

PROLOGUE: SOLVING THE PROBLEM OF THE SCIENTIFIC REVOLUTION

(1) The affairs of the Empire of letters are in a situation in which they never were and never will be again; we are passing now from an old world into the new world, and we are working seriously on the first foundation of the sciences.

Au reste les affaires de l'Empire des lettres sont dans une situation, où elles ne furent et ne seront jamais, on passe actuellement d'un vieux monde dans le nouveau, et on travaille sérieusement à la première fondation des sciences.

Dom Robert Desgabets OSB, letter of 18 September 1676; in *Oeuvres complètes* de Malebranche, 18, p. 122

(7) Man is bound to advance through the fog. But when he looks back to judge those who lived before him, he fails to see any fog on their path. From his present, which was their far-away future, the path looks to him entirely clear, visible over its full extension. He can see the path, he can see the people who advance, but the fog is no longer there.

L'homme est celui qui avance dans le brouillard. Mais quand il regarde en arrière pour juger les gens du passé il ne voit aucun brouillard sur leur chemin. De son présent, qui fut leur avenir lointain, le chemin lui paraît entièrement clair, visible dans toute son étendue. Il voit le chemin, il voit les gens qui s'avancent, il voit leurs erreurs, mais le brouillard n'est plus là.

Milan Kundera, 'Les chemins dans le brouillard', *L'Infini* 40 (November 1992); p. 42-64; p. 64.

(8) No understanding of our age is possible if we do not liberate ourselves from the illusion of necessity: The century is not explicable (to the extent that it is) if we fail to acknowledge all that was unforeseeable about it.

L'intelligence de notre époque n'est possible que si nous nous libérons de l'illusion de la nécessité: le siècle n'est explicable, dans la mesure où il l'est, que si on lui rend son caractère imprévisible ...

François Furet, *Le passé d'une illusion. Essai sur l'idée communiste au XX^e siècle*. Paris: Laffont, 1995; p. 16.

(10) Truth will sooner emerge from error than from confusion.

Attamen quia citius emergit veritas ex errore quam ex confusione ...

Francis Bacon, *Works* I, p. 261 (*Novum Organum*, second book, aphorism 20)

(11) ... all explanations, however plausible they may be, ultimately turn around in a circle. Which, after all, is not a scandal for the human mind. It is fairly normal in history — even in the history of the human mind — that there are inexplicable events, irreducible facts, absolute beginnings. ... It is impossible, in history, to empty the fact, and to explain everything.

Car toutes les explications, si plausibles qu'elles soient, finalement tournent en rond. Ce qui, après tout, n'est pas un scandale pour l'esprit. Il est assez normal qu'il y ait dans l'histoire — et dans l'histoire de l'esprit — des événements inexplicables, des faits irréductibles, des commencements absolus. ... Il est impossible, en histoire, d'évacuer le fait, et de tout expliquer.

A. Koyré, 'Les philosophes et la machine'. In: idem, *Etudes d'histoire de la pensée philosophique*, p. 305-339; p. 316; p. 339.

I GREEK FOUNDATIONS, CHINESE CONTRASTS

(23) ... in reaction to this dual danger — the emergence of [mathematical] knowledge outside the domain of philosophy, and of skepticism from the inside — philosophers tend at the price of mutual concessions to produce a unified system, a pool of respectable convictions.

This is the birth of eclecticism, with pieces borrowed from all systems under primary condition of

... pour réagir contre ce double danger — constitution d'une connaissance extra-philosophique et scepticisme au sein même de la philosophie — les philosophes tendent à constituer, au prix de concessions mutuelles, un système unitaire, un pool des convictions respectables.

L'eclecticisme s'installe, morceaux empruntés à tous les systèmes, auxquels on demande avant tout un certain état d'esprit commun — un 'bon' esprit, naturellement. Pour

their sharing a certain spiritual state – naturally, a ‘good’ spirit. So as to render this compromise the solidity that it can no longer draw from rigorous argument (which would be fatal to it), it is covered with a vague religiosity that must cement and dogmatize the whole ... Prolific to the point of overflowing, the artisans of this blend, Poseidonios and Philo give their responses to everything, satisfy everyone, handle every subject, soothe every controversy, draw from each system what suits them, and reconcile all dogmas with each other.

III GREEK NATURE-KNOWLEDGE TRANSPLANTED IN PART: MEDIEVAL EUROPE

(53) ... master of those who know ...

(54) ... whether in the motions of heavy and light bodies toward their natural places all succession arises from the resistance of the medium.

(55) Even if a sailor descends to the bottom of the sea so that he has hundred vessels of water upon his shoulders, he does not sense the weight of that water, as that water which is above him does not incline to be farther below.

... even if the water were not in its natural place, but very high in a vessel like on top of the tower of the Notre Dame, still one part of it would not incline to be below so that, if someone would be there in a bath with his leg on the bottom so that above that leg there would be a large quantity of water which in the air he would not be able to carry, he would still not feel the weight of that water.

(56) ... motion can be perceived only if we can see that one body assumes a different position relative to another body.

(57) ... moved toward the east very rapidly with the air through which it passes

(58) But everyone maintains, and I think myself, that the heavens do move and not the Earth. For God hath established the world which shall not be moved.

(59) ... which are not evidently conclusive

donner à ce compromis la solidité qu’il ne peut plus tirer de la rigueur de l’argumentation (elle lui serait fatale), on le coiffe d’une vague religiosité qui cimente et dogmatise le tout. ... Les artisans de cet amalgame ... luxuriants polygraphes, Posidonius et Philon donnent réponse à tout, satisfont tout le monde, traitent tous les sujets, apaisent toutes les controverses, empruntent à tous les systèmes, concilient tous les dogmes.

Jean-François Revel, *Histoire de la philosophie occidentale, I: De l’Antiquité à la Renaissance*. Paris: Stock, 1969; p. 233-234.

... il maestro di color che sanno ...

Dante Alighieri, *Divina Commedia*, Canto 4, line 131

Queritur consequenter nono utrum in motibus gravium et levium ad sua loca naturalia tota successio proveniat ex resistentia medii.

Acutissimi philosophi reverendi magistri Johannis Buridani subtilissime questiones super octo physicorum libros Aristotelis as printed in 1509 by Johannes Dullaert from Ghent (facsimile ed.: Frankfurt am Main: Minerva, 1964); ninth question on the fourth book: folio lxxiii^r.

... et immo si nauta descendit ad fundum maris ut habeat super humeros centum dolia aque ipse non sentit gravedinem illius aque quia illa aqua que est supra ipsum non inclinatur ad amplius esse deorsum sed respectu aeris inclinaret si aer esset inferior.

Et iterum quamvis aqua non esset in suo loco naturali sed multum alte in vase ut in cacumine turris beate marie tamen una pars respectu alterius non inclinaret ad esse deorsum ut si aliquis esset ibi in balneo et haberet tibiam suam in fundo ita quod supra eam esset magna quantitas aque quam ipse in aere non posset portare tamen non sentiret pondus illius aque.

Ibidem, folio lxxiii^v / lxxv^r.

je suppose que mouvement local ne peut estre sensiblement apparceu fors en tant comme l’en apparçoit un corps soy avoir autrement ou resgart d’autre corps.

Nicole Oresme (A.D. Menut & A.J. Denomy, eds., intr., trans., comm.), *Le Livre du ciel et du monde*. Madison: University of Wisconsin Press, 1968; p. 522/3 [NB In this and following passages I have somewhat adapted the translations there given]

que la seëtte traite en haut, aveques ce trait est meue vers orient tres isnelement aveques l’aer parmi le quel elle passe

Ibidem, p. 524/5

nientmoins touz tiennent et je cuide que il est ainsi meue et la terre non: Deus enim firmavit orbem terre, qui non commovebitur.

Ibidem, p. 536/7

car ce sont persuasions qui ne concludent pas evidanment.

Ibidem

(60) intellectual exercise and a diversion

esbatement

IV GREEK NATURE-KNOWLEDGE TRANSPLANTED, AND MORE: RENAISSANCE EUROPE

(65) The theorems of Euclid have the same certainty today as a thousand years ago. The discoveries of Archimedes will instill no less admiration in men to come after a thousand centuries than the delight instilled by our own reading.

Theoremata Euclidis eandem hodie quam ante mille annos habent certitudinem. Inventa Archimedis post mille secula venturis hominibus non minorem inducent admirationem quam legentibus nobis iucunditatem.

N.M. Swerdlow, 'Science and Humanism in the Renaissance: Regiomontanus' Oration on the Dignity and Utility of the Mathematical Sciences'. In: P. Horwich (ed.), *World Changes. Thomas Kuhn and the Nature of Science*. Cambridge, Mass.: MIT Press, 1993, p. 131-168; p. 149.

(66) the superhuman [also "the, as it were, most divine"] Archimedes

... me sub suprahumani Archimedis (quem nunquam absque admiratione nomino) alis memet protegere.

... subtilissimis mathematicis demonstrationibus ... utpote divini Ptolemaei et divinissimi Archimedis ...

Galileo Galilei, *Opere* 1, p. 300; p. 368.

(73) Once you add the voice, you see Derich himself here, such that you wonder whether it was the painter or the Creator who made him.

Derichus si vocem addas ipsissimus hic sit hunc dubites pictor fecerit an genitor.

Latin text (in capital letters on the balustrade on which Derich is pictured leaning) transcribed from the painting on display at a 2003 exhibition of Holbein paintings at the Mauritshuis in The Hague.

(78) I have seen things which the rude sailors, having long experience as their sole teacher and judging things by appearances, hold for certain and undoubtedly true, but which those who possess fuller powers of discrimination and who, through their sole intellect and their science, know the world's most recondite secrets, judge to be false or misunderstood.

Os casos vi, que os rudos marinheiros,
Que têm por mestra a longa experiência,
Contam por certos sempre e verdadeiros,
Julgando as cousas só pela aparência,
E que os que têm juizos mais enteiros,
Que só por puro engenho e por ciência
Vêem do mundo os segredos escondidos,
Julgam por falsos ou mal entendidos.

Luis de Camões, *Lusiadas*, canto V.

(79) ... regions of the material globe ...

... the intellectual globe should remain shut up within the narrow limits of old discoveries ...

Neque pro nihilo aestimandum, quod per longinquas navigationes et peregrinationes (quae saeculis nostris increbuerunt) plurima in natura patuerunt et reperta sint, quae novam philosophiae lucem immittere possint. Quin et turpe hominibus foret, si globi materialis tractus, terrarum videlicet, marium, astrorum, nostris temporibus immensum aperti et illustrati sint; globi autem intellectualis fines inter veterum inventa et angustias cohibeantur.

Francis Bacon, *Works* 1, p. 191 (*Novum Organum* I, aphorism 84).

(p. 153) ... there resulted a monstrous chimera composed of mutually disproportionate members, incompatible as a whole. Thus however well the astronomer might be satisfied merely as a calculator, there was no satisfaction and peace for the astronomer as a scientist.

... ma soggiugne che nel voler poi comporre insieme tutta la struttura delle fabbriche particolari, ne risultava un mostro ed una chimera composta di membra tra di loro sproporzionatissime e del tutto incompatibili, sì che, quantunque si sodisfacesse alla parte dell' astronomo puro calcolatore, non però ci era la sodisfazione e quiete

dell'astronomo filosofo.

Galileo Galilei, *Opere* 7, p. 369.

V THE FIRST TRANSFORMATION: REALIST-MATHEMATICAL SCIENCE

(87) ... how rich Copernicus was ...

Copernicus divitiarum suarum ipse ignarus ...

Johannes Kepler, *Gesammelte Werke* 3, p. 141.

(88) Geometry ..., coeternal with God, and radiating in the divine Mind, provided God with the models according to which He could furnish the world such as to make it the best and the most beautiful and, in short, the most alike to its Creator.

Geometria enim ..., Deo coaeterna, inque Mente divina relucens, exempla Deo suppeditavit ... exornandi Mundi, ut is fieret Optimus et Pulcherimus, denique Creatori similimus.

Johannes Kepler, *Gesammelte Werke* 6, p. 104-105.

Geometry, from before the origin of things co-eternal with the divine Mind, God himself (...) supplied God with the models to create the world, and together with the image of God it has passed into man.

Geometria ante rerum ortum Menti divinae coaeterna, Deus ipse (quid enim in Deo, quod non sit Ipse Deus) exempla Deo creandi mundi suppeditavit, & cum imagine Dei transivit in hominem ...

Johannes Kepler, *Gesammelte Werke* 6, p. 223.

(89) Man is an image of his maker, and it may well be that on certain things that have to do with the adornment of the world his views are the same as God's. For the world partakes of quantity, and there is nothing the human mind (a thing from above the world put into the world) understands better than those very quantities, for the grasping of which he has clearly been made.

Nam homo est imago conditoris, fierique potest, ut in quibusdam rebus ad ornatum mundi facientibus homini idem videatur, quod Deo. Nam mundus participat quantitate, et mens hominis (res supramundana in mundo) nihil rectius intelligit, quam ipsas quantitates, quibus percipiendis factus videri potest.

