

Émilie Du Châtelet, *Foundations of Physics*, 1740.

Translated by Katherine Brading *et al.*¹ at the University of Notre Dame and Duke University. Footnotes are ours except where otherwise indicated.

Du Châtelet's marginal notes are placed in **{bold}** in the closest appropriate place in the text. Please see the French original for the position of each note in the margin alongside the paragraph. Figures are available in the original text, and online via the BNF.

Chapter 16. Of Newtonian Attraction

385. All the Phenomena that I just explained to you in the three preceding Chapters, are brought about, according to the Newtonians, by the Attraction that all bodies exert upon one another.

{That which the Newtonians mean by attraction.} This attraction is, according to them, a property given by God to all matter, by which all parts of matter tend towards one another in direct proportion to their mass and in inverse proportion to the squares of their distances.

386. We find the germ of this idea in Kepler; the way he expresses himself in the introduction to the Book where he treats the Planet Mars is too noteworthy not to relate here the terms which he uses.²

Si duo lapides in aliquo loco mundi collocarentur propinqui invicem, extra orbem virtutis tertii cognati corporis, illi lapides ad similitudinem duorum Magnetum coïrent loco intermedio, quolibet accedens ad alterum tanto intervallo, quanta est alterius moles in comparatione.

Si terra & luna non retinerentur vi animali, aut aliâ aliquâ equipolenti qualibet, in suo circuitu, terra ascenderet ad lunam quinquagesimâ quartâ parte intervalli, luna descenderet ad terram quinquaginta tribus circiter partibus intervalli, ibique jungerentur. Posito tamen quod substantia utriusque sit unius & eiusdem densitatis.

¹ Especially Monica Solomon, Jamee Elder, Anne Seul, Penelope Brading.

² Du Châtelet offers a French translation of this Latin passage in a footnote. Here, we offer an English translation from William H. Donahue's *Johannes Kepler: Astronomia Nova*, revised edition, Green Lion Press, 2015, p. 25: "If two stones were set near one another in some place in the world outside the sphere of influence of a third kindred body, these stones, like two magnetic bodies, would come together in an intermediate place, each approaching the other by an interval proportional to the bulk [moles] of the other.

"If the moon and the earth were not each held back in its own circuit by an animate force or something else equally potent, the earth would ascend towards the moon by one fifty-fourth part of the interval, and the moon would descend towards the earth about fifty-three parts of the interval, and there they would be joined together; provided, that is, that the substance of each is of one and the same density."

This English translation does not reflect one aspect of Du Châtelet's French translation, where she translates "vi animali" as "acting soul" [âme agissante].

387. Kepler is not alone in having spoken about attraction. Frenicle, one of the first Academicians of the Sciences, conceived of it as a force put by the Creator into his Work to conserve it; and Roberval defined it: *Vim quamdam corporibus insitam qua partes illius in unum coire affectent.*³

388. {How attraction brings about the fall of bodies, and the Astronomical Phenomena, when one has once admitted it.} It is certain, that if we grant the Newtonians this assumption of an attraction distributed in all the parts of matter, they explain marvelously by this attraction the Astronomical Phenomena, the fall of bodies, the ebb and flow of the sea, the effects of light, the cohesion of bodies, and the chemical processes; and it is certain that almost all natural effects become a consequence of this force that one assumes is distributed in all matter, when one has once admitted it. Thus, in this system, the earth and the moon revolve around the Sun, because the Sun attracts them both; but the earth, having more mass than the moon, and being very much closer to this Planet⁴ than the Sun, forces the moon to revolve around it through the superiority of its attraction.

All the irregularities of the moon in its course are a palpable consequence of the combination of the attraction of the Sun and the earth upon the moon; for the energy of this attraction varying with the positions of the attracting bodies, it must continuously change the curve that the moon describes around the earth, since this Planet successively approaches and recedes from the earth and from the Sun.

Attraction, being regarded by some Newtonians as an essential property of matter, is always assumed to be reciprocal: thus, the earth in gravitating towards the Sun makes the Sun gravitate towards it, and the Sun and the earth attract one another reciprocally in direct proportion to their masses. But they move towards one another in inverse proportion to these same masses, and the path that the earth makes toward the Sun is to the path that the Sun makes toward the earth, in the same time by this attraction alone, as the mass of the Sun is to the mass of the earth. Likewise, the earth in forcing the moon to turn around it through the superiority of its attraction, itself obeys the attraction that the moon exerts upon it. This attraction of the moon greatly alters the curve that the earth describes in turning around the Sun; it is a partial cause of the tides, to which the attraction of the Sun also contributes a determinate quantity.

