

#### 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 XII<sup>th</sup> century - first universities

 beginning of the XIII<sup>th</sup> century – ban on teaching Aristotelian physics in Paris

 1277 - bishop Étienne Tempier of Paris - condemnation of 219 theses – increase of intelectual freedom

XIV<sup>th</sup> century – acceptance of modified Aristotelelian science



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										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)





**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

Paris type (administered by the students) (administered by the professors)



King's College, Oxford



Trinity College, Cambridge





Sorbonne



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

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University lecture (second half of the XIV<sup>th</sup> 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, VI<sup>th</sup> 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 XIII<sup>th</sup> 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 <u>cause</u> of motion, whereas our momentum is a <u>measure</u> 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 16<sup>th</sup> 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 > Rv = 0 for  $F \le R$  $F = 0 \rightarrow v = 0$  (principle of inertia) Philoponus:  $v \sim (F - R)$  for  $F \ge R$ v = 0 for F < RBradwardine:  $\mathbf{n} \cdot \mathbf{v} = \theta [(F/R)'']$  $v \sim \log (F/R)$ 



"motus uniformiter difformis"

Nicole Oresme (ca. 1320-1382)

Latitudo (Intensio)

Longitudo (Extensio)

"motus uniformis"

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

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#### Nicole Oresme De configuratione qualitatum

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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



# Experimental facts concerning light

(known since Antiquity)

propagation in straight lines

reflection

refraction

rainbow/colours

geometrical optics  $\rightarrow$  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,  $\Pi$ ερι 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 XVI<sup>th</sup> century



An imaginary portrait in Padua



### 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*)

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#### VITELLONIS FI-LII THVRINGORVM ET PO-

#### DEFINITIONES.



V A E uerò per modum principiorum huic primo libro præmittimus, funtifta. 1. Cathetum dicimus lineam perpendicularé fuper fuperficiem aliquam, erectam. 2. Polum dicimus omnem punctum lineas fuper fuperficiem circuit à centro osthogonaliter erectas. 3. Conuexam lineam uel fuperficiem dicimus, que extrinfecus aliquam regularem curuitatem habet. 4. Lineam cocauam uel fuperficiem dicimus, que intrinfecus

aliquam regularem curuitatem habet. 5. Lineam fuper fuperficiem connexam uel concauam perpendicularem dicimus, que fuper planam fuperficié in puncho fue incidentia fuperficiem conuexam uel concauam contingentem efteredta, 6. Circuli feinuicem fecantes dicuntur, quorum diametris eff ali qua linea communis,u. no reliquum non continente.7. Circulus magnus fpheræ dicitur, qui transiens cen ttam fphære, diuidit ipfam in duo æqualia. 8. Minor uerò circulus fehære dicitue. qui neque tranfit centrum fohæræ, neque diuidit ipfam in duo æqualia. 9. Sphæras æquales dicimus, quarum diametri funt æquales. 10. Sphæras uel circulos feinut. cem continentes, equidiffantes dicimus, inter quas à centro maioris ducta linea à conuexo minoris ad concauum maioris funt aquales. n. Spharas fe inuicem co tingentes dicimus, que fe tangentes extrinfecus uel intrinfecus no fecant. 12. Sphe ras feinuicem interfecantes dicimus, cum fpheris fe non continentibus, diameter unius per alteram refecatur. 13. Spheras intrinfecus fe interfecantes dicimus, quarum maior pars unius in altera continetur. 14. Superficiem planam fphæram contingere dicimus, que cum fphæram tangat, ad omnem partem educta, non fecar. 15. Denominatio proportionis primi ad fecundum, dicitur quantitas, que ducta in minorem producit maiorem : uel qua maiorem diuidit fecundum 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 fuperidem punčlum conflitutos, æqualem continere diflantiam æqualium linearum: ut fi anguli a b e, & c b d fint æquales, & linca a b & b d fint æquales:tantum diflabit linca a b à linea b c, quätum linca b d diflar ab eadem linca b c. a. Item inter qualibet duo pun&a lineam, & inter qualiblet duas lineas fuperficies for ontingunt, uni ex eis fieri fuperficiem. 4. L tem duas planas fuperficies corpus non includere. 5. Item omnes eafdem proportiones ex fimilibus proportionibus componi, & in fimiles proportionite denominationes.