Johannes Kepler, *Gesammelte Werke* 14, p. 73, l. 441-443.

(90) In the middle of all sits Sun enthroned. For who in this most beautiful temple would place this lamp at another or better place than from where it can at the same time illuminate the whole?

In medio vero omnium residet Sol. Quis enim in hoc pulcherimo templo lampadem hanc in alio vel meliori loco poneret, quam unde totum simul possit illuminare?

Nicolaus Copernicus, *De Revolutionibus Orbium Coelestium*, book I, chapter 10 (p. 10 in the first edition).

(92) It behooves us, to whom God's benevolence has given that most diligent observer, Tycho Brahe, from whose observations the error of eight minutes in the calculation for Mars according to Ptolemaic principles is revealed, with gratitude to accept, and to exploit, this divine benefit. Let us, then, exert ourselves such, that in the end (leaning upon the evidence by means of which our suppositions have been caught out as false) we hunt out the genuine form of the heavenly motions. And this is the way along which, in what follows, I myself shall precede others to the best of my ability. For if I had judged those eight minutes of longitude fit to be ignored, the correction already carried out (namely, by bisecting the eccentricity) of my hypothesis would have sufficed. But, since these eight minutes could not be ignored, they alone, therefore, have led the way toward the wholesale reformation of astronomy, and have provided the matter for the larger part of this work.

Nobis cum divina benignitas Tychonem Brahe observatorem diligentissimum concesserit, cujus ex observatis error hujus calculi Ptolemaici VIII minutorum in Marte arguitur; aequum est, ut grata mente hoc Dei beneficium et agnoscamus et excolamus. In id nempe elaboremus, ut genuinam formam motuum coelestium (his argumentis fallacium suppositionum deprehensarum suffulti) tandem indagemus. Quam viam in sequentibus ipse pro meo modulo aliis praeibo. Nam si contemnenda censuissem 8 minuta longitudinis, jam satis correxissem (bisecta scilicet eccentricitate) hypothesin cap. XVI inventam. Nunc quia contemni non potuerunt, sola igitur haec octo minuta viam praeiverunt ad totam Astronomiam reformandam, suntque materia magnae parti hujus operis facta.

Johannes Kepler, *Gesammelte Werke* 3, p. 178.

(p. 174) *New Astronomy, based upon causes, or: Celestial Physics, treated by means of commentaries on the motions of the star Mars, from the observations of Tycho Brahe, Gent., by the order and at the expenses of Rudolph II, Emperor of the Romans etc., worked out at Prague in a tenacious study*

Astronomia nova ΑΙΤΙΟΛΟΓΗΤΟΣ seu Physica coelestis, tradita commentariis de motibus stellae Martis, ex observationibus G.V. Tychonis Brahe: Jussu & sumptibus Rudolphi II. Romanorum Imperatoris &c: Plurium annorum pertinaci studio elaborata Pragae, a

lasting many years by His Holy Imperial Majesty's Mathematician Joannes Kepler.

(93) May God get me out of astronomy so that I can switch back and concern myself with my work on the harmony of the world.

(95) ... a plane [being], as it were, incorporeal or at least very exactly polished and hard.

... accidental resistance arising from roughness of the moving body or of the inclined plane, or from the shape of the body ...

(96) Motion, in so far as it is and acts as motion, to that extent exists relatively to things that lack it; and among things which all share equally in any motion, it does not act, and is as if it did not exist. Thus the goods with which a ship is laden leaving Venice, pass by Corfu, by Crete, by Cyprus and go to Aleppo. Venice, Corfu, Crete, etc. stand still and do not move with the ship; but as to the sacks, boxes, and bundles with which the boat is laden and with respect to the ship itself, the motion from Venice to Syria is as nothing, and in no way alters their relation among themselves. This is so because it is common to all of them and all share equally in it. If, from the cargo in the ship, a sack were shifted from a chest one single inch, this alone would be more of a movement for it, in relation to the chest, than the two-thousand-mile journey made by all of them together.

This is good, sound doctrine, and entirely Peripatetic.

(97) ... as smooth as a mirror and made of some hard material like steel ...

(100) SIMP. What anomalies are there in the Ptolemaic arrangement which are not matched by greater ones in the Copernican?

SALV. The illnesses are in Ptolemy, and the cures for them in Copernicus.

Dialogue of Galileo Galilei, member of the Academy of the Lynx-eyed, extraordinary mathematician at the university of Pisa, and primary Philosopher and Mathematician of the Most Serene Grand Duke of Tuscany; where in course of meetings over four days the two great systems of the world, the Ptolemaean and the Copernican, are discussed by putting forward without arriving at a definite conclusion the Philosophical and Natural reasons for the one as well as for the other part ...

S.^{ae} C.^{ae} M.^{tis} S.^{ae} mathematico Joanne Keplero.

Deus me ex Astronomia expediat, ut ad curam operis mei de harmonia mundi convertar.

Johannes Kepler, *Gesammelte Werke* 15, p. 233, l. 91-92.

Sed haec demonstratio intelligenda est nulla existente accidentali resistentia (aut mobilis, aut plani inclinati, asperitas; vel etiam mobilis figura): sed supponendum est, planum esse quodammodo incorporeum, vel saltem exactissime exolitum et durum, ne, dum mobile super planum gravat, inclinaret planum, et, quodammodo tanquam in fovea, in eo quiesceret. Necesse est etiam, mobile esse exolitissimum, et figura quae motui non resistat, qualis esset perfecta sphaerica, et, item, materia durissima, aut fluida ut aqua.

Galileo Galilei, *Opere* 1, p. 298-299.

... il moto in tanto è moto e come moto opera, in quanto ha relazione a cose che di esso mancano; ma tra le cose che tutte ne partecipano egualmente, niente opera ed è come s' e' non fusse: e così le mercanzie delle quali è carica la nave, in tanto si muovono, in quanto, lasciando Venezia, passano per Corfù, per Candia, per Cipro, e vanno in Aleppo, li quali Venezia, Corfù, Candia etc. restano, nè si muovono con la nave; ma per le balle, casse ed altri colli, de' quali è carica e stivata la nave, e rispetto alla nave medesima, il moto da Venezia in Soria è come nullo, e niente altera la relazione che è tra di loro, e questo, perchè è comune a tutti ed egualmente da tutti è partecipato; e quando delle robe che sono i nave una balla si sia dicostata da una cassa un sol dito, questo solo sarà stato per lei movimento maggiore, in relazione alla cassa, che'l viaggio di dua mila miglia fatto da loro di conserva.

Questa è dottrina buona, soda e tutta peripatetica.

Galileo Galilei, *Opere* 7, p. 141-142.

... una superficie piana, pulitissima come uno specchio e di materia dura come l'acciaio ...

Galileo Galilei, *Opere* 7, p. 171.

SIMP. Ma quali esorbitanze sono nella costituzione Tolemaica, che maggiori non ne sieno in questa Copernicana?

SALV. Sono in Tolomeo le infermità, e nel Copernico i medicamenti loro.

Galileo Galilei, *Opere* 7, p. 369.

DIALOGO / DI / GALILEO GALILEI LINCEO / MATEMATICO SOPRAORDINARIO / DELLO STUDIO DI PISA. / E Filosofo, e Matematico primario del / SERENISSIMO / GR.DUCA DI TOSCANA. / Dove ne i congressi di quattro giornate si discorre / sopra i due / MASSIMI SISTEMI DEL MONDO / TOLEMAICO, E COPERNICANO; / Proponendo indeterminatamente le ragioni Filosofiche, e Naturali / tanto per l'una, quanto per l'altra parte

(104) The present does not seem to me to be an opportune time to enter into the investigation of the cause of the acceleration of natural motion, concerning which various philosophers have produced various opinions, some of them reducing this to approach to the center; others ... [follow two more examples]. Such fantasies, and others like them, would have to be examined and resolved, with little gain. For the present, it suffices our Author [i.e., Galileo] that we understand him to want us to investigate and demonstrate some attributes of a motion so accelerated (whatever be the cause of its acceleration) that the momenta of its speed go increasing, after its departure from rest, in that simplest ratio with which the continuation of time increases, which is the same as to say that in equal times, equal additions of speed are made. And if it shall be found that the properties that then shall have been demonstrated are verified in the motion of naturally falling and accelerated heavy bodies, we may deem that the definition assumed includes that motion of heavy things, and that it is true that their acceleration goes increasing as the time and the duration of motion increases.

(105) a body subject to no external resistance on a plane sloping no matter how little below the horizon will move down [the plane] in natural motion, without the application of any external force ... And the same body on a plane sloping upward, no matter how little, above the horizon, does not move up [the plane] except by force. And so the conclusion remains that on the horizontal plane itself the motion of the body is neither natural nor forced. But if its motion is not forced motion, then it can be made to move by the smallest of all possible forces.

(106) on an exactly balanced surface the ball would remain indifferent and questioning between motion and rest, so that any the least force would be sufficient to move it, just as on the other hand any little resistance, such as that merely of the air that surrounds it, would be capable of holding it still.

(108) if any moveable descends from rest in uniformly accelerated motion, the spaces run through in any times whatever are to each other ... as the squares of those times.

(109) as much smoothed and cleaned as possible. In this there was made to descend a very hard bronze ball, well rounded and polished, the beam having been tilted by elevating one end of it above the horizontal plane from one to two braccia [c. 1 to 2 feet], at will.

by experiments repeated a full hundred times, the

Non mi par tempo opportuno d'entrare al presente nell'investigazione della causa dell'accelerazione del moto naturale, intorno alla quale da varii filosofi varie sentenzie sono state prodotte, riducendola alcuni all'avvicinamento al centro, altri al restar successivamente manco parti del mezo da fendersi, altri a certa estrusione del mezo ambiente, il quale, nel ricongiugnersi a tergo del mobile, lo va premendo e continuamente scacciando; le quali fantasie, con altre appresso, converrebbe andare esaminando e con poco guadagno risolvendo. Per ora basta al nostro Autore che noi intendiamo che egli ci vuole investigare e dimostrare alcune passioni di un moto accelerato (qualunque si sia la causa della sua accelerazione) talmente, che i momenti della sua velocità vadano accrescendosi, dopo la sua partita dalla quiete, con quella semplicissima proporzione con la quale cresce la continuazione del tempo, che è quanto dire che in tempi eguali si facciano eguali additamenti di velocità; e se s'incontrerà che gli accidenti che poi saranno dimostrati si verificano nel moto de i gravi naturalmente descendenti ed accelerati, potremo reputare che l'assunta definizione comprenda cotal moto de i gravi, e che vero sia che l'accelerazione loro vadia crescendo secondo che cresce il tempo e la durazione del moto.

Galileo Galilei, *Opere* 8, p. 202-203.

... mobile, nullam extrinsecam habens resistantiam, in plano sub horizonte quantumcunque inclinato naturaliter descendet, nulla adhibita vi extrinseca; ut patet in aqua: et idem mobile in plano quantumcunque super horizontem erecto non nisi violenter ascendit: ergo restat, quod in ipso horizonte nec naturaliter nec violenter moveatur. Quod si non violenter movetur, ergo a vi omnium minima moveri poterit.

Galileo Galilei, *Opere* 1, p. 299.

nella superficie esattamente equilibrata detta palla resti come indifferente e dubbia tra il moto e la quiete, sì che ogni minima forza sia bastante a muoverla, siccome, all'incontro, ogni pochissima resistenza, e quale è quella sola dell'aria che la circonda, potente a tenerla ferma.

Galileo Galilei, *Opere* 2, p. 179/180.

Si aliquod mobile motu uniformiter accelerato descendat ex quiete, spatia quibuscunque temporibus ab ipso peracta, sunt inter se in duplicata ratione eorundem temporum, nempe ut eorundem temporum quadrata.

Galileo Galilei, *Opere* 8, p. 209.

... un canaletto, poco più largo d'un dito; tiratolo drittissimo, e, per averlo ben pulito e liscio, incollatovi dentro] una carta pecora zannata e lustrata al possibile, si faceva in esso scendere una palla di bronzo durissimo, ben rotondata e pulita; costituito che si era il detto regolo pendente, elevando sopra il piano orizzontale una delle sue estremità un braccio o due ad arbitrio ...

... per esperienze ben cento volte replicate sempre

spaces were always found to be to one another as the squares of the times. And this for all inclinations of the plane ... with such precision that ... these operations repeated time and again never differed by any notable amount.

(111) SIMP. This proves it for abstract spheres, but not material ones ... Material spheres are subject to many accidents to which immaterial spheres are not subjected. Why might it not be that a metallic sphere being placed upon a plane, its own weight would press down so that the plane would yield somewhat, or indeed that the sphere would be mashed at the contact? Besides such a plane can hardly be perfect, if for no other reason than that matter is porous; and maybe it will be no less hard to find a sphere so perfect that it has all lines drawn from the center to the surface exactly equal point by point.

