart from visible objects in all directions, maintaining a fixed configuration as they passed, and enter the eye of an observer (Empedocles, the atomists);

b) ”Extramission” theory: radiation is sent out from the observers eye to ‘feel’ the visible object (Euclid, Ptolemy and others);

c) Light is the state of actual transparency in a potentially transparent medium and thus represents the necessary condition for vision (Aristotle).

”Now there clearly is something which is transparent, and by 'transparent' I mean what is visible, and yet not visible in itself, but rather owing its visibility to the colour of something else; of this character are air, water, and many solid bodies. Neither air nor water is transparent because it is air or water; they are transparent because each of them has contained in it a certain substance which is the same in both and is also found in the eternal body which constitutes the uppermost shell of the physical Cosmos. Of this substance light is the activity - the activity of what is transparent so far forth as it has in it the determinate power of becoming transparent; where this power is present, there is also the potentiality of the contrary, viz. darkness. Light is as it were the proper colour of what is transparent, and exists whenever the potentially transparent is excited to actuality by the influence of fire or something resembling 'the uppermost body'; for fire too contains something which is one and the same with the substance in question.”

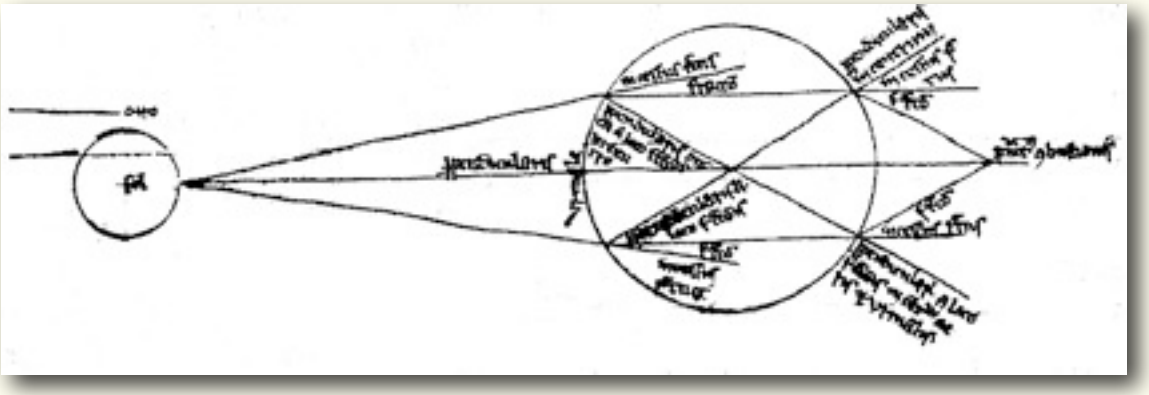
Aristotle, Περι ψυχης (*De anima*), Book II, 7

”We have now explained what the transparent is and what light is; light is neither fire nor any kind whatsoever of body nor an efflux from any kind of body (if it were, it would again itself be a kind of body) - it is the presence of fire or something resembling fire in what is transparent. It is certainly not a body, for two bodies cannot be present in the same place. The opposite of light is darkness; darkness is the absence from what is transparent of the corresponding positive state above characterized; clearly therefore, light is just the presence of that.”

Aristotle, Περι ψυχης (*De anima*), Book II, 7

Robert Grosseteste (1168-1253)
rector of Oxford university,
bishop of Lincoln

Grosseteste stressed multiplication of forms (*multiplicatio specierum*); light is the first ”corporeal form” of material things, and for this reason the study of optics is of particular importance



Refraction of light in a spherical lens according to Grosseteste

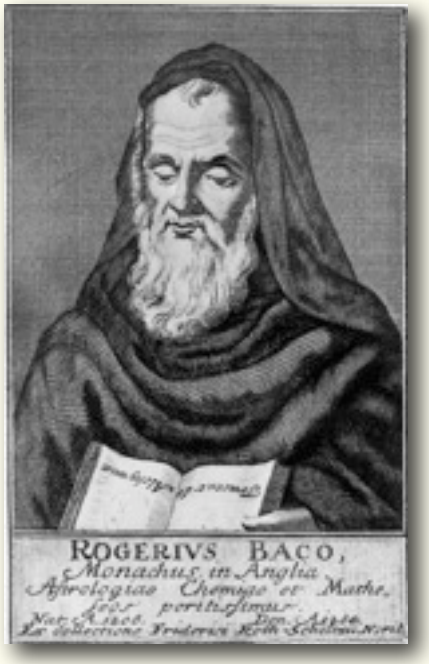
”We first say that optics is a science which is built on visual figures, and this includes the science which is based upon figures formed by radiant lines and surfaces, whether they are radiating projections from the sun, the stars, or any other radiant body. We must not think that emanation of visual rays is just an imaginary idea without reality, as those persons profess who consider the part and not the whole. But we ought to know that a visible *species* is a substance of like nature with the sun, which lights and radiates. The visible *species*, when conjoined with the radiation of an external illuminating body, completes perception”.

Grosseteste, *De Iride* (ca. 1235)

“Of this science the principal parts are three, corresponding to a triple means of passage of rays to a thing seen. Either the path of a ray to the thing seen is straight through the medium of a uniform transparency interposed between the viewer and the object; or its path follows a straight line to a body having the nature of that spiritual mode by which it is a mirror, and from the same is reflected to the thing seen; or the transit of the ray is through many transparencies of various kinds, in the contiguity of which the visual ray is bent and forms an angle, and the ray does not approach the viewed object along one straight line but along the route of many straight lines angularly connected.
The first part covers the science of vision; the second is the science of the mirror. The third part has remained untreated and unknown among us up to the present day.”