THEORE.

#### VITELLONIS OPTICAE

per faperficient foecoli a big por 72 chi a bairrepatet per anchi s'hoios quonian omnes reflectoreur in fapioa concurrint ergo fam socide son quien reflexi ormen in punito c, quod efficeration dio-

cuit: onnes enimilicrady font diametriplias fpecali, & omnes anguli femitirculi funt arquales per 43 ch.s haiust reflexio autera comis fit fer and son angulas se pastes, at paret per 20 th 5 hour. Quicangs itaq, radiorum folanum pertessiterint per crotrem fpeculi, quod elè c, le perucocrint ad que cano punda faperficici fpeculitili o noes selle tenos in implos, & concertent in centro ipfrastradij urró mquidiftantes illes radijs non concurrent. Sit e nim radius perpédicularis faper la perficié (peculi, qui elè e bchie ergo, at premitiam eft, tractibic centrum (paculi, quod off e: & reflectetur in feipfam. Huic er ga ducatar per p pa aliquis radies mquidiftans : quifir beife alius, qui o u inf, arcut n b inmqualis seearbs: fecerá, linea lo circulam a big in puncto y: &cin arcu y in fignetar ponchara le 3e ducatur linea e n. Quiainno, angulas lit. kertminor angulo cnk, at pars fuo toto: patet quod angulus liti keitminor angulo en bequotiam anguli en b de en k fant requisles per 41th thuins. Paret ergo per an th 5 haius quod radius In non refleftetar in pantiam c. Fut itaqi angulas bin f equalis? nit cadetij puoft im f eitra punft in ein punftum aligioidie. midiamein e bi Sein corpore folari continuetar linea el Siltapevadrangelumn fel, fico poro a fee fuolarere el timaginetar mourre, quorify, lineal transidat ad locum, under exister rune put Bas nimora fun deferibet gagadam circulum in faperficie fpeculi: &in tota pripheriailhas circulangulos Infreminer sequals : ergo angulas Ink eft aquals angolo binf. Fortergo per such g hous à tota peripherta illus circult reflexio omnourn radiorum incidentium ad prodhum f. Similiter gowy, fià puncho fa bs, quad eft a, duratur per paradius reguid it ins radio per yen. diculari, qui eit e hole fit ille radors æquidistans os, fecars circalum a bigin panéto x: & in arca xa figaetar panéton q in linea nf products, firq, ut perpendicularis e b fecer circultam a b gin

paugtto pole for areas b s minor area n beergo & areas x p (qui elt a qualis areas b s per gy tha buint) minor estaren py segaali bir ergo arons sigs remartet maior aron y kiec ergo per 44 tha burus angalar x s q th mator angel conk. Radius ergs o s non reflectiver ad punctum lifed ad aliqued pen etum inere fe, quod fith. Portio enun circul. y kn, qua ell aqualis portioni n b q, eft minor portione x q s,que elle qualis portioni s b kropuletur quoq-linea o e bitraq-fico latere e h,quadran gulania chis intelligit o morent quotifa linea o sredest ad locum, ande existit: tune pundham s mosu fao defenbet in faperficie freculi circulum, à curus totali peripheria fiet orfrexio ad pandram diametri fpeculi, pri e 8 h.E.e fimiliter eff de quibufcan quelque radge incidenadus taperficiel fpeculi aquid de sterradio e b. Semperenim fiet reflexis omnium fibi fundiori, radiorem à peripharia unias circuli totins forceli ad unum pundham diametri ipfius fortuli: & lines radiales propinquiores d'unierro, reflechio tur ad punchum propinquius centro cità linen radisles remotiones il d'unierro, ils is qui diffusiosi illi, reflectiuntur ad punchum remotios à centro, quod efficale quocung, auten illerum punctorum ponatar aliquad corpus combuffibile, per radios reflexos incen letur. Sed quia rada firre pauci & debiles, oporter us combufble diutius in puncho colleftionis radiorum mor in traber Pitet ergopropolition. Ethoc fpecelum, quintúm ad afhum combuflionis, efficacion elbiper alo composito explanis specalis, de quo locani famus in fine quinti liebishaios feiencie. Porfet quaq per dilgentian amfieis aliquod (peculum ex planbushusulmod speculia composit, quod effet matoris efficacie ad combucendem thos

Paten reingonus indefiniz perguirentis : qui a falficit nobia ut propatitum fri boc mode destan-Bratam.