SALV. Oh, I readily grant you all these things, but they are beside the point. For when you want to show me that a material sphere does not touch a material plane in one point, you make use of a sphere that is not a sphere and of a plane that is no plane, so that, by your own statement, such things [spheres and planes] are either not to be found in the world, or if found they are spoiled upon being used for this effect ...

SIMP. ... doubtless it is the imperfection of matter which prevents things taken concretely from corresponding to those considered in the abstract.

SALV. What do you mean, they do not correspond? Why, what you are yourself saying right now proves that they correspond exactly ... even in the abstract, an immaterial sphere which is not a perfect sphere can touch an immaterial plane which is not perfectly flat in not one point, but over a part of its surface, so that what happens in the concrete up to this point happens the same way in the abstract. It would be novel indeed if computations and ratios made in abstract numbers should not thereafter correspond to concrete gold and silver coins and merchandise. Do you know what does happen, Simplicio? Just as the calculator who wants his computations to deal with sugar, silk, and wool must discount the boxes, bales, and other packings, so the geometrical philosopher, when he wants to recognize in the concrete the effects which he has proved in the abstract, must deduct the material hindrances, and if he is able to do so, I assure you that things are in no less agreement than arithmetical computations. The errors, then, lie not in the abstractness or concreteness, not in geometry or natural philosophy, but in a calculator who does not know how to make a true accounting.

Hence if you had a perfect sphere and a perfect plane, even though they were material, you would have no doubt that they touched in one point; and if it is impossible to have these, then it was quite beside the purpose to say that a bronze sphere does not touch in one point.

(112) ... the knowledge of one single effect acquired through its causes opens the mind to the understanding

s'incontrava, gli spazii passati esser tra di loro come i quadrati de i tempi, e questo in tutte le inclinazioni del piano, cioè del canale nel quale si faceva scender la palla e questo con tal giustezza, che, come ho detto, tali operazioni, molte e molte volte replicate, già mai non differivano d'un notabil momento.

Galileo Galilei, *Opere* 8, p. 212-213.

SIMP. Questa dimostrazione conclude delle sfere in astratto, e non delle materiali ... Le sfere materiali son soggette a molti accidenti, a i quali non soggiacciono le immateriali. E perchè non può esser che, posandosi una sfera di metallo sopra un piano, il proprio peso non calchi in modo che il piano ceda qualche poco, o vero che l'istessa sfera nel contatto si ammacchi? In oltre, quel piano difficilmente potrà esser perfetto, quando non per altro, almeno per esser la materia porosa; e forse non sarà men difficile il trovare una sfera così perfetta, che abbia tutte le linee dal centro alla superficie egualissime per l'appunto.

SALV. Oh tutte queste cose ve le concedo io facilmente, ma elle sono assai fuor di proposito; perchè mentre voi volete mostrarmi che una sfera materiale non tocca un piano materiale in un punto, voi vi servite d'una sfera che non è sfera e d'un piano che non è piano, poichè, per vostro detto, o queste cose non si trovano al mondo, o se si trovano si guastano nell'applicarsi a far l'effetto ...

SIMP. ... non è dubbio che l'imperfezione della materia fa che le cose prese in concreto non rispondono alle considerate in astratto.

SALV. Come non si rispondono? Anzi quel che voi stesso dite al presente prova che elle rispondon puntualmente. ... Ma io vi dico che anco in astratto una sfera immateriale, che non sia sfera perfetta, può toccare un piano immateriale, che non sia piano perfetto, non in un punto, ma con parte della sua superficie; talchè sin qui quello che accade in concreto, accade nell'istesso modo in astratto: e sarebbe ben nuova cosa che i computi e le ragioni fatte in numeri astratti, non rispondessero poi alle monete d'oro e d'argento e alle mercanzie in concreto. Ma sapete, Sig. Simplicio, quel che accade? Si come a voler che i calcoli tornino sopra i zuccheri, le sete e le lane, bisogna che il computista faccia le sue tare di casse, invoglie ed altre bagaglie, così, quando il filosofo geometra vuol riconoscere in concreto gli effetti dimostrati in astratto, bisogna che difalchi gli impedimenti della materia; che se ciò saprà fare, io vi assicuro che le cose si risconteranno non meno aggiustatamente che i computi aritmetici. Gli errori dunque non consistono nè nell'astratto nè nel concreto, nè nella geometria o nella fisica, ma nel calcolatore, che non sa fare i conti giusti.

Però, quando voi aveste una sfera ed un piano perfetti, benchè materiali, non abbiate dubbio che si toccherebbero in un punto; e se questo era ed è impossibile ad aversi, molto fuor di proposito fu il dire che *sphaera aenea non tangit in puncto*.

Galileo Galilei, *Opere* 7, p. 232-234.

... e la cognizione d'un solo effetto acquistata per le sue cause ci apre l'intelletto a'ntendere ed assicurarci d'altri

and certainty of other effects without need of recourse to experiments

(113) ... it is impossible to remove the impediment of the medium ... all these difficulties make it highly improbable that anything demonstrated from such fickle assumptions can ever be verified in actual experiments.

SALV. All the difficulties and objections you advance are so well founded that I deem it impossible to remove them ... liberties [to be] pardoned ...

(114) No firm science can be given of such events of heaviness, speed, and shape, which are variable in infinitely many ways. Hence to deal with such matters scientifically it is necessary to abstract from them. We must find and demonstrate conclusions abstracted from the impediments, in order to make use of them in practice under those limitations that experience will teach us.

(118) I take more delight in geometry expressed in physical things than in the abstract.

(119) ... the astronomer as a priest of God to the book of nature ...

VI THE SECOND TRANSFORMATION: A KINETIC-CORPUSCULARIAN PHILOSOPHY OF NATURE

(122) ... join physics with mathematics ...

(123) "Mathematics", so he wrote, must be regarded as the "hands of physics", the "dignity" of natural philosophy being "as much greater as the shadow is less noble than the body itself".

(124) "smooth and round atoms" elicit sweetness; bitterness is caused by "atoms more hooked, ... accustomed to tear open their way into our senses and to break the texture by their intrusion", whereas atoms "rightly thought to be neither smooth nor altogether hooked with curved points, but rather to have small angles a little projecting ... rather tickle our senses than hurt them [as with] tartar of wine."

effetti senza bisogno di ricorrere alle esperienze ...

Galileo Galilei, *Opere* 8, p. 296: "

In oltre, è, per mio credere, impossibile lo schivar l'impedimento del mezo ... Dalle quali tutte difficoltà si rende molto improbabile che le cose dimostrate con tali supposizioni inconstanti possano poi nelle praticate esperienze verificarsi.

SALV. Tutte le promosse difficoltà e istanze son tanto ben fondate, che stimo essere impossibile il rimuoverle
... la qual licenza viene da alcuni scusata ...

Galileo Galilei, *Opere* 8, p. 274.

De i quali accidenti di gravità, di velocità, ed anco di figura, come variabili in modi infiniti, non si può dar ferma scienza: e però, per poter scientificamente trattar cotal materia, bisogna astrar da essi, e ritrovate e dimostrate le conclusioni astratte da gl'impedimenti, servircene, nel praticarle, con quelle limitazioni che l'esperienza ci verrà insegnando.

Galileo Galilei, *Opere* 8, p. 276.

... quod magis delector Geometria in Physicis rebus expressa, quam abstracta illa ...

Johannes Kepler, *Gesammelte Werke* 6, p. 279.

Ego vero sic censeo, cum Astronomi, sacerdotēs dei altissimi ex parte libri Naturae simus ...

Johannes Kepler, *Gesammelte Werke* 13, p. 193.

Hic Picto cum multis Jesuitis aliisque studiosis virisque doctis versatus est. Dicit tamen se nunquam neminem reperisse, praeter me, qui hoc modo, quo ego gaudeo, studendi utatur accurateque cum Mathematica Physicam jungat. Neque etiam ego, praeter illum, nemini locutus sum hujusmodi studii.

Isaac Beeckman, *Journael* 1, p. 244.

... tantoque major est physicae dignitas quanto umbra ignobilior ipso corpore. Est tamen ad physicam cognitionem consequendam tanta mathematicae necessitas ut aptissime ejus manus vocari possit

Isaac Beeckman, *Journael* 4, p. 41.

ut facile agnoscas e levibus atque rotundis esse ea quae sensus iucunde tangere possunt, at contra quae amara atque aspera cumque videntur, haec magis hamatis inter se nexa teneri proptereaque solere vias rescindere nostris sensibus introituque suo perrumpere corpus.

...
sunt etiam quae iam nec levia iure putantur esse neque omnino flexis mucronibus unca, sed magis angellis paulum prostantibus, ut qui titillare magis sensus quam laedere possint;

fecula iam quo de genere est inulaeque sapes.

Lucretius, *De rerum natura*; verses 2.398-407; 2.426-430.

(125) ... when separated from one another and agitated by the action of saliva in the mouth, [they] enter the tender pores of the tongue in a pointed manner, without folding ...

... d'autant que les parties des sels, étant séparées l'une de l'autre et agitées par l'action de la salive, entrent de pointe, et sans se plier, dans les pores qui sont en la peau de la langue ...

René Descartes, *Oeuvres* 11, p. 146.

(126)... it pulls by tiny jerks ...

... sy trect met cleyne hurtkens ...

Isaac Beeckman, *Journal* 1, p. 264 [NB due to a hurried oversight, in note 126 in my book I mistakenly referred this passage to René Descartes, *Oeuvres* 1, p. 264].

(128) But Mr. Descartes, who seems to me to have been very envious of Galileo's renown, had this great urge to pass for the author of a new philosophy, as appears from his efforts and his hopes to have it taught at the universities instead of Aristotle's, or from his wish that the Society of Jesus embrace it ... In his desire to make us believe that he has found the truth (as he does everywhere in founding himself upon, and in rejoicing in, the succession and the beautiful linkedness of his expositions) he has done something at great prejudice to the progress of philosophy, as those who believe him and those who have joined his sect fancy to possess knowledge of the causes of everything, insofar as it is possible to know them.

Mais M. des Cartes qui me paroît avoir esté fort jaloux de la renommee de Galilee avoit cette grande envie de passer pour autheur d'une nouvelle philosophie. Ca qui paroît par ses efforts et ses esperances de la faire enseigner aux academies à la place de celle d'Aristote; de ce qu'il souhaitoit que la societè des Jesuites l'embrassai ... Mais en voulant faire croire qu'il a trouvé la verité, comme il le fait par tout, en se fondant et se glorifiant en la suite et en la belle liaison de ses expositions, il a fait une chose qui est de grand prejudice au progrès de la philosophie. car ceux qui le croient et qui sont devenus ses sectateurs, s'imaginent de posseder la connoissance des causes de tout, autant qu'il est possible de les sçavoir ...

Christiaan Huygens, *Oeuvres Complètes* 10, p. 404-405.

(129) Larvatus prodeo.

I present myself from behind a mask.

René Descartes, *Oeuvres* 10, p. 213.

(130) ... what they might be like ...

... comment elles peuvent être ...

... by the wisest of men and by the church authorities ...

... je sousmets toutes mes opinions au jugement des plus sages & à l'autorité de l'Église [...haec omnia, tum Ecclesiae Catholicae auctoritati, tum prudentiorum judiciis submitto].

René Descartes, *Oeuvres* 8, p. 329; *Oeuvres* 9, p. 325.

(131) in order to find the true causes of all there is on Earth one must retain the hypothesis already posited, even though it is wrong.

Que pour trouver les vraies causes de ce qui est sur la Terre il faut retenir l'hypothèse déjà prise, nonobstant qu'elle soit fausse [Falsam hypothesim, qua iam ante usi sumus, esse retinendam, ad veras rerum naturas explicandas].

René Descartes, *Oeuvres* 8, p. 203; *Oeuvres* 9, p. 201.

(132) I would like people to think that, if what I have written ... on any ... matter that I have treated in more than 3 lines in my printed works appears to be wrong, all the rest of my Philosophy is worthless.

Cependant ie veux bien qu'on pense que, si ce que i'ay escrit de cela, ou des refractions, ou de quelque autre matiere que i'aye traitée en plus de 3 lignes dans ce que i'ay fait imprimer, se trouve faux, tout le reste de ma Philosophie ne vaut rien.

René Descartes, *Oeuvres* 2, p. 501.

(133) pleasing novels, that impress one as if they were true stories. ...

Mr. des Cartes avoit trouvé la maniere de faire prendre ses conjectures et fictions pour des veritez. Et il arrivoit a ceux qui lisoient ses Principes de Philosophie quelque chose de

[how exactly] had Mr Descartes hit upon the way to have his conjectures and fictions accepted as truths ...

semblable qu'à ceux qui lisent des Romans qui plaisent et font la mesme impression que des histoires veritables.

Christiaan Huygens, *Oeuvres Complètes* 10, p. 403.

(135) Who can mentally conceive what that [force] is, or how it keeps the stone moving, or in what part of the stone it resides?