Grosseteste, *De Iride* (ca. 1235)

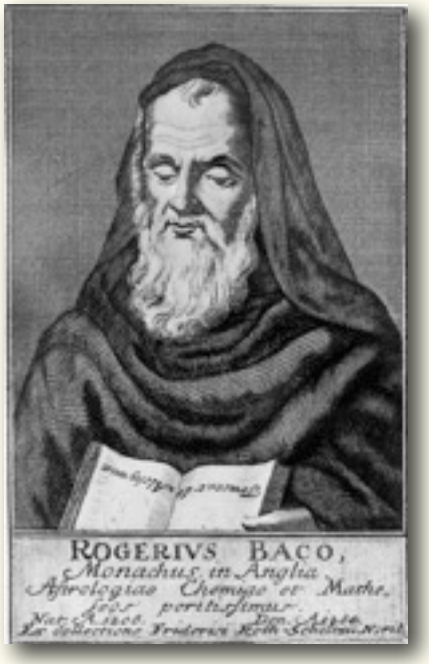
Roger Bacon (ca. 1214-1294)



”Having laid out the roots of the wisdom of the latins so far as they are found in languages and mathematics and perspective, I wish now to take up the roots of experimental science. There are, in fact, two ways of knowing, namely, by argumentation and experience. Argumentation concludes and makes us grant the conclusion, but does not make certain not remove doubt that the mind may be quiet in the contemplation of truth, unless it finds truth by the way of experience...”

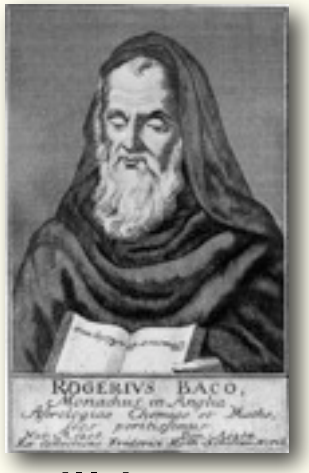
Opus maius

Roger Bacon (ca. 1214-1294)



”...for it is easily shown by the rules stated above [demonstrating the workings of lenses] that very large objects can be made to appear small, and the reverse, and very distant objects will seem very close at hand, and conversely... Thus from an incredible distance we might read the smallest letters and number grains of dust and sand owing to the magnitude of the angle under which we viewed them. And we may cause the stars to appear wherever we wish...”

Opus maius



”It is possible that great ships and sea-going vessels shall be made which can be guided by one man and will move with greater swiftness than if they were full of oarsmen. It is possible that a car shall be made which will move with inestimable speed, and the motion will be without the help of any living creature. Such, it is thought, were the chariots which the ancients used in combat. It is possible that a device for flying shall be made such that a man sitting in the middle of it and turning a crank shall cause artificial wings to beat the air after the manner of a bird’s flight. Similarly it is possible to construct a small-sized instrument for elevating and depressing great weights...It is possible also that devices can be made whereby, without bodily danger, a man may walk on the bottom of the sea or of a river. Alexander used these to observe the secrets of the sea...”

Roger Bacon. *Epistola de secretis operibus artis et naturae*

Witelo (ca. 1230-1280)

Optics written ca. 1270-1273, printed firstly in the XVIth century

An imaginary portrait in Padua

Nürnberg, 1535

Basel, 1572

Ten books of *Optics* by Witelo

1. Geometry (from Euclid's *Elements*, and Apollonios, but including some original theorems by Witelo)
2. Propagation of rays through one or more media, formation of shadows
3. The structure of the eye, the process of vision
4. Optical illusions
5. Reflection from mirrors; phenomena common to all mirrors: plane, spherical, cylindrical, conical, concave, and convex
6. Reflection from convex spherical mirrors
7. Reflection from convex cylindrical and conical mirrors
8. Reflection from concave spherical mirrors
9. Reflection from concave cylindrical and conical mirrors; burning mirrors
10. Process of vision through two transparent media and illusions originating from it; the rainbow

”There are three ways of vision. The first – through only one medium, or direct vision, the second – through reflection of visible forms from smooth bodies, and the third – through refraction of visible forms resulting from dissimilarity of media. These three ways of visions are equivalent to the triple action of forms and all the powers of the heaven and nature...”

[From the Prologue to Witelo’s *Optics*]

Witelo (ca. 1230-1280)

(Basel edition of *Optics*)

VITELLONIS FI-
LII THVRINGORVM ET PO-
LONORVM OPTICAE LIBER PRIMVS.

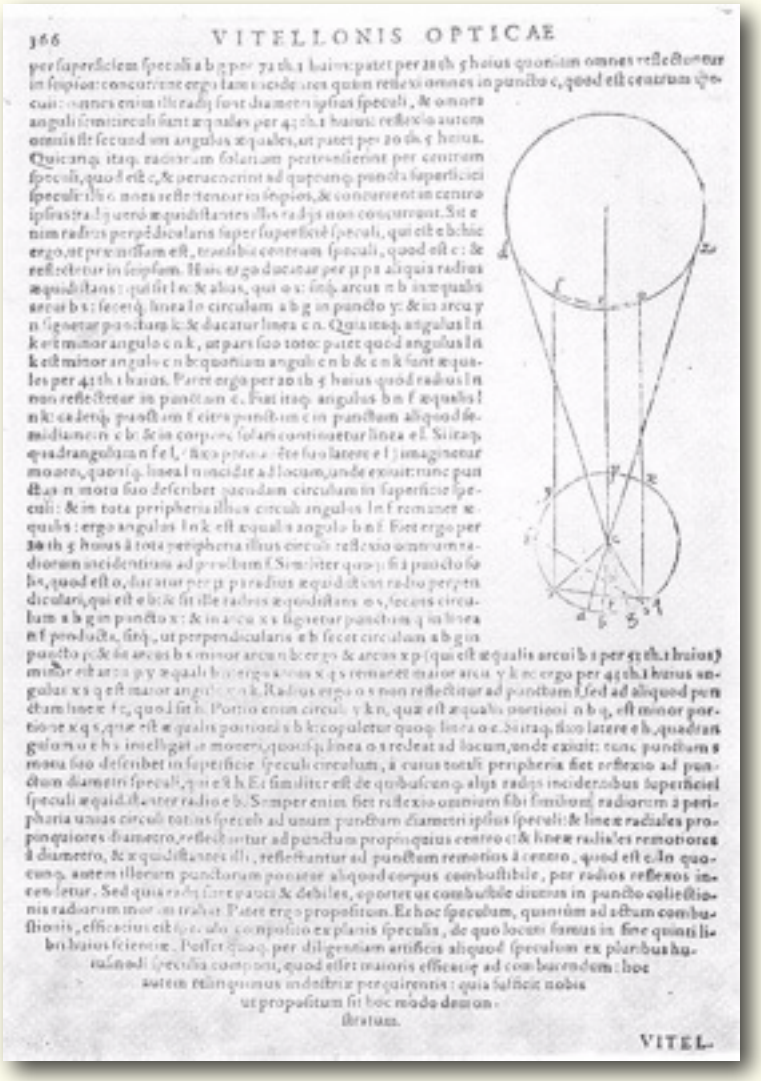
DEFINITIONES.