VITEL.

## Witelo (ca. 1230-1280) (Some pages from *Optics*)

#### VITELLONIS OFTICAE

them, quod fir f. & en has puntle specia redutur diameter per centrú e, que fit fgilt à dueb. termi. nis iftius diametri f g ducktur dag lineg in intrinfera faperficie organiscipag necellario eront perpidicu-laren faper faperficie tandclaming.ideo. per faperfi teres are for any appropriate and the galaxies of the second seco fecundù quitezzoi medietaris grani bordei , que fire Lm, n, quarti primit, qdf eft Life propingatus bali un fis feigli punche f, à que diffet per quantient medie tatia grans hordes Et deinde reducatur uas ad torna torium, & fignérar in ipla tres circuli equidifiers, tranleuntes p ila tria plicha l.m. ni q circuli douident Intek g k illi diaifg integ, quy ell f h. uppefek ... ppertional ter prias desile per ty pit, firsty desilior neggi punita o, p. q. it fent in in unaquage iftera mile circulară dua păche appafra, și funi extremira nes alienius diametri illoră circulară - ur păcha diui

fonni lineq (h ( qd' ell puniti i ) opponier in lines g k puniti n, k felines i n dismeter circuli so-quidilizatio circulo a c b d ik familiar lines m p fit dismeter alterius circuli , k lines n q fit disme. ter circult terris. Diaidatar itaq, medica ilbori otrealară în 160 partes, & fi pafaibile faerie, parima au deinde faper linei fi alteră duară linerară prepidiculară, șoț fancțis în gi, pandă medid, of ell m perforetur forami rorandi: & fit me dietas d'amero foraminis fer un da quantitari diffantia circulară, que eficineu in l'artinget erga forant illud ambos circulus extremos, le medius circulu ră dinăder corentă faramante portpastin, quertă trăfit p constă faramenis. Deinde acceptator lamina mora plana aliquantulam (pifa, îc fit riut (pifaitada licut arț ipfița înfirameni, Arman ligirada fit duard digeneră, ficur în are unfe, în rean întradu în prope înce, în în providilantei înperficierei: pla nerveră adeci, at câmunis fective înperficierei cap întradore în înfeitetudore în finite ordia, que ficre, dividurarly in day separate proprie to first medio pushes, of first durarur lines refls perpendieutorier fugeripfen inetra in faperficie latitudinis, dag ferter & her, at pater en premitie & per an p strevellarie equidilabit ambabas lineis lógitad inst duidens foperficié tabale per equalia de in has horn perpendiculari, que ell cu, à parte l'any r y, cui fuperitar, incipienda , fignamar tria pan An equativer deltantis ab innici feriedà qui traté antiperito grani bardei, que fint a, y, a, la 1 media ithere publiced, quod eff y plareter lamina for appen sufficio. ficio, forominis peripheria ad alla duo pundla peringet, etito, hoc foramen equile formului lun nevus fattuin

ora unfin. Deinde in dio pousia dividurar femidiameter unfin fundi, que eff e, caius extremitați in are sufis faperitat ana liveară pespendiculari que eft fte feb puntter diaifonis t & ab hor puntto medio t durarar lines perpendiculuris foper eandé dismetrum, que fit r tet deinde panatur balls parag laming laper his linei, donee linea, que eff differêria cômunia larizadini de gelandezein lamine, copelleren, fopponatur lineg illi perpen diculari duthe lap re diametrik, que limitere elle en foip punttut duidens lineà lamine, que ett cômunie differentia faperficieram latitudinis Repra-