Quis enim mente potest concipere quid sit illa, aut quomodo lapidem in motu contineat, quave in parte lapidis sedem figat?

Isaac Beeckman, *Journal* 1, p. 25.

(p. 239) ... the actualization of a potentiality insofar as it is potential ...

Motus est actus entis in potentia prout in potentia est.

VII THE THIRD TRANSFORMATION: TO FIND FACTS THROUGH EXPERIMENT

(p. 249) New physiology, demonstrated by means of several arguments as well as experiments, concerning the magnet and magnetic bodies and that grand magnet, the Earth

De magnete, magneticisque corporibus, et de magno magnete tellure; physiologia nova, plurimis & argumentis, & experimentis demonstrata

William Gilbert, *De Magnete* (title page)

VIII CONCURRENCE EXPLAINED

(149) ... it being very true that our reputation starts from ourselves, and that he who wants to be esteemed ought to have self-esteem first.

... essendo verissimo che la reputazione comincia da noi medesimi, et che quello che vuole essere stimato bisogna che sia il primo a stimarsi ...

Galileo Galilei, *Opere* 10, p. 298.

(150) .. if from my youth onward I had been taught all the truths of which I have since sought the proofs ... I would never have acquired this ability and facility I think I have of finding new ones whenever I apply myself to seeking them.

... ie me persuade que, si on m'eust enseigné, dès ma ieunesse, toutes les veritez dont j'ay cherché depuis les démonstrations, & que ie n'eusse eu aucune peine a les apprendre, ie n'en aurais peuestre iamais sceu aucunes autres, & du moins que iamais ie n'aurais acquis l'habitude et la facilité, que ie pense avoir, d'en trouver tousiours de nouvelles, a mesure que ie m'applique a les chercher.

René Descartes, *Oeuvres* 6, p. 72.

(151) Myself, then, I found to be equipped, more than for other things, for the contemplation of truth.

Me ipsum autem ad veritatis contemplationes, quam ad alia, magis fabrefactum deprehendi ...

Francis Bacon, *Works* 3, p. 518.

IX PROSPECTS AROUND 1640

(153) free steps have I been the first to make into the void

libera per vacuum posui vestigia princeps

Horace, as quoted by Christiaan Huygens, *Oeuvres Complètes* 16, p. 302.

X ACHIEVEMENTS AND LIMITATIONS OF REALIST-MATHEMATICAL SCIENCE

(154) ... well, then, I throw the dice and write a book, no matter whether it be read by contemporaries or later generations — it may await its reader for hundred years, as God himself waited six thousand years for a witness.

... jacio en aleam, librumque scribo, seu praesentibus, seu posteris legendum, nihil interest; expectet ille suum lectorem per annos centum; si Deus ipse per annorum sena millia contemplatorem praestolatus est.

Johannes Kepler, *GW* 6, p. 290.

(155) The force of necessary demonstrations is full of marvel and delight; and such are mathematical [demonstrations] alone.

(156) ... trying to deal with the questions of nature without geometry is attempting to do that which is impossible to be done

(157) ... the path shall be cleared and made accessible for a very ample, very excellent science, of which these our labors will be the elements, and in the more hidden recesses of which farther-seeing minds than mine shall penetrate.

(160) [In the main text I merely paraphrase Fabricius' remark to Kepler, as follows: "Fabricius suggested in response that Kepler better try one more little epicycle." Here is the original remark in the original Latin:]

(161) ... in trying to prove the Copernican hypothesis from natural-philosophical reasoning, Kepler introduces strange speculations which belong, not in the domain of astronomy, but of natural philosophy.

(162) ... the endeavours of receding from the Sun will be reciprocally as the squares of their distances from the Sun.

(165) ... devoid of erudition, and of little worth.

(166) The cross-sections of the same River discharge equal quantities of water in equal times, even though the cross-sections themselves are unequal.

(167) The late Mr. Blondel wrote a large treatise on this, claiming to give a far more secure demonstration for proper shooting than done by all those concerned with it previously.

But it seems to me far better to stick to the example of those who exercise with cannon balls all the time and who find themselves at ease with their method, being certain that experience, with powder above all, always gets the better over even the most learned

Piena di meraviglia e di diletto insieme è la forza delle dimostrazioni necessarie, quali sono le sole matematiche.

Galileo Galilei, *Opere* 8, p. 296.

... è forza confessare che il voler trattar le questioni naturali senza geometria è un tentar di fare quello che è impossibile ad esser fatto.

Galileo Galilei, *Opere* 7, p. 229

... aditus et accessus ad amplissimam praestantissimamque scientiam, cuius hi nostri labores erunt elementa, recludetur, in qua ingenia meo perspicaciora abditiores recessus penetrabunt.

Galileo Galilei, *Opere* 8, p. 190.

... per ovalitatem vel ellipsin tuam, tollis circularitatem et aequalitatem motuum, quod mihi imprimis penitus consideranti absurdum videtur ... Quod si igitur retento circulo perfecto, ellipsin per alium circellum excusare posses, commodius esset.

David Fabricius to Johannes Kepler, 20 January 1607; In: Johannes Kepler, *Gesammelte Werke* 15, p. 377.

De caetero Keplerus dum Hypotheses Copernici rationibus Physicis demonstrare laborat, mirabiles introducit speculationes non tam ad Astronomiam quam ad Physicam pertinentes ...

Peter Crüger to Phillip Müller, 1 July 1622 (old style); in: Johannes Kepler, *Gesammelte Werke* 18, p. 92.

Denique in Planetis primariis cum cubi distantiarum a sole reciproce sunt ut quadrati numeri periodorum in dato tempore: conatus a sole recedendi reciproce erunt ut quadrata distantiarum a sole.

Isaac Newton, *Correspondence* 1, p. 297-303.

author ineruditus ac parvi pretii.

Christiaan Huygens, *Oeuvres Complètes* 20, p. 133.

Le sezioni del medesimo Fiume scaricano uguali quantità d'acqua in tempi eguali, ancorche le sezioni medesime siano disuguali.

Benedetto Castelli, *Della misura dell'acque correnti*. Rome, 1628; p. 48.

Feu M. Blondel a fait un grand Traitté la-dessus, prétendant avoir donné une démonstration pour tirer juste, beaucoup plus sûre que n'ont peu faire tous ceux qui s'en sont mélez par le passé.

Mais il me semble qu'il vaille mieux s'attacher à suivre ceux qui sont dans le continuel exercice des bombes et qui se trouvent bien de leur methode, estant sûr que l'expérience, sur tout en fait de poudre, l'emporte toujours sur les observations les plus sçavantes.

considerations.

Even though it remains true that, in attaining perfection in the arts, theory joined to practice forms the culmination point, nonetheless experience has made me aware that theory has been of very little utility in the usage of mortars.

Mr. Blondel's book described well enough for us the distance of parabolic lines, according to the different degrees of elevation of a quarter circle, but practice has shown that there is no theory at all in the effects of powder, for, on committing myself to direct the mortars with all possible exactitude in conformity to the calculations, I have never been able to establish any foundation upon their principles.

Still, I would not claim that, if each ball proved to be of equal weight; if for each shot one could give the powder the same arrangement, and if the platform were so solid as never to change its situation, one might not put theory to useful service.

(169) There is so little difficulty in this science, which can be understood in one or two rules, that I don't doubt your ability to find it out all by yourself.

(174) ... from the crew's frequent scolding and mockery of this effort to measure longitude in a new way.

(175) ... some of those [to treat of gunnery] have made it too speculative: their books are burdened with infinitely many Mathematical rules, suppositions, and reductions more suitable for refined tastes than for instructing young men, most of whom lack education and several of whom cannot, in view of the nature of their minds, apply themselves to so abstract matters, knowledge of which presupposes that of the principles of geometry which they do not have or are hardly capable of acquiring.

Quoi qu'il soit constant que la théorie jointe à la pratique forme le plus haut point pour atteindre à la perfection des arts, néanmoins l'expérience m'a fait connaître que la théorie était d'une très petite utilité dans l'usage des mortiers.

Le livre de M. Blondel nous a décrit avec assez de justesse la distance des lignes paraboliques, selon les différents degrés d'élevation du quart de cercle, mais la pratique a démontré qu'il n'y a aucune théorie dans les effets de la poudre car m'étant attaché à pointer les mortiers avec toute l'exactitude possible conformément à les calculs, je n'ai jamais pu établir aucun fondement sur leurs principes.

Je ne prétends pourtant pas avancer que si les bombes se trouvaient toutes d'un poids égal; que si l'on pouvait tous les coups donner le même arrangement à la poudre, et que la plateforme fut si solide, qu'elle ne changeât jamais de situation, que l'on ne pût se servir utilement de la théorie ...

As quoted in M. Blay, 'Le développement de la balistique et la pratique du jet des bombes en France à la mort de Colbert'. In: L. Godard de Donville (ed.), *De la mort de Colbert à la révocation de l'édit de Nantes: un monde nouveau?* Marseille: Centre Méridional de Rencontres sur le XVII^e siècle, 1984, p. 33-51: p. 45 and p. 47, respectively, with reference to Surirey de Saint-Rémy, *Mémoires d'Artillerie* of 1697, and to De Resson, 'Méthode pour tirer les bombes avec succès'. *Mémoires de l'Académie des sciences*. 1716, p. 79.

Il y a si peu de difficulté en cette science, qui se peut comprendre dans une ou deux règles, que je ne doute pas, que vous ne puissiez trouver tout par vous même.

Christiaan Huygens, *Oeuvres Complètes* 6, p. 216.

... dat voorn. Helder en de Graef veel te lijden gehad hadden en door 't scheepvolck dickwils beschimpt en belacht wierden over dit werck der nieuwe Lengde-metingh.

Christiaan Huygens, *Oeuvres Complètes* 9, p. 272-291; p. 289

... quelques-uns d'eux [qui ont traité de l'artillerie] l'ont rendu trop spéculative: leurs livres sont chargez d'une infinité de règles Mathématiques, de supputations et de reductions plus propres à degouter qu'à instruire de jeunes gens la plupart sans etude, et dont quelques-uns par le caractère de leur esprit ne peuvent point s'appliquer à des matières si abstraites, dont la connoissance suppose celle des principes de geometrie qu'ils n'ont point, ou dont ils sont peu capables.

As quoted in M. Blay, 'Le développement de la balistique et la pratique du jet des bombes en France à la mort de Colbert'. In: L. Godard de Donville (ed.), *De la mort de Colbert à la révocation de l'édit de Nantes: un monde nouveau?* Centre Méridional de Rencontres sur le XVII^e siècle, 1984; p. 33-51: p. 49, with reference to

- (176) He seems to take him for one of his fortification engineers. I was not aware of having craftsmen among my children.
- Surirey de Saint-Rémy, *Mémoires d'Artillerie* of 1697: preface, p. 2.
- Mon fils vient de me faire rire de la superscription de la lettre de M^r. de Louvois, ou il y a: à Mons.^r Huygens etc. mathématicien. Il semble le prendre pour un des ingénieurs de ses fortifications. Je ne croyois pas avoir des gens de mestier parmi mes enfans.
- J.A. Worp (ed.), *De briefwisseling van Constantijn Huygens (1608-1687)*; 6 vols. Den Haag: RGP, 1911-1917: vol. 6, p. 450-1.
- (178) ... produces such a Titillation upon the Cartilage of the *Timpanum*, that, allaying the Sweetness by a Mixture of Tartness, it seems at one and the same Time to kiss and bite.
- ... fa una titillazione ed un solletico tale sopra la cartilagine del timpano, che temperando la dolcezza con uno spruzzo d'acrimonia, par che insieme soavemente baci e morda.
- ... this Mixture of Vibrations is the same with that which being made in Strings of Instruments, presents to the Ear an *Eighth* [octave] with an intermediate *Fifth*.
- ... la qual mistione di vibrazioni è quella che, fatta dalle corde, rende all'udito l'ottava con la quinta in mezzo.
- Galileo Galilei, *Opere* 8, p. 149.
- (179) I suppose that those water jets which flow out with violence, possess at their point of outflow the same impetus which any heavy body, or one drop of that very water, would possess if it were to fall naturally from the upper surface of that water down to the orifice out of which it flows.
- Aquas violenter erumpentes in ipso eruptionis puncto eundem impetum habere, quem habere grave aliquod, sive ipsius aquae gutta una, si ex suprema eiusdem aquae superficie usque ad orificium eruptionis naturaliter cecidisset.
- As quoted in M. Blay, *Les raisons de l'infini. Du monde clos à l'univers mathématique*. Paris: Gallimard, 1993, p. 114 (passage referred to Evangelista Torricelli, *De motu gravium naturaliter descendentium et projectorum libri duo*. Firenze, 1644; book 2 'De motu aquarum', p. 191).
- (180) the experiment itself seems in a certain sense to prove the principle, even though in a certain sense it also seems to destroy it.
- Experimentum etiam aliquo modo principium nostrum probat, quamquam aliqua ex parte reprobare videatur.
- As quoted in M. Blay, *Les raisons de l'infini. Du monde clos à l'univers mathématique*. Paris: Gallimard, 1993, p. 114 (referred to Evangelista Torricelli, *De motu gravium naturaliter descendentium et projectorum libri duo*. Firenze, 1644; book 2 'De motu aquarum', p. 192).
- (181) ... demonstrated by reason ...
- ... un effect de la nature, qui ne s'estant pû jusqu'icy demonstrer par raison, mais seulement prouver par experience ...
- Christiaan Huygens, *Oeuvres Complètes* 19, p. 171
- (182) ... since the water is contiguous over its entire length, the water above descends with the same speed as the water below; consequently, there is no acceleration in the vessel at all.
- ... il m'a paru que l'eau y etant contigue dans toute sa longueur, celle d'en haut descendoit aussy vite que celle d'en bas; et que par consequent il n'y avoit aucune acceleration dans ce tuyau.
- As quoted in M. Blay, *Les raisons de l'infini. Du monde clos à l'univers mathématique*. Paris: Gallimard, 1993, p. 117 (referred to the archival collections of the *Académie Royale des Sciences*, vol. 14, folio 94 v^o).
- (183) ... asked what ratio does the time of a very small oscillation of a pendulum have to the time of perpendicular fall through the height of the pendulum.
- Quaeritur quam rationem habeat tempus minimae oscillationis penduli ad tempus casus perpendicularis ex penduli altitudine.
- Christiaan Huygens, *Oeuvres Complètes* 16, p. 392.