VAE uerò per modum principiorum huic primo libro præmittimus, sunt ista. 1. Cathetum dicimus lineam perpendicularē super superficiem aliquam, erectam. 2. Polum dicimus omnem punctum lineæ super superficiem circuli à centro orthogonaliter erectæ. 3. Conuexam lineam uel superficiem dicimus, quæ extrinsecus aliquam regularem curuitatem habet. 4. Lineam cōcauam uel superficiem dicimus, quæ intrinsecus aliquam regularem curuitatem habet. 5. Lineam super superficiem conuexam uel concauam perpendicularem dicimus, quæ super planam superficiē in puncto suæ incidentiæ superficiem conuexam uel concauam contingentem est erecta. 6. Circuli seinuicem secantes dicuntur, quorum diametris est aliqua linea communis, uno reliquum non continente. 7. Circulus magnus sphęræ dicitur, qui transiens centrum sphæræ, diuidit ipsam in duo æqualia. 8. Minor uerò circulus sphæræ dicitur, qui neque transit centrum sphæræ, neque diuidit ipsam in duo æqualia. 9. Sphæras æquales dicimus, quarum diametri sunt æquales. 10. Sphæras uel circulos se inuicem continentes, æquidistantes dicimus, inter quas à centro maioris ductæ lineæ à conuexo minoris ad concauum maioris sunt æquales. 11. Sphæras se inuicem cō tingentes dicimus, quæ se tangentes extrinsecus uel intrinsecus nō secant. 12. Sphęras seinuicem intersecantes dicimus. cùm sphęris se non continentibus, diameter unius per alteram tesecatur. 13. Sphęras intrinsecus se intersecantes dicimus, quarum maior pars unius in altera continetur. 14. Superficiem planam sphæram contingere dicimus, quæ cum sphæram tangat, ad omnem partem educta, non secat. 15. Denominatio proportionis primi ad secundum, dicitur quantitas, quę ducta in minorem producit maiorem: uel quæ maiorem diuidit secundum minorem. 16. Proportio dicitur componi ex duabus proportionibus, quando denominatio illius proportionis producitur ex ductu denominationum illarum proportionum, unius in alteram.

PETITIONES.

Petimus autem hæc. 1. Aequales angulos super idem punctum constitutos, æqualem continere distantiam æqualium linearum: ut si anguli a b c, & c b d sint æquales, & linea a b & b d sint æquales: tantum distabit linea a b à linea b c, quātum linea b d distat ab eadem linea b c. 2. Item inter quælibet duo puncta lineam, & inter quaslibet duas lineas superficiem posse extendi. 3. Item, cum duæ planæ superficies se contingunt, unā ex eis fieri superficiem. 4. Item duas planas superficies corpus non includere. 5. Item omnes easdem proportiones ex similibus proportionibus componi, & in similes proportiones dividi, & easdem habere denominationes.