It is for the same reason that the earth goes more slowly when it is in the sign of Pisces, because being then closer to the Planets Mars and Venus, the attractions that these two Planets exert upon it partially counterbalance in part that of the Sun, and as a consequence slow the path of the earth towards this star.

The Comets themselves find their routes completely mapped out by this attraction. When the Comet of 1680 appeared, Mr. Newton, having calculated according to this principle the path that it must make, had the satisfaction of seeing the Comet respond every day to the points that he

³ “The inner force of bodies whereby a body's parts endeavor to combine into one.”

⁴ This “Planet” is the moon.

had marked.

The alterations that Jupiter and Saturn receive in their courses are also an effect calculated from this attraction; for when these two powerful Planets find themselves in conjunction, the course of each undergoes changes that must result from their mutual attraction. This conjunction, that rarely happens because of the time that each of these two enormous Globes takes to make its revolution in its orbit, happened during Mr. Newton's time, and he saw them undergo, in a perceptible manner, the disturbances that he had foreseen and calculated.

All Astronomical Phenomena, then, that appear to be almost inexplicable in the system of vortices, seem to be nothing other than necessary corollaries of the universal attraction that is distributed in matter. For not only does this attraction show why a Planet revolves around another, why the moon⁵, for example, revolves around the earth; but it also shows how much time it must take to make that revolution, and on this we could take the calculations instead of the observations, so closely do they agree.

389. {Attraction produces also chemical effects, the cohesion of bodies, etc.} This principle, so fruitful in Astronomy, is no less so in most of the effects that take place here below; weight and the fall of bodies toward the earth, the flattening of the earth at the poles, and its elevation at the equator are also marvelously well deduced from attraction in inverse proportion to the square of the distances.

{But then it decreases in a greater proportion than that of the squares.} The Newtonians who make of attraction a property inseparable from matter, want to make it reign everywhere. But when they want to explain by means of it the cohesion of bodies, chemical effects, the Phenomena of light, etc., they are obliged to suppose other laws of attraction than that which directs the course of the Stars, and which acts in inverse proportion to the squares of the distances.

Mr. Newton, in calculating the effects that should result from the different possible laws of attraction, found and demonstrated: *that if the attraction that a body undergoes in contact is much stronger than that which it undergoes at every finite distance, this attraction decreases in a greater proportion than that of the square of the distances; and vice versa.*

The Disciples of Mr. Newton, most of whom have pushed their conjectures much further than he in many things, have concluded from this theorem that since, according to them, we cannot attribute these Phenomena to any ambient fluid, nor to conspiring motions of the parts of bodies, nor to any external cause, it must be that there is between the parts of these bodies an internal force capable of holding them united together. They have also concluded that since this force increases to such a point during contact that it becomes perceptible, and since the bodies can then no longer be separated except with difficulty, it must be that the attraction they then exert upon one another decreases in greater proportion than that of the square of the distances.

We could already deny this hasty conclusion: *that no ambient fluid nor shared [conspirants]*

⁵ In the 1740 edition, this is the earth ("la terre") rather than the moon, but in the 1742 edition it is corrected to the moon ("la Lune").

motions of the parts of bodies can be the cause of these Phenomena. But I will not engage here in the details of the Phenomena and their mechanical causes, my goal being only to show you in general how the Newtonians claim to explain these Phenomena by attraction, and what the reasons are that should make us reject this attraction when it is given as cause.

The Newtonians explain by this attraction, which they suppose acts at least in proportion to the cube of distances, and which is so powerful in contact, almost all the Phenomena that surround us. Thus, they say, if the parts of bodies cohere together it is because, since they are touching at several points of their surface, the attraction (being proportional to the cubes, and which alone acts between them in a perceptible way) attaches them strongly to one another. Thus, the different cohesions, hardness, softness, and fluidity, depend upon the different degrees of contact of the parts that compose the bodies: this is why pitch or some other sticky matter put in between two bodies, filling the interstices that are found between their parts and joining their surfaces, increases their cohesion.