(191/192) ... instants of time instantibus temporis ...
... maximum and final maximus et ultimus ...
... the increasing degrees of speed after the instant A crescentes velocitatis gradus post instans A ...
... aggregate aggregatum ...
... the deficit of momenta in the first half of the accelerated motion (the momenta represented by the parallels in triangle AGI falling short) [are] made up by the momenta represented by the parallels of triangle IEF.	... momentorum deficit in prima motus accelerati medietate (deficiunt enim momenta per parallelas trianguli AGI repraesentata), reficitur a momentis per parallelas trianguli IEF repraesentatis.

Galileo Galilei, *Opere* 8, p. 208-209.

XI ACHIEVEMENTS AND LIMITATIONS OF KINETIC CORPUSCULARIANISM

(194) ... making my mind pass once again over all objects which at any time have presented themselves to my senses, I venture to say that I have never come across any thing which I could not explain adequately enough by means of the Principles I had found.	... repassant mon esprit sur tous les objets qui s'estoient jamais presentez a mes sens, i'ose bien dire que ie n'y ay remarqué aucune chose que ie ne puisse assez commodement expliquer par les Principes que i'avois trouvez.
	René Descartes, <i>Oeuvres</i> 6, p. 64.
(195) ... the foundations of my Natural Philosophy ... are, almost all of them, so evident that one need only hear them to believe them.	... si ie publiois les fondemens de ma Physique. Car, encore qu'ils soient presque tous si evidens, qu'il ne faut que les entendre pour les croire ...
... although I have often explained some opinions of mine to people with a very good mind and who, while I was talking to them, seemed to understand them quite distinctly, I have noted nonetheless that, when they reproduced them, almost always they had changed them in such a way that I could no longer avow them as mine.	... bien que i'aye souvent expliqué quelques unes de mes opinions a des personnes de tres bon esprit, & qui, pendant que ie leur parlois, sembloient les entendre fort distinctement, toutefois, lorsqu'ils les ont redites, i'ay remarqué qu'ils les ont changées presque tousiours en telle sorte que ie ne les pouvois plus avouër pour miennes.
	René Descartes, <i>Oeuvres</i> 6, p. 68; p. 69.
(196) A string, by its tremor dispersing the air, breaks it into nearly equal globules; however, as all parts of the string tremble equally frequently indeed, but not equally fast, and as some particles of air are perhaps more fragile than others, and as the thickness of the string is not everywhere exactly the same, it happens that a certain amount of those globules is broken into two, three, four, etc. parts. Those that are broken in two represent to the ear the <i>octave</i> , because in the same time it is affected by a doubled sting ...	Chorda tremore sua aerem dispergens, eum in aequales fere globulos frangit; attamen cum omnes partes chordae aequae frequenter, sed non aequae celeriter tremant, et aliae aeris particulae aliis fortasse fragiliores sint, nec chordae crassities ubique sit exacte aequalis, fit ut eorum globulorum quidam in duas, tres, quatuor etc. partes frangantur. Quae in duas frangantur, <i>octavam</i> auribus repraesentant, quia eodem tempore duplici punctura afficiuntur ...
	Isaac Beeckman, <i>Journal</i> 4, p. 214-215.
(197) correspond to the pores of the brain, or of the members, or of the collection of spirits.	... sic ex diversis instrumentis, ex quibus vox excutitur, oritur qualitas quaedam aliquando delectabilis, aliquando minus, quia aer in partes secatur quae poris cerebri, vel membrarum, vel collectionis spirituum, non respondent.
	Isaac Beeckman, <i>Journal</i> 1, p. 177.
(199) ... how something immaterial can move some-	Nunquam enim ego sonum vocaverim speciem

thing material.

(200) ... this foundation [ought to be] posited that ... the sounds of the consonances actually cause, through motion, something inside us to change place.

(201) ... all things of such a nature, the existence of which does not manifest itself to any of our senses, are as difficult to believe as they are easy to invent.

(202) The novelty in the figures of his particles and whirlpools make[s] it a great pleasure. When I read this book of *Principles* for the first time it seemed to me that everything in the world ran as well as it could, and when I found some difficulty in it I believed that it was my fault for not grasping well what he meant there. I was only 15 or 16 years old.

(206) ... fabricating ... this entire new system, and for giving it such a turn of truth-likeness as to make infinitely many people satisfied with it and pleased with it.

(207) Senguerd apparently belongs to those scholars who seek indeed to modernize the concepts of the Aristotelian school, but actually bring about a retreat from the great pioneers of a mechanical [i.e., kinetic-corpuseular] explanation of nature ... This becomes particularly clear in Senguerd's doctrine of motion, which suffers in an essential way from motion being conceived as an inherent accident of a body so as to be subjected to the logical definitions of substance and accident ...

(208) those who reject qualities and introduce everywhere their corpuscles and subtle spirits believe to have resolved all difficulties when by way of illustration of their opinion they adduce one or another comparison or analogy. But those who shrink back from corpuscles seem mistaken in their views, too.

(209) *Synopsis, written for the usage of studious youth, of*

immateriatam. Qui enim immateriatum movere possit materiatum?

Isaac Beeckman, *Journael* 3, p. 67.

... posito tamen hoc fundamento quod ... consonantiarum soni, aliquid revera in nobis loco moveant.

Isaac Beeckman, *Journael* 3, p. 69.

Car toutes les choses de cette nature, dont l'existence ne se manifeste à aucun des sens, sont aussi difficiles à croire, qu'elles sont faciles à inventer.

'Réponse de Blaise Pascal au très bon Réverend Père Noël' (29 October 1647; p. 373 in Chevalier's 'Pléiade' edition of Pascal's *Oeuvres Complètes*).

La nouveauté des figures de ses petites particules et des tourbillons y font [sic] un grand agrément. Il me sembloit lorsque je lus ce livre des Principes la première fois que tout alloit le mieux du monde, et je croiois, quand j'y trouvais quelque difficulté, que c'étoit ma faute de ne pas bien comprendre sa pensée. Je n'avois que 15 à 16 ans.

Christiaan Huygens, *Oeuvres Complètes* 10, p. 403.

... qu'il ait fait paroître bien de l'esprit à fabriquer, comme il a fait, tout ce système nouveau, et a luy donner ce tour de vraisemblance qu'une infinité de gens s'en contentent et s'y plaisent.

Christiaan Huygens, *Oeuvres Complètes* 10, p. 406.

Wie man sieht, gehört Wolferd Senguerd zu jenen Gelehrten, die zwar die aristotelischen Schulbegriffe zu modernisieren streben, thatsächlich aber gegenüber den großen Bahnbrechern der mechanischen Naturerklärung einen Rückschritt veranlassen ... Dies zeigt sich besonders in Senguerds Bewegungslehre, die wesentlich darunter leidet, daß die Bewegung als ein inhärentes Accidens des Körpers aufgefaßt wird und nun den logischen Bestimmungen über Substanz und Accidens unterliegen soll; ...

K. Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton*. Leipzig: Voss, 1890; vol. 2, p. 498 in the 2nd ed. of 1926.

Diejenigen, welche die Qualitäten verwerfen und ihre Korpuskeln und feinen Spiritus überall einführen, glauben, sie hätten alle Schwierigkeiten gelöst, wenn sie einen oder den andern Vergleich oder eine Ähnlichkeit beibringen, wodurch sie ihre Meinung erläutern. Aber auch diejenigen, welche vor den Korpuskeln erschrecken, scheinen in ihren Ansichten ungerecht.

Claude François Milliet Dechaies, *Cursus seu mundus mathematicus*. Lyon, 1674 [I have not been able so far to locate the original Latin passage, to be found in the neighborhood of p. 661 according to K. Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton*. Leipzig: Voss, 1890; vol. 2, p. 488 in the 2nd ed. of 1926.]

Physicae veteris-novae adornatae Secundum Democriti,

enriched old-new natural philosophy according to the principles of Demokritos, most ancient philosopher, as reconstituted by Gassendi, Bacon, Boyle, de Rodon, Digby, and other modern authors, and as proven by means of various experiments.

(210) ... to show that all events in the world of body are are up for explanation by the force of heaviness alone, if only one attributes fitting shapes to the particles of bodies, so that the force of heaviness, directed toward the center of the Earth, compels them according to mechanical laws [i.e., those of statics] to move in other directions, too, depending on circumstance. He therefore regards the corpuscles as machines, which are moved by the force of heaviness yet determined as to direction by their construction. Since the only driving force is thus the pressure of bodies upon others and themselves, he conceives of the totality of movements on Earth as a problem in *hydrostatics*.

(212) Its treatment seemed so easy that anybody could take it upon himself to penetrate by its means the inside of nature.

XII LEGITIMACY IN THE BALANCE

(213) ... flat objects of iron or lead... whereas others smaller and less heavy, if they are round or elongated – a needle for instance – sink ...

(214) ... necessary to show how far from the truth are those who want to demonstrate natural phenomena through mathematical reasoning ... The natural philosopher studies natural phenomena whose essence entails movement, while, instead, the subject matter of mathematics does not comprehend movement.

I would like Signor Galileo to adopt some philosophical propriety, because, although he adorns himself with that title, he does not behave accordingly.

(215) ... concerning the things that fall within the domain of the senses and that we see all the time, he wants to demonstrate them mathematically. Instead, concerning those things that cannot (or only full of imperfections) be grasped through the senses, he insists on explaining them through the senses ...

antiquissimi Philosophi, a Gassendo, Verulamio, Boyleo, Derodone, Digbyaeo aliisque recentioribus redintegrata, variisque Experimentis comprobata Principia, Synopsis conscripta In usum Studiosae Juventutis.

As quoted in K. Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton*. Leipzig: Voss, 1890; vol. 2, p. 518 in the 2nd ed. of 1926.

... zu zeigen, daß alle Vorgänge in der Körperwelt sich allein aus der Schwerkraft erklären lassen, wenn man nur den Teilchen der Körper passende Gestalten zuschreibt, so daß sie durch die nach dem Zentrum der Erde gerichtete Schwerkraft nach mechanischen Gesetzen gezwungen werden, je nach den Umständen, auch in andern Richtungen sich zu bewegen. Die Körperteilchen sieht er daher als Maschinen an, welche durch die Schwere bewegt, aber durch ihre Konstruktion in ihrer Richtung bestimmt werden. Da die treibende Kraft somit nur der Druck der Körper auf andre und auf sich selbst ist, so faßt er sämtliche Bewegungen auf der Erde als ein *hydrostatisches Problem* auf.

K. Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton*. Leipzig: Voss, 1890; vol. 2, p. 301 in the 2nd ed. of 1926.

Ihre Behandlung schien so leicht, daß ein jeder sich zutrauen konnte mit derselben ins Innere der Natur einzudringen.

K. Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton*. Leipzig: Voss, 1890; vol. 2, p. 520 in the 2nd ed. of 1926.

ἄπορείται γὰρ νῦν διὰ τὰ πλατεὰ σιδηρὰ καὶ μολιβδοῦς ἐπιπλεῖ ἐπὶ τοῦ ὕδατος, ἄλλα δὲ ἑλαττώ καὶ ἥττων βάρεια, ἂν ἦι στρογγυλὰ ἢ μακρὰ, ὄιον βελονή, κατὰ φέρεται ...

Aristotle, *Peri Ouranou*, IV:6.