THEORE-



366 VITELLONIS OPTICAE

per superficiem speculi a b per 31 th. 1 huius: patet per 28 th. 5 huius quoniam omnes reflectentur in sepion: concurrent ergo tam incidentes quam reflexi omnes in puncto c, quod est centrum sphæræ: omnes enim illi radij sunt diametri ipsius speculi, & omnes anguli semicirculi sunt æquales per 31 th. 1 huius: reflexio autem omnis fit secundum angulos æquales, ut patet per 20 th. 5 huius. Quicunq. itaq. radiorum solarium perrexerint per centrum speculi, quod est c, & peruenerint ad quæcunq. puncta superficiei speculi: illi omnes reflectentur in sepion, & concurrent in centro ipsius: radij uerò æquidistantes illis radijs non concurrent. Sit enim radius perpendicularis super superficiē speculi, qui est b c: hic ergo, ut prædictum est, transibit centrum speculi, quod est c: & reflectetur in seipsum. Hoc ergo ducatur per 31 pr. aliquis radius æquidistans: qualis est h k: & alius, qui o x: sintq. arcus a b inæquales arcui b x: secetq. linea k o circulum a b g in puncto y: & in arcu y n signetur punctum l: & ducatur linea c n. Quia itaq. angulus l n k est minor angulo c n k, ut pars suo toto: patet quod angulus l n k est minor angulo c n b quoniam anguli c n b & c n k sunt æquales per 13 th. 1 huius. Patet ergo per 20 th. 5 huius quod radius l n non reflectetur in punctum c. Fiat itaq. angulus b n f æqualis l n k: cadetq. punctum f citra punctum c in punctum aliquod semidiametri c b: & in corpore solari continuetur linea e f. Si itaq. quadrangulum f e l, cuius opposita sint latera e l & imaginemur moueri, quousq. linea n incidat ad locum, unde exiit: nunc punctus n motu suo describet secundum circulum in superficie speculi: & in tota peripheria illius circuli anguli in f remanent æquales: ergo angulus l n k est æqualis angulo b n f. Est ergo per 20 th. 5 huius à tota peripheria illius circuli reflexio omnium radiorum incidentium ad punctum f. Similiter quoq. si à puncto sphæ, quod est o, ducatur per p paradius æquidistans radio perpendiculari, qui est b c: hic sit ille radius æquidistans o x, secetq. circulum a b g in puncto x: & in arcu x s signetur punctum q in linea n f producta, sitq., ut perpendicularis e b secet circulum a b g in puncto p: & in arcu b s minor arcu b c: ergo & arcus x p (qui est æqualis arcui b s per 31 th. 1 huius) minor erit arcu p y æquali b c: ergo arcus x q s remanet maior arcu y b c: ergo per 33 th. 1 huius angulus x s q est maior angulo c n k. Radius ergo o s non reflectitur ad punctum f, sed ad aliquod punctum lineæ f c, quod sit h. Portio enim circuli y k n, quæ est æqualis portioni a b q, est minor portione x q s, quæ est æqualis portioni a b c: coaptetur quoq. linea o c. Si itaq. fiat latere e h, quadrangulum e h s intelligatur moueri, quousq. linea o s redeat ad locum, unde exiit: tunc punctum s motu suo describet in superficie speculi circulum, à cuius totali peripheria fiet reflexio ad punctum diametri speculi, qui est h. Et similiter est de quibuscunq. aliis radijs incidentibus superficiei speculi æquidistanter radio c b. Semper enim fiet reflexio omnium sibi similium radiorum à peripheria unius circuli totius speculi ad unum punctum diametri ipsius speculi: & lineæ radiales propinquiores diametro, reflectentur ad punctum propinquius centro c: & lineæ radiales remotiores à diametro, & æquidistantes illi, reflectantur ad punctum remotius à centro, quod est c. In quocunq. autem illorum punctorum ponatur aliquod corpus combustibile, per radios reflexos incenderetur. Sed quia radij sunt parui & debiles, oportet ut combustibile ponatur in puncto collectionis radiorum maiorem in radium. Patet ergo propositum. Ex hoc speculum, quantūm ad actum combustionis, efficacius erit speculo compositio ex planis speculis, de quo locuti sumus in fine quinti libri huius scientiæ. Posset quoq. per diligentiam artificis aliquod speculum ex pluribus humanis speculis componi, quod esset maioris efficatiæ ad combuscendum: hoc autem relinquimus industriæ perquirentis: quia sufficit nobis ut propositum sit hoc modo demonstratum.