It is this attraction that makes all drops of fluid have a spherical form, and flatten themselves on the side on which they touch that which supports them, and flatten themselves to a greater or lesser extent according to whether that which supports them is more or less attractive, that is to say, according to whether it is more or less dense. And it is this attraction that makes the parts of the fluid that compose these drops attract one another more or less strongly. It is for this same reason that the surface of water contained in a vase is concave while that of mercury is convex, for the parts of water attract one another less strongly than the sides of the vase attract them, and so they move upwards at the sides, whereas the opposite happens with mercury for the opposite reason.

{It is this attraction that raises water in capillary tubes.} The ascent of water in capillary tubes, so difficult to explain in detail by the pressure of a subtle matter, is a result of the attraction of the parts of the tube, this being more powerful on the water than the mutual attraction that the parts of the water exert upon each other. But mercury, on the contrary, never rises in capillary tubes because of the density of its parts, the mutual attraction of which is greater than that of the glass. It is again, according to them, by this same principle that oil rises in the cotton⁶ of a lamp, that ink attaches itself to my pen, that sap circulates in plants, etc.

{The effects of light depend also upon attraction according to the Newtonians.} Refraction, and even the reflection of light in certain circumstances, depend also, according to the Newtonians, upon this attraction, in inverse proportion to the cube of distances. Thus, the ray breaks up all the more as the medium that it traverses is more dense, because this medium attracts it the more strongly the more dense it is. The ray is reflected at a certain oblique angle of incidence, when passing from crystal into the air, because at a certain oblique angle the attraction of the crystal on the ray is more powerful than its vertical motion, by which it tends to penetrate the crystal. The ray is deflected when passing near the sides of bodies because at a very small distance bodies attract it perceptibly. Finally, the prism separates the different rays because it attracts each differently.

⁶ i.e. the wick.

Fermentations, crystallizations, dissolutions, effervescences, indeed all chemical effects, are also subject to this attraction that is so powerful in contact, and the celebrated Englishman Mr. Frenid has provided an entire chemistry founded on this principle. But as chemical effects are infinitely complicated, we are often obliged to assume new laws of attraction when that of the cubes is not sufficient for the detail of the explanations. Thus, we are obliged to make the laws vary as [*à mesure que*] the Phenomena vary.

390. Some Newtonians, finding it inconvenient to suppose in this way laws of attraction according to need, and finding how many criticisms this readiness to create new laws of nature for each effect exposed them to, contrived to explain all Phenomena, celestial as well as terrestrial, by one and the same attraction, that acts like an algebraic quantity $a/xx + b/x^3 + \text{etc.}$, x marking the distance, that is to say (for you do not yet understand this language) as the square, plus the cube, plus etc. In the case of large distances, as for example that of the Planets, the part of attraction that acts as the cube is almost zero, and disturbs by only an infinitely small amount the other part of attraction, which acts as the square and on which the ellipticity of orbits depends (§348).

But in the case of very small distances, and in the contact of bodies, the part of attraction that acts in proportion to the cube, or to a greater power, becomes in its turn very strong with respect to the other, which is then almost imperceptible.

This explanation is certainly very ingenious, and anticipates well the objections and criticisms that one could make against to the overly zealous Partisans of attraction.

391. {Uses that Messrs Freind and Keill have made of this principle of attraction.} Mr. Keill put at the end of his *Introductio ad veram Astronomiam* several propositions, by means of which he claims that one could geometrically deduce the majority of Phenomena from this attraction that is so powerful in contact.

According to these propositions, not only are cohesion and chemical effects the consequences of attraction, but the elasticity of bodies and the Phenomena of electricity are also subject to it.

Mr. Keill, the brother of the one whom I have just been talking about, wrote a treatise on animal secretion, which he also explained by attraction.

We find the source of all these applications of attraction in the questions that Mr. Newton put at the end of his *Opticks*. The disciples of this great man believed that these doubts could even serve as a foundation for their hypotheses. It must be admitted that some of these hypotheses are a little forced, and that there is a lot of difference in accuracy and precision between the applications that are made in the attraction of Celestial Phenomena and the uses made of them in the other effects I have just spoken about. Also, this use of attraction is not as universally received even by Newtonians as that by which Astronomical Phenomena are explained.