... ci è paruto necessario il dimostrare quanto sieno lontani coloro dal vero, che con ragioni matematiche vogliono dimostrare le cose naturali ... Imperciocchè lo scientifico naturale considera le cose naturate che hanno per propria e naturale affezione il movimento, là dove il matematico il proprio soggetto astrae da ogni movimento.

... io desiderei nel Sig. Galileo un poco più di quella modestia filosofica, essendo che egli di tal nome si va adornando e di poi non adopra conforme al nome ...

Galileo Galilei, *Opere* 4, p. 385; 391.

... che egli nelle cose che non sottoposte al senso, e che noi continuamente veggiamo, vuole dimostrarle con matematiche ragioni; e nelle cose dove non arriva il senso, o almeno ripieno d'imperfezioni, egli le vuol cognoscere col senso

Galileo Galilei, *Opere* 4, p. 436 .

(216) ... it is impossible to say anything good and solid regarding velocity without a true explication of what heaviness is, and altogether the entire system of the world. ...

[Galileo had failed to derive his views on fall] in orderly fashion [...] without considering the primary causes of nature [so that, in just seeking] reasons for some specific effects ... he has built without foundation.

(218) ... some would maintain that it can rarefy to the point of filling the whole world, rather than admit the void.

(219) not one little philosopher of nature is left who does not know inside out the story of Mr. Pascal's experiment.

(221) ... the essence and existence of [substantial] forms is being denied ... Once this dangerous axiom is granted, the vanity, skepticism, and excessive licence of the human mind shall lead it down the slope of adversely arguing that there is no rational soul, no generation and conception of man in the mother's womb, no wind, no light, no Trinity, no Incarnation, no original sin, no miracles, no prophecies, no awakening of a sense of God in the human mind and will, no regeneration of man through God's grace, no demonic action inside the body of man or around his mind, etc. ...

(223) The king has learned that certain opinions previously censured by the Faculty of theology and forbidden by the Parlement [of Paris] to be taught or published are now spreading, not only at the university but also elsewhere in this city and in some others in the realm, be it by strangers or by people from the inside. He wishes to prevent the circulation of this opinion, which might bring some confusion to the explication of our mysteries [of the faith]. Moved by his ordinary zeal and piety, he has ordered me to tell you his intentions. The king exhorts you, Sirs, to act such as to have no one at the universities teach any doctrine other than the one which is taken up in the rules and statutes of the university [of Paris], and to have no one put anything of it in his theses. He leaves it to your prudence and sage conduct to take the paths necessary for this.

Car il est impossible de rien dire de bon & solide touchant la vitesse, sans avoir expliqué au vray ce que c'est que la pesanteur, & ensemble tout le systeme du monde.

Mais il me semble qu'il [Galilée] manque beaucoup en ce qu'il fait continuellement des digressions & ne s'arreste point a expliquer tout a fait une matiere; ce qui monstre qu'il ne les a point examinées par ordre, & que, sans avoir considéré les premieres causes de la nature, il a seulement cherché les raisons de quelques effets particuliers, & ainsy qu'il a basti sans fondement.

René Descartes, *Oeuvres* 2; p. 355; 380.

... et que quelques-uns soutiendraient se pouvoir rarefier assez pour remplir tout le monde, plutôt que d'admettre du vide.

Blaise Pascal, Proposition n° 4 in the second part of his *Expériences nouvelles touchant le vide*. Paris, 1647.

... il n'y a point maintenant de petit Physicien qui ne sçache sur le bout du doigt l'Histoire de l'Expérience de M. Pascal.

Gabriel Daniel SJ, *Voyage du monde de Descartes*. Paris, 1691, p. 188.

... negatur essentia et existentia formarum ... Hoc periculoso axioma semel hausto, proclive erit vanitati, scepticismo, et petulantiae humani ingenii disputare, non dari animam rationalem, nec generationem et conceptionem hominis in utero matris, nec ventum, nec lumen, nec processionem divinarum personarum, nec assumptionem carnis, et unionem hypostaticam in Christo, nec peccatum originale, nec miracula, nec prophetias, nec illapsus Dei in mentem et voluntatem hominis, nec regenerationem hominis per gratiam Dei, nec energemata demonum intra corpus hominis, aut circa ejus mentem, etc. ...

As quoted in A.C. Duker, *Gisbertus Voetius* (4 vols.). Leiden: Brill, 1897-1915 (reprint Leiden: Groen, 1989); vol. II, p. xlv-xlvi.

Le roi ayant appris que certaines opinions que la Faculté de théologie avait censurées autrefois et que le parlement avait défendu d'enseigner ni de publier, se répandent présentement, non-seulement dans l'Université, mais aussi dans le reste de cette ville et dans quelques autres du royaume, soit par des étrangers, soit par des gens du dedans, voulant empêcher le cours de cette opinion qui pourrait porter quelque confusion dans l'explication de nos mystères, poussé de son zèle et de sa piété ordinaire, il m'a commandé de vous dire ses intentions. Le roi vous exhorte, Messieurs, de faire en sorte que l'on n'enseigne point dans les universités d'autre doctrine que celle qui est portée par les règlements et les statuts de l'Université, et que l'on n'en mette rien dans les thèses, et laisse à votre prudence et à votre sage conduite de prendre les voies nécessaires pour cela.

As quoted in F. Bouillier, *Histoire de la philosophie Cartésienne*. Paris, 1868 (3rd ed. in 2 vols.; facs. reprint:

Genève: Slatkine Reprints, 1970; vol. 1, p. 469), with reference to *Quaedam recentiorum philosophorum ac praesertim Cartesii propositiones damnatae et prohibitae*. Paris: 1705.

(226) Whereas has been seen by the Court a request presented by the regents, Masters of Arts, doctors, and professors of the University, both in their own name and as tutors and defenders of the doctrine of Master Aristotle, ancient Professor Royal in Greek at the college of the Lyceum, and preceptor of the late king of quarrelsome memory, Alexander called the Great, acquirer of Asia, Europe, Africa and other places, which [request] is of the content that for some years an unknown dame called Reason would have undertaken to enter through force the schools of said University and, so as to attain that effect, would have prepared herself, with the aid of certain fractious persons taking the fractious names of Cartesians, of new philosophers, of circulators and of Gassendists, all people on the loose, to have Aristotle, ancient and peaceful possessor of said schools, expelled from them ...

(227) God of Abraham, Isaac, and Jacob [in dire need of vindication against] the God of the philosophers.

Vu par la Cour la requête présentée par les régents, maîtres ès arts, docteurs et professeurs de l'Université, tant en leur nom que comme tuteurs et défenseurs de la doctrine de maître Aristote, ancien professeur royal en grec dans le collège du Lycée, et précepteur du feu roi de querelleuse mémoire, Alexandre dit le Grand, acquéreur de l'Asie, Europe, Afrique et autres lieux, contenant que, depuis quelques années, une inconnue, nommée la Raison, aurait entrepris d'entrer par force dans les écoles de ladite Université, et pour cet effet, à l'aide de certains quidams factieux prenant les surnoms factieux de cartésiens, nouveaux philosophes, circulateurs et gassendistes, gens sans aveu, se serait mise en état d'en expulser Aristote, ancien et paisible possesseur desdites écoles ...

As quoted in F. Bouillier, *Histoire de la philosophie Cartésienne*. Paris, 1868 (3rd ed. in 2 vols.; facs. reprint: Genève: Slatkine Reprints, 1970; vol. 1, p. 470 (note 1).

Dieu d'Abraham, Dieu d'Isaac, Dieu de Jacob, non des philosophes et des savants.

Blaise Pascal, 'Mémorial' (of his night of religious ecstasy, Monday 23 November 1654; on p. 552-553 in Chevalier's 'Pléiade' edition of his *Oeuvres complètes*).

XIII: ACHIEVEMENTS AND LIMITATIONS OF FACT-FINDING EXPERIMENTALISM

(233) Here the makers may help philosophy by dressing up a list of pipes that rise only by a semitone, or a third, a fourth, a fifth, etc., for it will be easier to find the reason for that when one knows the properties of the pipes that are the cause of the difference between the notes.

(238) Oh GOD, thy Works are inscrutable, and all we know or can know of them is nothing but the dead shadows of the shadows of the shadows of thy adorable and inscrutable works; before which all the minds of men, however ingenious they may be, must become dull and confess their dumb ignorance.

(254) such that it can be applied to mount large stones for buildings; to erect obelisks; to raise water for fountains; to make flourmills go, in places that are not suitable, or lack enough room, for the services of horses. And this motor has the advantage that there are no maintenance costs during the time it is not being employed.

Or les Facteurs peuvent ayder à la Philosophie, en dressant le catalogue des tuyaux qui montent seulement d'un demyton, ou d'une Tierce, d'une quarte, d'une quinte, &c., car il sera plus aysé d'en trouver la raison, lorsque l'on cognoistra les qualitez des tuyaux qui sont cause de la difference de ces sons.

Marin Mersenne, *Harmonie Universelle*. Paris, 1636/7; p. 347 of the 'Livres des instrumens'.

O GODT, uwe Werken syn ondoorsoekelijk, en alles dat wij daar van weten, of weten kunnen, syn niet als de doode schaduwen van de schaduwen der schaduwen uwer aanbiddelijke en ondoorsoekelijke werken; waar voor alle de verstanden der Menschen, hoe spitsvindig sy syn, moeten stomp worden, en haar domme onwetentheid bekennen.

Jan Swammerdam (Herman Boerhaave ed.), *Biblia naturae; sive historia insectorum ...*. Leiden, 1737-1738, p. 664.

de sorte qu'on pourra l'appliquer a monter des grosses pierres pour les bastimens, a dresser des obelisques, a monter des eaux pour les fontaines, a faire aller des moulins pour moudre du bled en des lieux ou l'on n'a pas la commodité ou assez de place pour se servir de chevaux. Et ce moteur a cela de bon qu'il ne couste rien a entretenir pendant le temps qu'on ne l'employe point.

Christiaan Huygens collection of papers in Leyden

University Library: p.241 of v.22, midpage (coming from HUG 2, f.163r).

(260) ... unless the nature of the air is known first ...

... that they [i.e., experimentalists in weekly Royal Society session] may meet and confer in study and make as many experiments as they like, yet unless they use my principles they will advance nothing.

(261) Do you really judge, with all the approaches and entrances to all minds beset and blocked by the most obscure idols — idols very much fixed upon and burned into them — that any undistorted and polished surfaces remain for the true and original rays of things?

(262) For the Human Mind (...) is so far from similarity to a plane, equal, and clear mirror (which receives and reflects the rays of things without distortion) as to be rather like some enchanted mirror, full of superstitions and ghosts. Idols, then, are imposed upon the intellect ...

XIV NATURE-KNOWLEDGE DECOMPARTMENTALIZED

(272) ... a miracle of almost instantaneous transmission of information and ideas ...

(274) Descartes. — One must say at large: 'These things happen through their shapes and their motions'; for that is true. But to say which ones, and to construct the machinery — that is ridiculous, because it is useless and uncertain and awkward.

(275) ... whenever, so as to find the cause of several known phenomena, one posits a hypothesis, this hypothesis can be of three kinds.

For sometimes a manifest absurdity follows from its negation, and then the hypothesis is true and constant; or a manifest absurdity follows from its affirmation, and then the hypothesis is held to be false; and when one has not yet been able to draw absurdity from either its negation or its affirmation, the hypothesis remains in doubt; so that, in order to make a hypothesis evident, it does not suffice for all phenomena to follow from it, whereas instead, if something ensues contrary to just one of these phenomena, this suffices to ascertain its falsity.

Neque unde repleri potest, nec quid sequuturum sit sciri posse puto, nisi natura aeris sit ante cognita.

Nam convenient, studia conferant, experimenta faciant quantum volunt, nisi et utantur principiis meis, nihil proficient.

Thomas Hobbes (ed. W. Molesworth), *Opera* 2, p. 243-4; p. 236.

An tu censes, cum omnes omnium mentium aditus ac meatus obscurissimis idolis, iisque alte haerentibus et inustis, obsessi et obstructi sint, veris rerum et nativis radiis sinceris et politas areas adesse?

Francis Bacon, *Works* 3, p. p. 529.

Nam Mens Humana (...) tantum abest ut speculo plano, aequali, et claro similis sit (quod rerum radios sincere excipiat et reflectat), ut potius sit instar speculi alicujus incantati, pleni superstitionibus et spectris. Imponuntur autem intellectui Idola ...

Francis Bacon, *Works* 1, p. 643.

Cependant l'Europe pensante est alors un tel miracle de transmission presque instantanée des informations et des idées, les échanges de lettres sont si abondants, l'impression des opuscules, réponses et contre-réponses si rapide ...

J.-F. Revel, *Histoire de la philosophie occidentale*, vol. 2, *La philosophie pendant la science*. Paris: Stock, 1970, p. 229.

Descartes. — Il faut dire en gros: 'Cela se fait par figure et mouvement'; car cela est vrai. Mais de dire quels, et composer la machine, cela est ridicule; car cela est inutile et incertain et pénible.