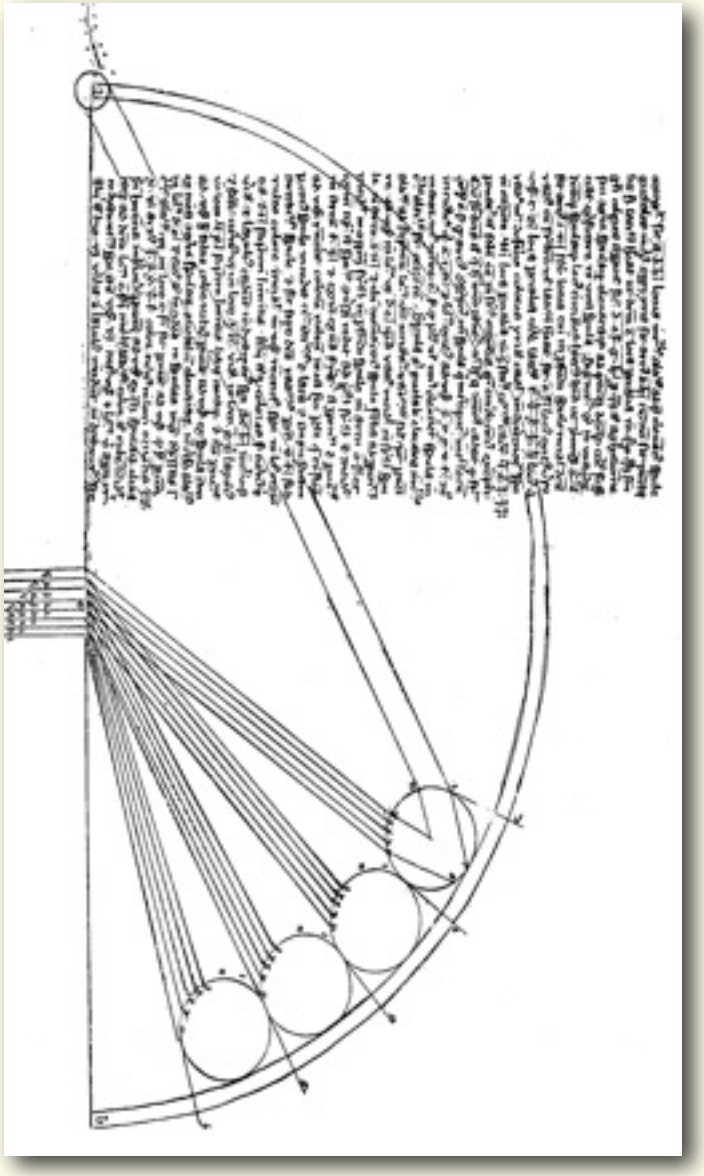
VITEL-

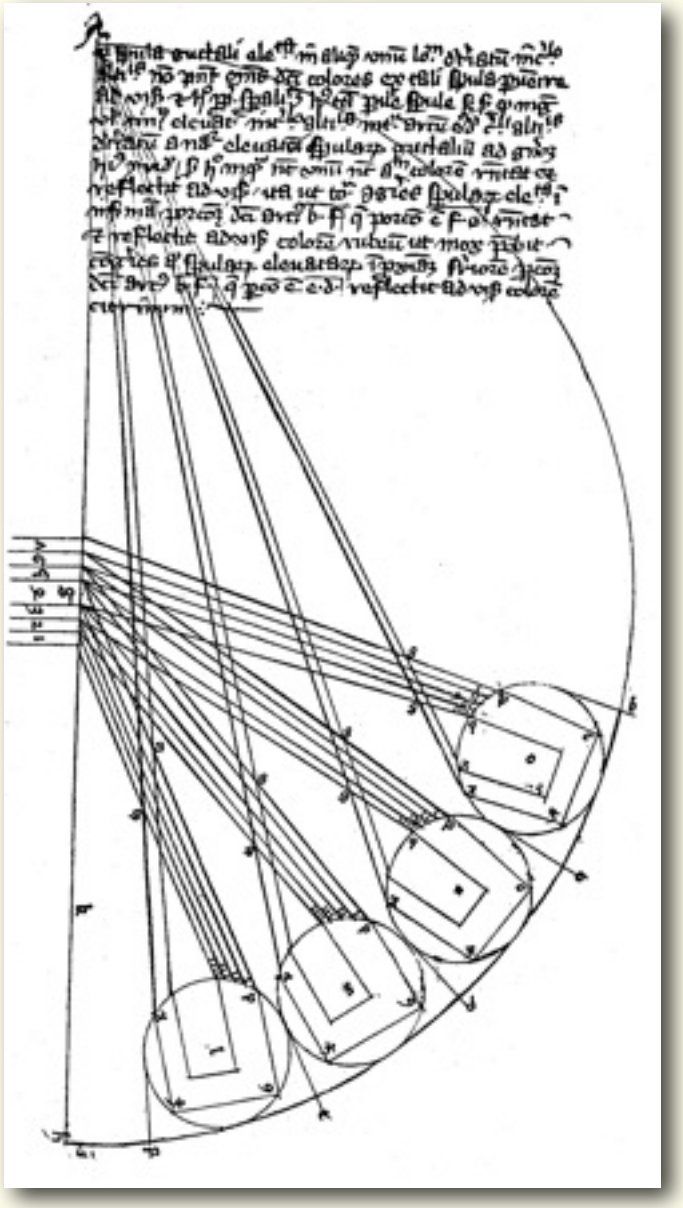
Witelo (ca. 1230-1280)

(Some pages from *Optics*)

Theodoric of Freiberg - *De iride*

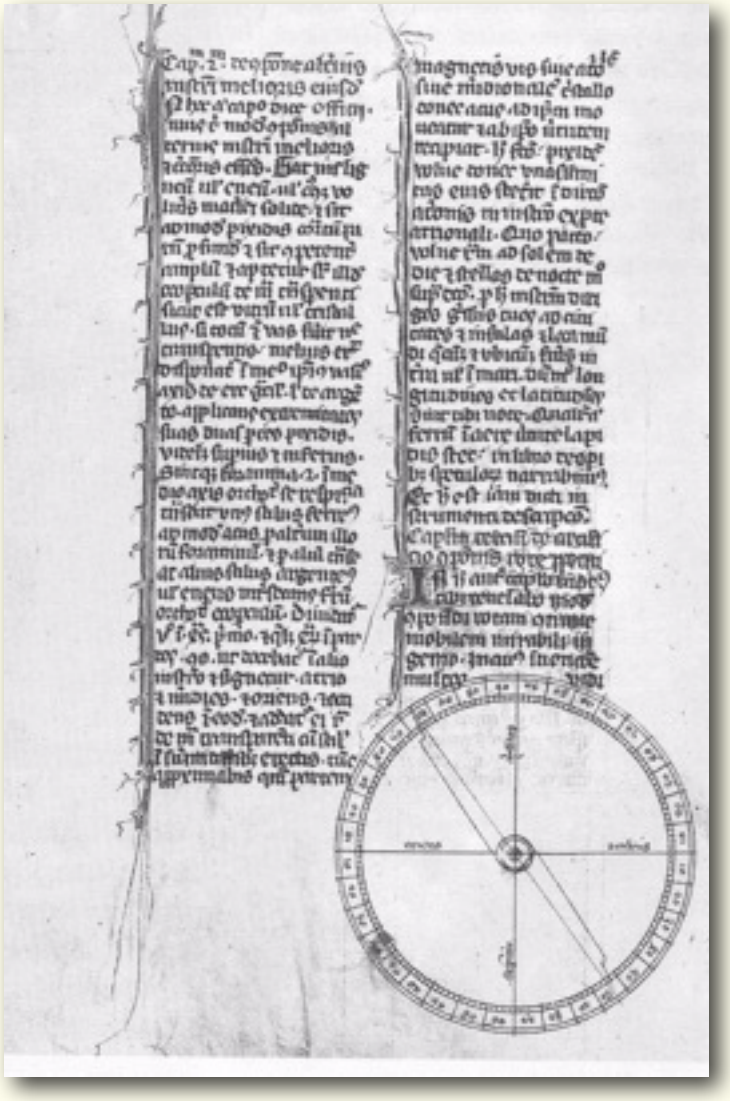
Theodoric of Freiberg - *De iride*





Magnetism

Pierre de Maricourt
(Petrus Peregrinus)
Epistola...de magnete (1269)



”Finished in camp at the siege of Lucera on the eighth day of August, Anno Domini MCCLXIX.”

”You must know, my dear friend, that whoever wishes to experiment, should be acquainted with the nature of things, and should not be ignorant of the motion of the celestial bodies. He must also be skilful in manipulation in order that, by means of this stone, he may produce these marvellous effects...
I wish to inform you that this stone bears in itself the likeness of the heavens, as I will now clearly demonstrate. There are in the heavens two points more important than all others, because on them, as on pivots, the celestial sphere revolves: these points are called, one the arctic or north pole, the other the antarctic or south pole. Similarly you must fully realize that in this stone there are two points styled respectively the north pole and the south pole...”