fundentis, qui ell puedtas t, faperpulitas puedta t, fignato in lines fa lensi diametro unfor deinde chialidetar parus lamina funda unfo; erit papo, the forund a y a good eft in paraa lamina, que eft r a,a, diretté oppofició faramini las n, qd' eft in uafe ora & evid ince ordia, que ell m y, copular efera ellar foramină în înperficie cir culi medițerià circuloră grian fignatori, cuine diameter efficien m prezida linea m y pquidiftant diametro unfis, que eff fe. Deinde refecetor en ora unfis para interiacia duas dumentos orthogonaliser is fectres, que fir para quarta proximé frequên quard illuin que els forunt, confortend lamine opponierer de els in circule a els duceres foi dens arcui a due planetar locus fectiona, dones first una laparíticies els faporíficies fan di unfin. Er duffa quarta eibruli, que fir a d, fecun dù quâtitard circuli are dinidarar in go grud. R deutdetter grud in ministe. R ihr und redere informato it figurate, deia-cepa damas nomi informatio. Deinde accipitare regula pres quadriguis, ceisa bigu malg fit uniste auben. R fit or quattore forgerficies opfen eiterserene . Larendenia daard digitari di adequitar foperficies vina, donce fiant quadra redhigule. Deinde in me-cies inframéti obiungstur lupficiei regule : arit & lógitudo regule qualis diametra

inflorents.

#### LIBER TERTIVI.

st.erithicula, ut patet ex collderänbus anathomiä oculi, fugficiet ergo anterior jella espartio fagéiciei maioris fphævæ (à fie fphæva unea consinens ipfam, Schare compref for qualiter deflections ad oppolitum for aminis, quod eft in antersori parte uner, quia foreian ab no eft confirmitis, ficur, autem for amen rotandam, quod eft in anteniori parganez elè directiz oppofinim extremitati concauitatis nerui fuper què collocatur os chat, li crià in parte politeriore cocauitatis uneze efit foramen rotundam, quod efi fup commitation concatitatis nervi, & foramen, quod eff in anteriori unea, eft oppolini Examiniconcaultatis nenai quoniam nerusas opticus interfecat tunicam consistential Suncan & penetrat ornets tunicas oculius(g ad [pharram criftallinam, gan pyramide nou interfecat, ficut & humor uitrean, § in neuti optici pyramidali cóciato collocatur, inte communis fectio pyramidis neuti optici. & Ipharae criftallin a, est circulus p. 109. primi haius, foltarra itaqi glacialis fil compolita in extremitate concauitatis neval opei o & inforamine pofferiori uneze rotando. Extremitat ergo nerui continet medium Educite glacialis & eff nersus ille concasus deferens in fe fpicitum utilbilem i corebra al outrin & per eius uenas paruas peruenti ad nutrimennam ad oculam. & difundiur en illo per utas inflramenti. & ell in interfectione hutas nervi in anteriori parte cere bri airtus tafiua fenriens & dijudicana omne utilbde. & confolidatur unea cum glaciala activate continente foramé notandam in polleriori anez. Interfecant quog le lphae sediar du e feiliert glacialis déuitrea neceffario, cum consersum unitas obutet educos aberias, licat esh fant diaerfænanaræ & diafonitatis, lic fant portiones dioerfaril føbæ uson fe fecanzium, communis izaq fectio illarum fphærarum eft circulus p.74. primi har an Idem er go circultas ell balls pyramidis neruí optici A interfectionas endidem py