Blaise Pascal, *Pensées*, n° 79 in Brunschvicg's arrangement.

... toutes les fois que, pour trouver la cause de plusieurs phénomènes connus, on pose une hypothèse, cette hypothèse peut être de trois sortes.

Car quelquefois on conclut un absurde manifeste de sa négation, et alors l'hypothèse est véritable et constante; ou bien on conclut un absurde manifeste de son affirmation, et alors l'hypothèse est tenue pour fausse; et lorsqu'on n'a pu encore tirer d'absurde, ni de sa négation, ni de son affirmation, l'hypothèse demeure douteuse; de sorte que, pour faire qu'une hypothèse soit évidente, il ne suffit pas que tous les phénomènes s'en ensuivent, au lieu que, s'il s'ensuit quelque chose de contraire à un seul des phénomènes, cela suffit pour assurer de sa fausseté.

'Réponse de Blaise Pascal au très bon Réverend Père Noël' (29 October 1647; p. 374 in Chevalier's 'Pléiade' edition of Pascal's *Oeuvres Complètes*).

XV THE FOURTH TRANSFORMATION: CORPUSCULAR MOTION GEOMETRIZED

(277) ... it often happens that experience may seem at first to conflict with the rules I have just explicated.

En effet, il arrive souvent que l'expérience peut sembler d'abord repugner aux règles que je viens d'expliquer.

René Descartes, *Oeuvres* 9, p. 93.

(279) ... the center of gravity of bodies taken together continues always with a uniform motion in the same direction and is not disturbed by any impact of the bodies.

... centrum grav. corporum simul sumptorum aequabili semper motu eodem versus pergat neque impulsu corporum ullo desistit.

Christiaan Huygens, *Oeuvres complètes* 16, p. 132.

(281) Each and every thing, insofar as it is simple and undivided, always remains, insofar as it can, in the same state, nor is it ever changed except by external causes ... And therefore we must conclude that whatever moves, always moves insofar as it can.

... unamquamque rem, quatenus est simplex & indivisa, manere, quantum in se est, in eodem semper statu, nec unquam mutari nisi a causis externis ... Atque ideo concludendum est, id quod movetur, quantum in se est, semper moveri.

Each and every part of matter, regarded by itself, never tends to continue moving in any curved lines, but only along straight lines.

... unamquamque partem materiae, seorsim spectatam, non tendere unquam ut secundum ullas lineas obliquas pergat moveri, sed tantummodo secundum rectas ...

René Descartes, *Oeuvres* 8, p. 62; p. 63.

(289) this notion of bodies having, as it were, a complete, absolute and independent reality in themselves ...

... haec notio corporum quasi habentium realitatem in se completam absolutam et independentem ...

absurd ... confused and incongruous with reason.

Jam vero quam confusa et rationi absona est haec doctrina non modo absurdae consequentiae convincunt ...

Isaac Newton (A.R. & M.B. Hall, eds.), *Unpublished Scientific Papers*. Cambridge UP, 1961; p. 144; p. 124, with the original Latin on p. 110; p. 92)

(291) ... for satisfying that curiosity of the mind which loves to know the reason of everything.

... pour tascher de donner encore cette satisfaction a la curiosité de l'esprit qui aime à sçavoir raison de toute chose.

Christiaan Huygens, *Oeuvres complètes* 13/II, p. 741.

(292) ... what he asserted about every ray without distinction, as if the refraction of all of them were quite alike, we assert only about the individual kinds of them, in positing that the sines of refraction of equally refrangible rays are as the sines of incidence.

... quod ... is de quibuslibet radiis indifferenter affirmaverit, quasi omnium persimilis fuisset refractionis, nos tantum affirmamus de singulis eorum generibus, ponendo quod radorum aequae refrangibilium sinus refractionis sunt ut sinus incidentiae.

Isaac Newton, *Optical Papers* 1, p. 170-171 and 312-313.

XVI THE FIFTH TRANSFORMATION: THE BACONIAN BREW

XVII LEGITIMACY OF A NEW KIND

(p. 569) ... stargazers, surveyors, gaugers of tapistry, wine and bodies in general, further mint masters and all merchants ...

Den Sterrekyckers, Landtmeters, Tapytmeters, Wijnmeters, Lichaemmeters int ghemeene, Muntmeesters ende allen Coopliden wenscht Simon Stevin Gheluck.

Simon Stevin, dedication of *De Thiende*. Leiden: Plantijn, 1585.

(325) ... by and large in accordance with Verulam's design.

... à peu près suivant le dessein de Verulamius.

XVIII NATURE-KNOWLEDGE BY 1684: THE ACHIEVEMENT SO FAR

(335) We have an incapacity for proof which no amount of dogmatism can overcome. We have an idea of truth which no amount of skepticism can overcome.

Nous avons une impuissance de prouver, invincible à tout le dogmatisme. Nous avons une idée de la vérité, invincible à tout le pyrrhonisme.

Blaise Pascal, *Pensées*; n° 395 in Brunschvicg's arrangement.

(337) ... masters and possessors of Nature ...

... maîtres et possesseurs de la Nature ...

René Descartes, *Oeuvres* 6, p. 62.

(338) [Those who] dare to speak of nature as a thing already sufficiently explored ... have been effective in quenching and stopping inquiry.
[With those who] assert that absolutely nothing can be known ... zeal and affectation have carried them much too far.

Qui de natura tanquam de re explorata pronuntiare ausi sunt ... ad inquisitionem extinguendam et abrumpendam efficaces fuerunt.

Qui ... nihil prorsus sciri posse asseruerunt ... studio quodam atque affectatione proveci, prorsus modum excesserunt.

... a position between these two extremes, — between the presumption of pronouncing on everything, and the despair of comprehending anything ...
... whether or no anything can be known [is a question] to be settled not by arguing but by trying.

At antiquiores ex Graecis (quorum scripta perierunt) inter pronuntiandi janctantiam et *Acatalepsiae* desperationem prudentius se sustinuerunt.

... hoc ipsum (videlicet utrum aliquid sciri possit) non disputare, sed experiri.

Francis Bacon, *Works* 1, p. 151 (Latin); *Works* 4, p. 39 (English)

(340) What force is.

I say that force is a spiritual virtue, an invisible power which, by means of accidental, external compulsion, is caused by motion and located and infused into bodies which are drawn and forced out of their natural state of being; in giving these an active life of wonderful power, it constrains all created things to change shape and place; it runs with fury toward its death, and takes different guises as the case requires.

Che cosa e forza.

Forza dicho essere una virtu spirituale, una potentia invisibile, laquale per accidentale essterna violenza e chausata dal moto e chollocata e infusa ne corpi iguali sono dalloro naturale uso retratti e epiegati; dando acquelli vita attiva di miravigliosa potentia, chostrignie tutte le create chose a mutatione di forma e di sito; chore con furia alla sua morte e vassi diversifichando mediante le chagioni.

As quoted in E.J. Dijksterhuis, *Val en worp*. Groningen: Noordhoff, 1924, p. 147 (referred to Leonardo da Vinci, manuscript A, p. 34^v in vol. 1 of *Les manuscrits de Léonard de Vinci* (ed. C. Ravaisson-Mollien). 6 vols. Paris: Quantin, 1881–1891.

(341) To discover a cause of weight that is intelligible, it is necessary to investigate how weight can come about, while assuming the existence only of bodies made of one common matter in which one admits no quality or inclination to approach each other but solely different sizes, figures, and motions ...

Pour chercher une cause intelligible de la pesanteur il faut voir comment il se peut faire, en ne supposant dans la nature que des corps faicts d'une mesme matiere, dans lesquels on ne considere nulle qualité, ny inclination a s'approcher les unes des autres, mais seulement des differentes grandeurs, figures et mouvements ...

Christiaan Huygens, *Oeuvres complètes* 19, p. 631.

(342) ... the force that must be employed, in the place where the body is and in the direction it can take, to prevent it from beginning to move.

... la quantité de l'incitation a chasque instant se mesure par la force qu'il faudroit employer pour empescher le corps de commencer a se mouvoir, a l'endroit ou il se trouve, et dans la direction qu'il a.

... the incitations of a body can be equal to each other

... les incitations d'un corps quoyque causees par

although they are caused by different causes, as weight, elasticity, wind, attraction of a magnet, or something else.

‘Brief demonstration of a memorable error committed by Descartes and others concerning a law of nature.’

(345) The mark of substances is to act.

XIX THE SIXTH TRANSFORMATION: THE NEWTONIAN SYNTHESIS

(354) Let A therefore designate the resistance of the box on its external surface, and B the resistance of the empty box on its internal parts; then, if the resistances of equally swift bodies on their internal parts are as the matter, or the number of particles that are resisted, 78B will be the resistance of the full box on its internal parts; and thus the whole resistance A + B of the empty box will be to the whole resistance A + 78B of the full box as 77 to 78, and by separation A + B will be to 77B as 77 to 1, and hence A + B will be to B as 77 x 77 to 1, and by separation A will be to B as 5,928 to 1. The resistance encountered by the empty box on its internal parts is therefore more than 5,000 times smaller than the resistance on the external surface. This argument depends on the hypothesis that the greater resistance encountered by the full box does not arise from some other hidden cause but only from the action of some subtle fluid upon the enclosed metal. But I believe the cause is quite another. For the periods of the oscillations of the full box are less than the periods of the oscillations of the empty box, and therefore the resistance on the external surface of the full box is greater than that of the empty box in proportion to its velocity and the length of the space described in oscillating. Hence, since it is so, the resistance on the internal parts of the box will be either nil or wholly insensible.

(359) Using equal pendula, let the oscillations of two bodies of the same weight be counted, and the bulk of matter in each will be reciprocally as the number of oscillations made in the same time. When experiments were carefully made with gold, silver, lead, glass, sand, common salt, water, wood, and wheat, however, they resulted always in the same number of oscillations.

(360) Therefore if the times are equal, the quantities of matter in individual bodies will be as the weights.

differentes causas, comme pesanteur ressort vent attraction d’aimant ou autre, peuvent estre egales l’une a l’autre.

Christiaan Huygens, *Oeuvres complètes* 18, p. 496; 497.

‘Brevis demonstratio erroris memorabilis Cartesii et aliorum circa legem naturalem.’

Agere est character substantiarum.

As quoted in J.C. Boudri, *What Was Mechanical About Mechanics. The Concept of Force between Metaphysics and Mechanics from Newton to Lagrange*. Dordrecht: Kluwer, 2002; p. 89 (passage referred to Gottfried Wilhelm Leibniz, ‘Specimen dynamicum’. *Acta eruditorum*, April 1695, p. 235.

Designet igitur A resistantiam pyxidis in ipsius superficie externa, & B resistantiam pyxididis vacuae in partibus internis; & si resistantiae corporum aequivelocium in partibus internis sint ut materia, seu numerus particularum quae resistuntur: erit 78B resistantia pyxididis plenae in ipsius partibus internis: ideoque pyxididis vacuae resistantia tota A+B erit ad pyxididis plenae resistantiam totam A+78B ut 77 ad 78, & divisim A+B ad 77B, ut 77 ad 1, indeque A+B ad B ut 77 x 77 ad 1, & divisim A ad B ut 5928 ad 1. Est igitur resistantia pyxididis vacuae in partibus internis quinque minor quam ejusdem resistantia in externa superficie, & amplius. Sic disputamus ex hypothesi quod major illa resistantia pyxididis plenae, non ab alia aliqua causa latente oriatur, sed ab actione sola fluidi alicujus subtilis in metallum inclusum. At causam longe aliam esse opinor. Nam tempora oscillationum pyxididis plenae minora sunt quam tempora oscillationum pyxididis vacuae, & propterea resistantia pyxididis plenae in externa superficie major est, pro ipsius velocitate & longitudine spatii oscillando descripti, quam ea pyxididis vacuae. Quod cum ita sit, resistantia pyxididis in partibus internis aut nulla erit aut plane insensibilis.

Isaac Newton, *Philosophiae Naturalis Principia Mathematica*, Book II, end of General Scholium at the end of Section 6.

Pendulis aequalibus numerentur oscillationes corporum duorum ejusdem ponderis, et copia materiae in utroque erit reciproce ut numerus oscillationum eodem tempore factarum. Experimentis autem in auro, argento, plumbo, vitro, arena, sale communi, aqua, ligno, tritico, diligenter factis incidi semper in eundem oscillationum numerum.

As quoted on pp. 318-319 of the edition of one of Newton’s revisions of ‘De Motu ...’ provided by J. Herivel in his *The Background to Newton’s Principia. A Study of Newton’s Dynamical Researches in the Years 1664-1684*. Oxford: Clarendon, 1965.

Ideoque si tempora sunt aequalia, quantitates materiae in singulis corporibus erunt ut pondera.

... to discover the variation of gravity. Moreover, by the most accurate experiments I have found that the quantity of matter in individual bodies is always proportional to their weight.