Petrus Peregrinus, *Epistola ...de magnete* (English translation, 1904)

”If you are very careful, you can discover these two points in a general way. One method for doing so is the following : With an instrument with which crystals and other stones are rounded let a lodestone be made into a globe (*magnes rotundus*) and then polished. A needle or an elongated piece of iron is then placed on top of the lodestone and a line is drawn in the direction of the needle or iron, thus dividing the stone into two equal parts. The needle is next placed on another part of the stone and a second median line drawn. If desired, this operation may be performed on many different parts, and undoubtedly all these lines will meet in two points just as all meridian or azimuth circles meet in the two opposite poles of the globe. One of these is the north pole, the other the south pole...”

Petrus Peregrinus, *Epistola ...de magnete* (English translation, 1904)

”The poles of a lodestone having been located in a general way, you will determine which is north and which south in the following manner: Take a wooden vessel rounded like a platter or dish, and in it place the stone in such a way that the two poles will be equidistant from the edge of the vessel; then place the dish in another and larger vessel full of water, so that the stone in the first-mentioned dish may be like a sailor in a boat. The second vessel should be of considerable size so that the first may resemble a ship floating in a river or on the sea.

I insist upon the larger size of the second vessel in order that the natural tendency of the lodestone may not be impeded by contact of one vessel against the sides of the other. When the stone has been thus placed, it will turn the dish round until the north pole lies in the direction of the north pole of the heavens, and the south pole of the stone points to the south pole of the heavens. Even if the stone be moved a thousand times away from its position, it will return thereto a thousand times, as by natural instinct...”

Petrus Peregrinus, *Epistola ...de magnete* (English translation, 1904)

”Should you wish to see how one lodestone attracts another, then, with two lodestones selected and prepared as mentioned in the preceding chapter, proceed as follows: Place one in its dish that it may float about as a sailor in a skiff, and let its poles which have already been determined be equidistant from the horizon, i.e., from the edge of the vessel. Taking the other stone in your hand, approach its north pole to the south pole of the lodestone floating in the vessel; the latter will follow the stone in your hand as if longing to cling to it.”

Petrus Peregrinus, *Epistola ...de magnete* (English translation, 1904)

”If, conversely, you bring the south end of the lodestone in your hand toward the north end of the floating lodestone, the same phenomenon will occur; namely, the floating lodestone will follow the one in your hand. Know then that this is the law: the north pole of one lodestone attracts the south pole of another, while the south pole attracts the north. Should you proceed otherwise and bring the north pole of one near the north pole of another, the one you hold in your hand will seem to put the floating one to flight. If the south pole of one is brought near the south pole of another, the same will happen. This is because the north pole of one seeks the south pole of the other, and therefore repels the north pole...”

Petrus Peregrinus, *Epistola ...de magnete* (English translation, 1904)

”…it is clear that the poles of the lodestone derive their virtue from the poles of the heavens. As regards the other parts of the stone, the right conclusion is, that they obtain their virtue from the other parts of the heavens, so that we may infer that not only the poles of the stone receive their virtue and influence from the poles of the world, but likewise also the other parts, or the entire stone from the entire heavens.”

Petrus Peregrinus, *Epistola ...de magnete* (English translation, 1904)

Medieval world picture

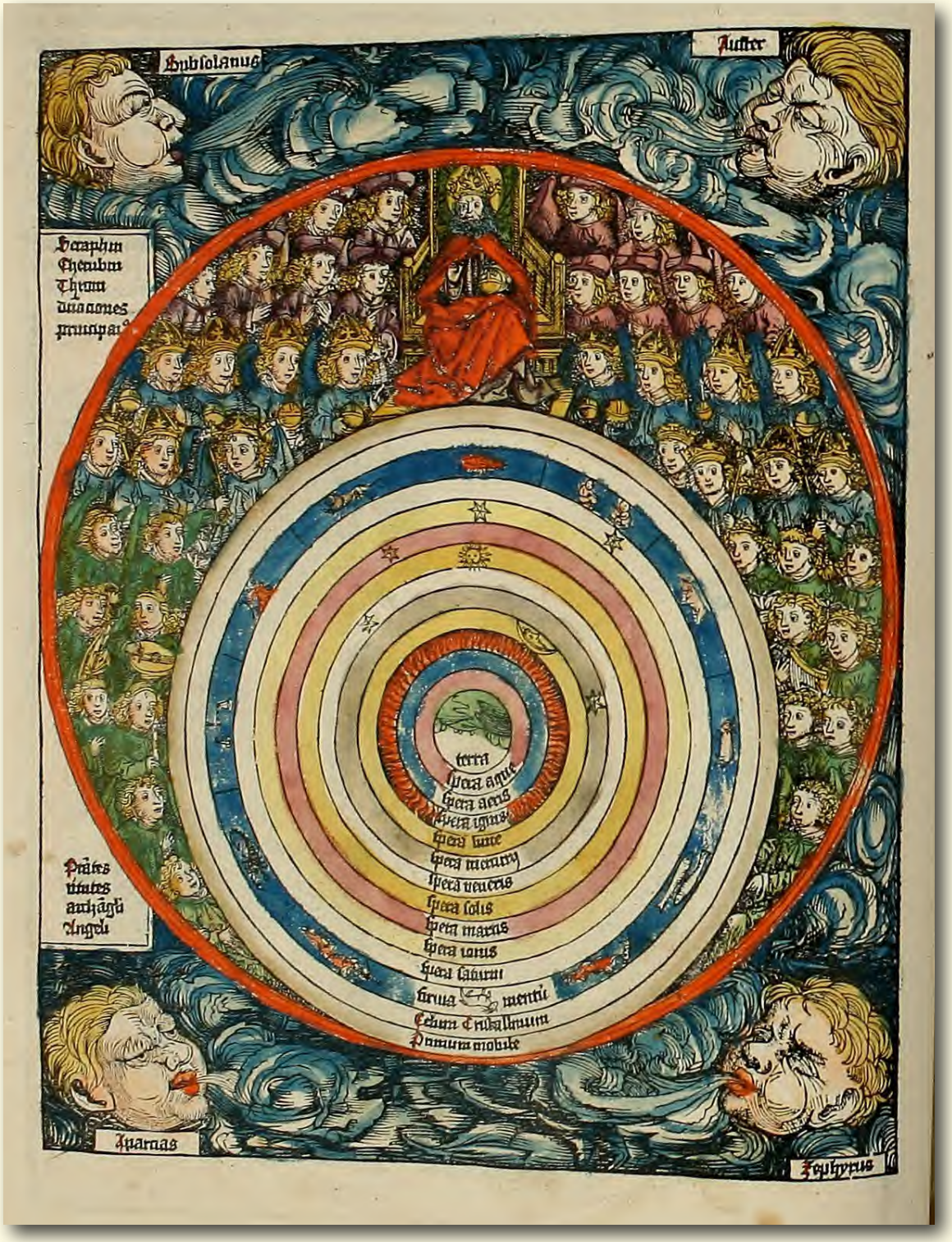
Seraphim	**Primum mobile**
Cherubim	**Fixed stars**
Thrones	**Saturn**
Dominations	**Jupiter**
Virtues	**Mars**
Powers	**Sun**
Principalities	**Venus**
Archangels	**Mercury**
Angels	**Moon**