392. {Idea of Mr. Maupertuis on the law of attraction in our planetary system. Acad. des

Sciences, 1732.} Mr. Maupertuis is, of all the French philosophers, the one who has advanced the furthest in his research on attraction. In 1732, he presented to the Academy of Sciences a Paper in which he inquired into the reason why the Creator gave preference to the inverse square law of attraction, that takes place in the Astronomical Phenomena and in the fall of bodies, over the other possible laws that seem to have had an equal right to be used. And he finds from his calculation that, of all of the laws he examined, only the inverse square law yields the same attraction for the whole and for the parts that compose it, as well as having the advantage of the effects decreasing with the distance of the causes. It seemed to Mr. Maupertuis that these two advantages, of uniformity and of analogy, could be the reasons that determined the Creator to choose the inverse square law of attraction in preference to all the other laws that He surveyed.

393. {A singular phenomenon that would result from attraction in inverse proportion to the squares of the distances in a concave Sphere.} The consideration of the effects that must result from the law of attraction in inverse proportion to the squares of the distances, such as takes place in nature according to the Newtonians, leads to the discovery of a truly singular Phenomenon: according to this law, in the concave interior of a hollow Sphere there could be, using the inverse square attraction hypothesis, a world devoid of the Phenomena of weight, and whose inhabitants would move in every direction with equal ease. For inside a hollow sphere, the parts of the spherical surface which act on a corpuscle placed at any point inside the sphere, always have equal actions: the narrower part⁷ exerts on the corpuscle, due to its closer proximity, an attraction that is counterbalanced by the attraction exerted by the larger part. These two things, the distance of the corpuscle and the size of the spherical surface that acts on it, always increase in the same proportion according to this law. Thus, according to this system, in a concave Sphere bodies would not have any weight, but they would attract each other very perceptibly, since their mutual attraction would not be absorbed, as it is here on Earth, by a more powerful attraction.

Mr. Maupertuis's Paper, of which I just spoke, is, like everything this Philosopher does, full of wisdom and sophisticated calculation. He presents there his opinion concerning the reason for the preference for the inverse square law over all others only as a query, but these are assuredly the queries of a great man.

394. If this Philosopher, before inquiring into the reason for the preference of one law of attraction over another, had inquired into the sufficient reason for attraction itself, it is likely that he would soon have recognized that this attraction, as it is propounded by the Newtonians (that is

⁷ From the location of the corpuscle, take an axis through the center of the sphere, and extend a solid angle ω from the corpuscle to the surface in each direction along the axis, forming two cones going off in opposite directions. The "narrower part" of the surface is that part of the surface of the sphere reached by the smaller cone (i.e. the one formed in the direction where the particle is closer to the surface than in the other direction along the chosen axis). The "larger part" is the part of the surface reached by the larger cone.

to say, insofar as we make it a property of matter and the cause of the majority of the Phenomena), is inadmissible. For according to the principles of even Mr. Maupertuis, if there had been a reason for the preference for the law of attraction that God employed, there would have to have been one for attraction itself.

395. {The principle of sufficient reason shows that attraction is only a Phenomenon.} This principle of sufficient reason, which as you saw in the first chapter is impossible to give up, destroys this enchanted Palace founded on attraction. **{Plate 6, Fig. 36}**

For, let body A be attracted by body B according to a certain law, through the void BA; body A will approach body B in the direction AB with a speed at every moment accelerated, and the state of body A, when it moves with this accelerated speed and in a determined direction, is assuredly different from the preceding state, that is to say, from the state of rest in which it was before being transported into the Sphere of activity of body B, for the moved body cannot be substituted, without all its determinations, into the place of the body at rest, and therefore a change occurs in body A. This change had its reason: thus we must seek this reason, either in the moved body, or outside of it and in the exterior Beings that act on it.

This reason is not in the body, for this body A that was first at rest could not move itself or give itself a certain speed and a certain direction, being by its nature indifferent to motion and to rest, and to all directions and speeds.

This reason is not outside of it either, for the space AB being void by supposition, and the Newtonians excluding all intermediary subtle matter or matter emanating from body B toward body A, nothing enters body A that is part of body B through which we could explain the change that happened in body A. **{Fig. 36.}** Consequently this body A has lost nothing, and has received nothing, since nothing has entered it and nothing has left it, and all its internal determinations are the same as when it was at rest; nevertheless a change has occurred in this body A. Thus, we must say that this change did not have sufficient reason, and even the Creator could not say (in this supposition) whether a body that is at rest will move, and according to which law, were He to judge only by what He can see and know in the body itself, abstracting away the attracting body and seeing only the attracted body and that which acts immediately upon it. For we judge the changes of a body by the change of its internal determinations, by the changes that happen to what is mutable in the body, so that its present state is different from the one that preceded it. These are the givens of the problem, by means of which we must proceed to what we are seeking. Now, we can say that in the system of attraction, not even God could resolve this problem: for all the determinations of the body remaining perfectly the same, and no alteration being able to occur from the outside, it is absolutely impossible, even for God, with the unique basis of prediction being removed, to say if this body has to move or not, and what law it will follow in its motion.