unido, & fohreræ criftallinæ, & confolidationis uneæ Lilaste cum lohaera cniltallina , & forte interfectionis eanadem foforrarum. Corpus uero cofolidatiue co enerpassen pyramidalem nerui, spaze eft intra foram? ell'sper quod transit merutur, & intra circunferentiam foture glacialis, & continet folteram uncam. Ex his rater att himorem glacialem propeie eile organium urremolitar, nam huits folius diafonitas eff receptia bits forma-û utîbilitê, ôz etk in medio omnitê ôz humorû & unicarum collocature, & fi alij colouring nanice oel hu mori accidat lelio faloo glaciali hamore, femper autilis medicing recipit oculus curation?, & fanatur ac refotainar unfan : Ipfa uero corrupta, corrumpitar uifas transfine fpe reflitutionis per autollium curat medicina. liorititaqahumor cnifallinas uel glacialis principaliteraistaris usliag organum, propter quod eft ante dill gentias conferentil, & côfittuit natura duos oculos pe pers perfectionem bonitatis utilonis, & complemenfleius, Sicergo patet, quod humores & tunice ocus li ligherice le interfecant, de patet declaratio diffinition mipropolite ocali fecădam omniă eoram experiennă qui de gollus anathomia hachenus feripferunt. Hare auté contia, que feilicet de copolitione oculi, in hac quarta propolitione haius terujildri noltrie perforchitze fant præmila, nunc fummanim per figur am mathematicam diroinus ecomplanda, que eft talis. Sit enim omtril ocalipanchi a de faperficies consensa ipfius glacialis ar onbed, & faperficies coaexa ipfius unven areas bed, & tela aranea cooperiens glacialem anterias fir arcus b e d,tela quoq aranez inter corpus glacialis & vitreze fit lines



#### Theodoric of Freiberg - De iride

and quistoon f talk ? man the men the me the vast Dies com ut tim conferte nt chi on te upte ont reflocies as por that & part & peaks the adres be maling phy solution or received as excelling to fue fort mag attent a fie yust as git methoused 18 abifut abauce polite vest is far make a pr yebuln ag an cost in at cost maker of most by and messeles diup mfrit tel cost por ante fine par stin estar cost nomena l'ent sont selles value av locopt fine mass f & f delace on to profit selles locopt fine mass of & f delace on to profit set mA store to for oblig makered + fach Bu vefleger co los made her postere 2 2m and time the as low to be mering \$ 1 ? for exercites prestile most wat mentiles from the so valy a ful metion and ford the Proceeding a few fractions sould me the first of the source of the cons or souto fue merche 27 folin or har at also In the people service 2 man por fin people min villast & fie es elleg putte f storis lan" a man beforts quite yeig dors rahers ment ville a bard on the guite yeig dors rahers ment ville a bard on the guite yeig dors rahers and a fait with source - Bost me a he fi fi firsta vale a fait with source - Bost me a he fi fi firsta vale a fait for for 1 suitene reverflecter ad und oppin fr 4 at 6 a for a all rates mlos mush par averain to for vade for y cond often ma congronale fie A horas ATD - for good of the control of the series and grouble for it abing minister the al cappion at about goin at Fre And mat pi to & goult art Burt.





And an and a star for the set of Frin agits was gradie for af all info sai hil og ade Ad bada men color yridelin pruch metidut Cardinated & a this ab point . CAN" 10. Sofighter from a con at new tory clour mi With application of land bern 2 81 to all vone & Panle Juin and fund the first all and the art of parts of the second and per a comit pett por all prime a gitte mon a gitte and pett a comit pett por all prime and a mon and port his ut por a prime all prime prime por for the sort of a prime prime a fear all of gives and a prime many portal for p and a bounce someting p spins all all of at 2000 prime part all of a port of port and a second and a second and prime a second prime of second a second and a second prime a second a second a second a second a second a second a for a second a second a second a second a second a second a for a second must romit furtient or and in reards allow me or atta hundo Berros Fisito Ba hunde an te fit un a fran Art Blad der of fatte a to face all a fre " fra "

### 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..."

"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..."

"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."

"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..."

"...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."

# 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* (V<sup>th</sup> 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, 7,157<sup>1</sup>/<sub>2</sub> 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 XII<sup>th</sup> 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)
" <u> </u> "	Robert Recorde (1557)
"×"	William Oughtred
	(beginning of the XVII <sup>th</sup> cent.)
"<" and ">"	Thomas Harriot (1631)
"√"	Christoph Rudolff (1525)



Competition between "algorists" and "abacists"