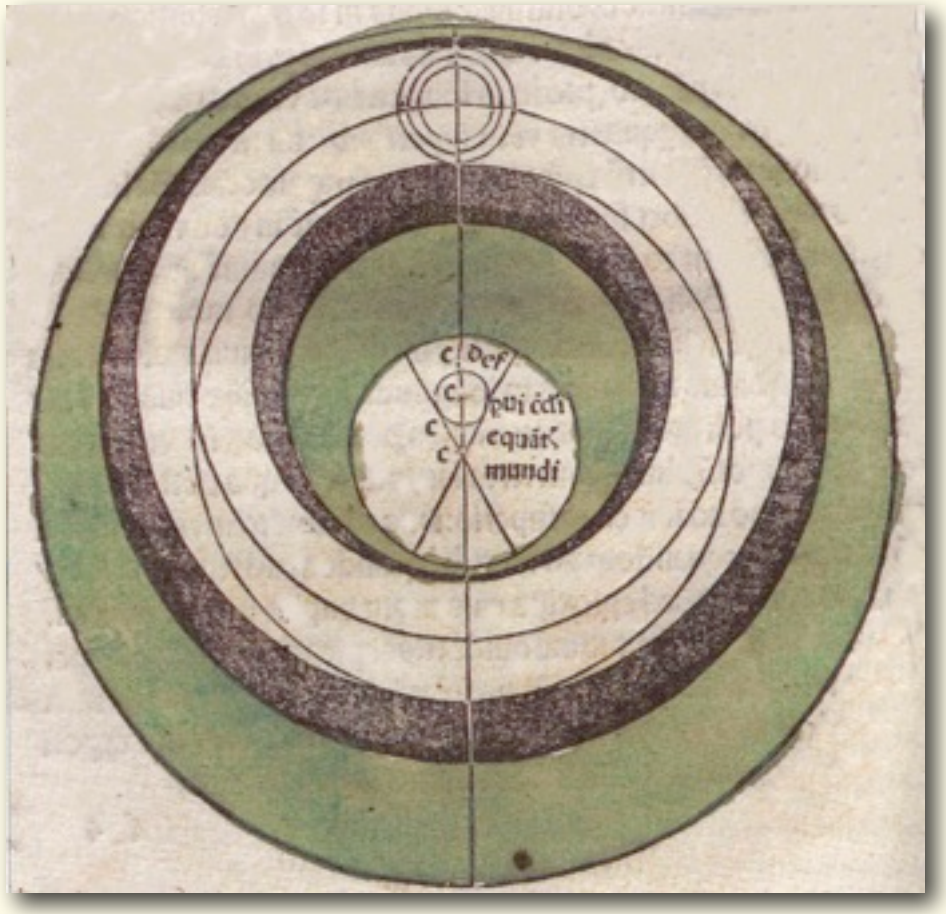
Hierarchy of nine orders of the angelic beings
according to Dionysius the Areopagite (Pseudo-Dionysus)
On the Celestial and Ecclesiastical Hierarchy (Vth century)

A representation of the world

Hartman Schedelius,
Opus de historiis aetatum mundi

[*Chronicle of the World* (1493)]





A model of epicycles and deferents inscribed between crystalline spheres of varying thickness

Woodcut (1559)

"Fro therthe vnto the heuen, wherin the sterres ben sette, is as moche grete espace; ffor it is ten thousand and .lv. sythes as moche, and more, as is alle therthe of thycknes*. And who that coude acompte after the nombre and fourme, he myght knowe how many ynches it is of the honde of a man, and how many feet, how many myles, and how many Journeyes it is from hens to the firmament or heuen. Ffor it is as moche way ynto the heuen as yf a man myght goo the right way without lettyng, and that he myght goo euery day xxv myles of Fraunce,... and that he taried not on the waye, yet shold he goo the tyme of seuen .M.i.C. and .lvii. yere and a half** er he had goon somoche way as fro hens vnto the heuen where the sterres be inne."

* That is, 10,055 earth diameters
** That is, 7,157½ years

Gossouin "Image du Monde" (1245);
[English translation from 1480]

”It is generally known that medieval man had faith in the geocentric picture of the world...
He was convinced that his conception of the world, at least its broad outline, is fully compatible with reality... He did not have any doubts concerning the truth of this conception. He believed that it had been confirmed both by the Bible and by the great minds of antiquity... Given that, how could anyone have even the tiniest doubt concerning credibility of science guaranteed by great human and divine authorities?”

Norbert Max Wildiers, *World picture and theology*

In spite of the successes of medieval physics the Aristotelian system remained accepted as the true description of the world. It was because of the great coherence of that system, which could not be seriously damaged by small modifications such as the theory of *impetus* or alternative laws of motion.