That all bodies gravitate to each of the planets, and that their weights toward whichever particular planet you please, at equal distances from the center of the planet, are proportional to the quantity of matter in each.

That gravity is given in bodies universally, and that it is proportional to the quantity of matter in each.

The planets move in ellipses having their focus at the center of the sun, and by radii drawn to that center describe areas proportional to the times.

Hitherto we have reasoned about these motions from the phenomena. Now that the principles of the motions are known, we infer from these the celestial motions *a priori*.

... ad cognoscendam variationem gravitatis. Factis autem experimentis quam accuratissimis inveni semper quantitatem materiae in corporibus singulis eorum ponderi proportionalem esse.

Corpora omnia in planetas singulos gravitare, & pondera eorum in eundem quemvis planetam, paribus distantis a centro planetae, proportionalia esse quantitati materiae in singulis.

Gravitatem in corpora universa fieri, eamque proportionalem esse quantitati materiae in singulis.

Planetae moventur in ellipsis umbilicum habentibus in centro solis, & radiis ad centrum illud ductis areas describunt temporibus proportionales.

Disputavimus supra de his motibus ex phaenomenis. Jam cognitis motuum principiis, ex his colligimus motus coelestes *a priori*.

Isaac Newton, *Philosophiae Naturalis Principia Mathematica* (Compiled from D. Densmore, *Newton's Principia: The Central Argument. Translation, Notes, and Expanded Proofs*. Santa Fe: Green Lion Press, 1995)

(361)

I	1	The method of first and last ratios	De methodo rationum primarum & ultimarum
	2	To find centripetal forces	De inventione virium centripetarum
	3	The motion of bodies in eccentric conic sections	De motu corporum in conicis sectionibus eccentricis
	4	To find elliptical, parabolic, and hyperbolic orbits, given a focus	De inventione orbium ellipticorum, parabolicorum & hyperbolicorum ex umbilico dato
	5	To find orbits when neither focus is given	De inventione orbium ubi umbilicus neuter datur
	6	To find motions in given orbits	De inventione motuum in orbibus datis
	7	The rectilinear ascent and descent of bodies	De corporum ascensu & descensu rectilineo
	8	To find the orbits in which bodies revolve when acted upon by any centripetal force	De inventione orbium in quibus corpora viribus quibuscunque centripetis agitata revolvuntur
	9	The motion of bodies in mobile orbits, and the motion of the apsides	De motu corporum in orbibus mobilibus, deque motu apsidum
	10	The motion of bodies on given surfaces, and the oscillating motion of simple pendula	De motu corporum in superficiebus datis, deque funependulorum motu reciproco
	11	The motion of bodies drawn to one another by centripetal forces	De motu corporum viribus centripetis se mutuo petentium
	12	The attractive forces of spherical bodies	De corporum sphaericorum viribus attractivis
	13	The attractive forces of nonspherical bodies	De corporum non sphaericorum viribus attractivis
	14	The motion of minimally small bodies, that are acted on by centripetal forces tending toward each of the individual parts of some great body	De motu corporum minimorum, quae viribus centripetis ad singulas magni alicuius corporis partes tendentibus agitantur
II	1	The motion of bodies that are resisted in the ratio of their velocity	De motu corporum quibus resistitur in ratione velocitatis
	2	The motion of bodies that are resisted in the squared ratio of their velocity	De motu corporum quibus resistitur in duplicata ratione velocitatis
	3	The motion of bodies that are resisted partly in the ratio of their velocity and partly in the squared ratio of their velocity	De motu corporum quibus resistitur partim in ratione velocitatis, partim in eiusdem ratione duplicata
	4	The revolving motion of bodies in resisting media	De corporum circulari motu in mediis resistentibus
	5	The density and compression of fluids, and hydrostatics	De densitate & compressione fluidorum, deque hydrostatica
	6	The motion of simple pendula and the resistance to them	De motu & resistentia corporum funependulorum
	7	The motion of fluids and the resistance encountered by projectiles	De motu fluidorum & resistentia projectilium
	8	Motion propagated through fluids	De motu per fluida propagato

9	The circular motion of fluids	De motu circulari fluidorum
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(362) If there be given both the density of the globe and its velocity at the beginning of the motion, and the density of the compressed quiescent fluid in which the globe moves, there is given at any time both the velocity of the globe and its resistance, and the space described by it.

(363) ... some active principle is required from which the globe may receive continually the same quantity of motion which it is always communicating to the matter of the vortex ...

Therefore the hypothesis of vortices is utterly irreconcilable with astronomical phenomena, and rather serves to perplex than explain the heavenly motions.

(366) ... we put forward this work of ours as mathematical principles of philosophy. For the whole difficulty of philosophy seems to reside in this, that from the phenomena of motions we investigate the forces of nature and then from these forces demonstrate the other phenomena. It is to these ends that the general propositions in books 1 and 2 are directed. Then, in book 3, we have put forward as an example of this an explanation of the system of the world. For there, by means of propositions demonstrated mathematically in the earlier books, we derive from celestial phenomena the gravitational forces by which bodies tend toward the sun and the individual planets. Then the motions of the planets, the comets, the moon, and the sea are deduced from these forces by propositions that are also mathematical. If only we could derive the other phenomena of nature from mechanical principles by the same kind of reasoning! For many things lead me to suspect that all phenomena may depend on certain forces by which the particles of bodies, by causes not yet known, either are impelled toward one another and cohere in regular figures, or are repelled from one another and recede. Since these forces are unknown, philosophers have hitherto made trial of nature in vain. But I hope that the principles set down here will shed some light on either this mode of philosophizing or some truer one.

(384) For the best and safest method of philosophizing seems to be, first to enquire diligently into the properties of things and to establish these properties by experiments, and then to proceed more slowly to hypotheses for the explanation of them. For hypotheses should only be employed for explaining the properties of things, not abused for determining them; unless so far as they may furnish experiments. For if one were from the sheer possibility of hypotheses to make a

Data & densitate globi & velocitate ejus sub initio motus, ut & densitate fluidi compressi quiescentis in qua globus movetur; datur ad omne tempus & velocitas globi & ejus resistentia & spatium ab eo descriptum ...

Isaac Newton, *Philosophiae Naturalis Principia Mathematica*. Book II, Corollary 3 to Proposition 38.

Proinde ad conservationem Vorticis constanter in eodem movendi statu, requiritur principium aliquod activum a quo globus eandem semper quantitatem motus accipiat quam imprimit in materiam vorticis.

Isaac Newton, *Philosophiae Naturalis Principia Mathematica*. Book II, Corollary 4 to Proposition 52.

Itaque Hypothesis Vorticum cum Phaenomenis Astronomicis omnino pugnat, & non tam ad explicandos quam ad perturbandos motus coelestes conducit.

Isaac Newton, *Philosophiae Naturalis Principia Mathematica*. Book II, Scholium to Proposition 53 (penultimate sentence of Book II).

... haec nostra tanquam philosophiae principia mathematica proponimus. Omnis enim philosophiae difficultas in eo versari videtur, ut a phaenomenis motuum investigemus vires naturae, deinde ab his viribus demonstremus phaenomena reliqua. Et huc spectant propositiones generales, quas libro primo & secundo pertractavimus. In libro autem tertio exemplum huius rei proposuimus per explicationem systematis mundani. Ibi enim, ex phaenomenis coelestibus, per propositiones in libris prioribus mathematice demonstratas, derivantur vires gravitatis, quibus corpora ad solem & planetas singulos tendunt. Deinde ex his viribus per propositiones etiam mathematicas, deducuntur motus planetarum, cometarum, lunae & maris. Utinam caetera naturae phaenomena ex principiis mechanicis eodem argumentandi genere derivare liceret. Nam multa me movent, ut nonnihil suspicer ea omnia ex viribus quibusdam pendere posse, quibus corporum particulae per causas nondum cognitatas vel in se mutuo impelluntur & secundum figuras regulares cohaerent, vel ab invicem fugantur & recedunt: quibus viribus ignotis, philosophi hactenus naturam frustra tentarunt. Spero autem quod vel huius philosophandi modo, vel veriori alicui, principia hic posita lucem aliquam praebeant.

Isaac Newton, *Philosophiae Naturalis Principia Mathematica* (end of first paragraph of 'Auctoris Praefatio' to the first edition).

Optimus enim & tutissimus philosophandi modus videtur, ut imprimis rerum proprietates diligenter inquiramus & per experimenta stabiliamus; ac dein tardius contendamus ad Hypotheses pro earum explicatione. Nam Hypotheses ad explicandas rerum proprietates tantum accommodari debent, & non ad determinandas usurpari, nisi quatenus experimenta subministrare possint. Et si quis ex sola Hypothesium possibilitate de veritate rerum conjecturam faciat, non video quo pacto quicquam certi in ulla scientia

conjecture of the true state of things, I see not in what manner one can determine anything in any science with certainty, since one may always think up other and again other hypotheses, which shall then appear richly to supply new difficulties. Which is why I have judged that consideration of hypotheses ought here to be abstained from, as inappropriate to the argument ...

XX EPILOGUE: A DUAL LEGACY

(408) If man is capable of predicting, with almost full assurance, the phenomena of which he knows the laws; if even when these are not known to him he is capable from past experience to foresee with great probability the events of the future; why then would we regard it as a chimerical enterprise to draw with a certain amount of likelihood the table of future destinies of humankind from the results of its history? The sole foundation of belief in the natural sciences is this idea that the general laws (be they known or not) that rule the phenomena of the universe are necessary and constant; and for what reason would this principle be less true for the development of the intellectual and moral faculties of man than for the other operations of nature?

(414) Enlightenment is man's emergence from his self-imposed immaturity. Immaturity is the inability to use one's understanding without guidance from another. This immaturity is self-imposed when its cause lies not in lack of understanding, but in lack of resolve and courage to use it without guidance from another. *Sapere aude!* [dare to know] "Have courage to use your own understanding!" – that is the motto of enlightenment.

(418) That general revolution of the human mind has now been accomplished almost entirely. As I have explained, no more remains to complete the positive philosophy by including in it the study of social phenomena, and then to take it up in one body of homogenous doctrine. Once that dual operation has advanced sufficiently, the definitive triumph of the positive philosophy shall take place spontaneously, and restore social order.

determinare possit; siquidem alias atque alias Hypotheses semper liceat excogitare, quae novas difficultates suppeditare videbuntur. Quamobrem ab Hypothesium contemplatione, tanquam improprio argumentandi loco, hic abstinendum esse censui ...

'Mr. Newtons Answer to the foregoing Letter'. In: *Philosophical Transactions*. 1672, p. 5014 [as reproduced in I. Bernard Cohen (ed.), *Isaac Newton's Papers & Letters on Natural Philosophy*. Cambridge UP, 1958].

Si l'homme peut prédire, avec une assurance presque entière, les phénomènes dont il connaît les lois; si, lors même qu'elles lui sont inconnues, il peut, d'après l'expérience du passé, prévoir, avec une grande probabilité, les événements de l'avenir; pourquoi regarderait-on comme une entreprise chimérique, celle de tracer, avec quelque vraisemblance, le tableau des destinées futures de l'espèce humaine, d'après les résultats de son histoire? Le seul fondement de croyance dans les sciences naturelles, est cette idée, que les lois générales, connues ou ignorées, qui règlent les phénomènes de l'univers, sont nécessaires et constantes; et par quelle raison ce principe serait-il moins vrai pour le développement des facultés intellectuelles et morales de l'homme, que pour les autres opérations de la nature?

Marquis de Condorcet, *Esquisse d'un tableau historique des progrès de l'esprit humain* [1793; first lines of the 10th 'époque', 'Les progrès futurs de l'esprit humain'].

Aufklärung ist der Ausgang des Menschen aus seiner selbstverschuldeten Unmündigkeit. Unmündigkeit ist das Unvermögen, sich seines Verstandes ohne Leitung eines anderen zu bedienen. Selbstverschuldet ist diese Unmündigkeit, wenn die Ursache derselben nicht am Mangel des Verstandes, sondern der Entschließung und des Mutes liegt, sich seiner ohne Leitung eines andern zu bedienen. Sapere aude! Habe Mut, dich deines eigenen Verstandes zu bedienen! ist also der Wahlspruch der Aufklärung.

Immanuel Kant, 'Beantwortung der Frage: Was ist Aufklärung?' [1784; first published in the *Berlinische Monatsschrift*].

Cette révolution générale de l'esprit humain est aujourd'hui presque entièrement accomplie: il ne reste plus, comme je l'ai expliqué, qu'à compléter la philosophie positive en y comprenant l'étude des phénomènes sociaux, et ensuite à la résumer en un seul corps de doctrine homogène. Quand ce double travail sera suffisamment avancé, le triomphe définitif de la philosophie positive aura lieu spontanément, et rétablira l'ordre dans la société.

Auguste Comte (eds. M. Serres, F. Dagognet, A. Sinaceur), *Philosophie première. Cours de philosophie positive. Leçons 1 à 45*. Paris: Hermann, 1975; p. 39.