Only the idea of Copernicus concerning multiple centres of gravitation was a blow at the very basis of the Aristotelian system

Development of mathematics in Europe

Muhammad ibn Mūsā al-Khwārizmī (ca. 780-850)

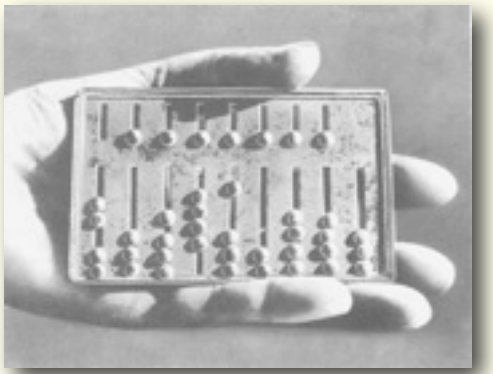
books translated from Arabic to Latin under titles

Algorithmi de numero Indorum
Liber algebrae et almucabala

(from his work on elementary algebra, *al-jabr wa'al-muqābala*)
Terms such as algebra, algorithm, originated from al-Khwārizmī's works.

Introduction of zero and Hindu numerals (now called Arabic) in Europe since the XIIth century was a slow process which met with resistance (for example, in 1299 the new numerals were prohibited in Florence)

Development of mathematics in Europe

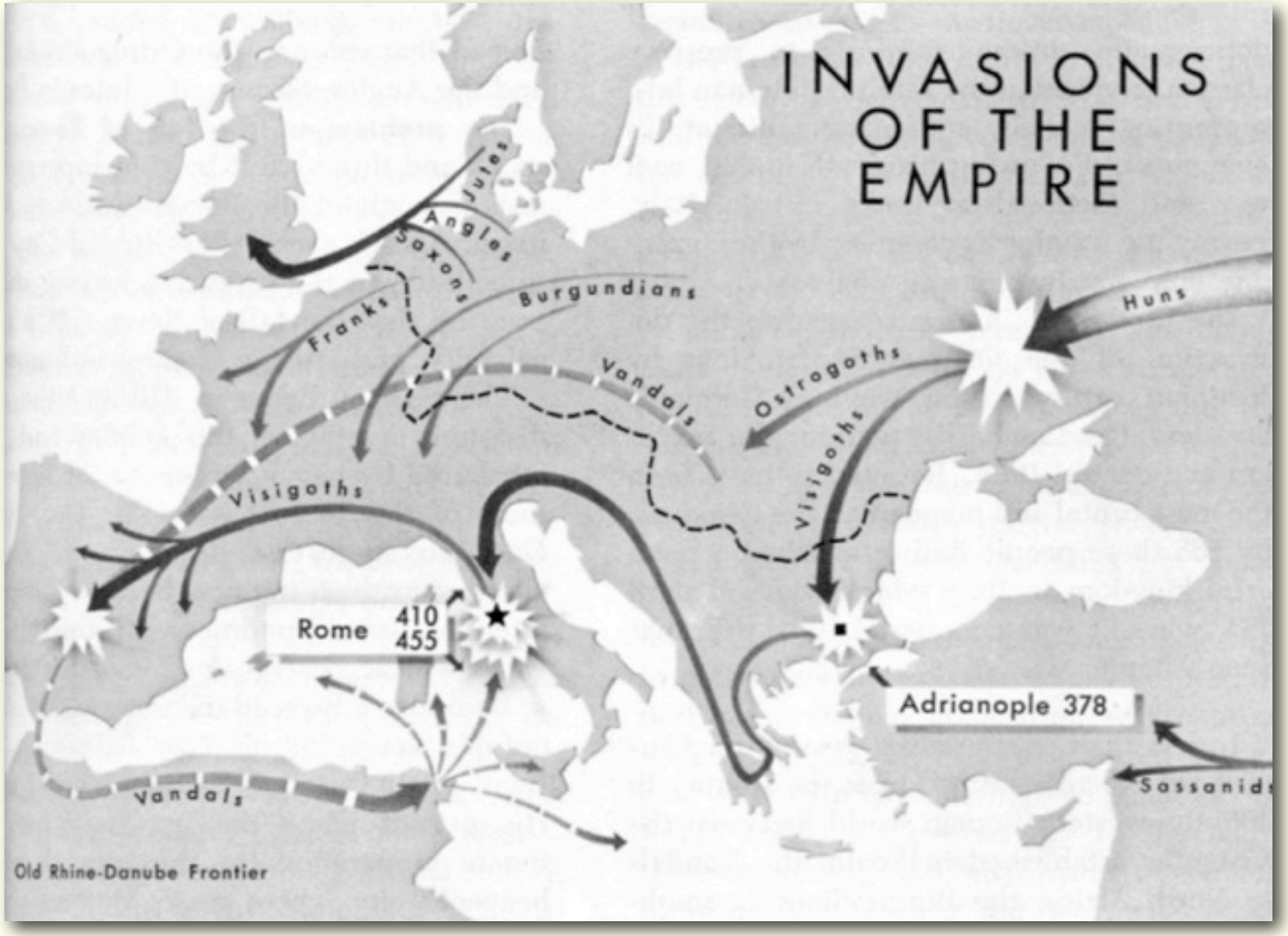


Roman abacus

Originally words *minus* and *piu* were used in calculations;
they were later replaced by letters ”*m*” and ”*p*”
Introduction of mathematical symbols:

”+” and ”–”	Johann Widmann (1479)
”=”	Robert Recorde (1557)
”×”	William Oughtred (beginning of the XVIIth cent.)
”<” and ”>”	Thomas Harriot (1631)
”√”	Christoph Rudolff (1525)

Competition between ”algorists” and ”abacists”


INVASIONS OF THE EMPIRE
Jutes
Angles
Saxons
Franks
Burgundians
Huns
Vandals
Ostrogoths
Visigoths
Visigoths
Rome 410 455
Adrianople 378
Vandals
Sassanids
Old Rhine-Danube Frontier