396. {Attraction cannot be an inherent property, nor given to matter by God.} We cannot say: God could know what would happen to the body in the present supposition because the

attraction that we suppose is a property belonging to all matter (and so God could have foreseen what must happen as a consequence of this property). For attraction makes bodies move with a certain speed and in a certain direction; now neither this direction nor this speed is necessary, since on earth this attraction directs heavy bodies toward the center of the Earth, and on the Moon it makes them tend toward the center of the Moon, and on the other Planets toward the centers of those Planets, and it makes them arrive more or less quickly, according to the mass and the diameter of these Planets, as Mr. Newton has shown.

Therefore, by the consideration solely of a body and what acts directly on it, even God himself could not foresee what its direction or speed would be in virtue of its attraction, since this speed is different on the different Planets, and varies on the same planet, according to the different distances of the body from the center of this Planet. Now, since the direction and the acceleration from which the degree of speed results are variable, and the cause that is assigned to them, that is to say, attraction, being unable to provide a reason for either, it follows clearly that this cause is not an admissible cause since it contains nothing by which an intelligent Being could understand why the speed and the direction (which are the relevant determinations of the Being under consideration) are what they are and not otherwise. For it is this alone that distinguishes a sufficient cause from an insufficient cause (see chap. 1, § 9 & 10.)

It follows from all that has just been said that, since the direction and the speed that result from the attraction are variable, attraction is not a property of matter. For properties being founded in the essence are, like the essence, necessary (see ch. 3). **{And it is this that follows necessarily from the doctrine of essences.}** Now, the necessary can be possible in only one way. Furthermore, attraction does not flow from the essence of the matter. Thus, it cannot be, any more than thought, an attribute given by God to matter. For we saw in chapter 3 that properties are incommunicable, and cannot be transplanted into subjects by the will of God alone, for it is absolutely contrary to the principle of sufficient reason that essences are arbitrary. Now, since attraction cannot be essential to matter, and since it does not flow from its essence, it follows that God could not give this property to matter.

397. We cannot therefore avoid recognizing that attraction, if we understand by this word something other than a Phenomenon for which we are seeking the cause, would be absolutely without sufficient reason.

398. Since all that is, must have a sufficient reason for why it is as it is rather than otherwise, the direction and the speed impressed by attraction must therefore find their sufficient reason in an external cause, in some matter that collides with the body that we regard as pulled, and that determines by its action the direction and the speed of this body, to which by itself these determinations are indifferent. Thus, we must seek by means of the laws of Mechanics some matter capable of producing by its motion the effects that we attribute to attraction.

399. Knowing whether the matter that Messrs. Descartes, Huygens, and others suppose is

adequate to account for all the Phenomena remains a problem; but even if no supposed matter were adequate, the truth would not suffer at all from this, and it would not be less established that all these effects must come about by mechanical causes, that is to say, by matter and motion.

A fault into which some of the English, who were overzealous about attraction, have fallen, is to make all objections against vortices into demonstrations in favor of their view. Thus, when they destroyed some of the attempted mechanical explanations of the Phenomena that they themselves attribute to attraction, they then concluded, *that one must therefore attribute all these effects to the attraction of all matter* {Keill's *Animal Secretion*}; but this conclusion is in no way legitimate; for it is to make a leap in reasoning, which is not permitted in correct logic.

{Experiment done in Peru by Mr. Bouguer with the plumb-line.} I will not talk to you about the observations that Mr. Bouguer just made on the Mountain of Simbolasso in Peru, with the Astronomical Instrument of the plumb-line, for they have not yet been presented to the public, so we cannot know anything about them, except that Mr. Bouguer believed he observed a perceptible deviation in the direction of the plumb-line from his Quadrant, and that he attributed this disturbance to attraction. But the accuracy of this experiment depends upon the smallest differences, even according to Mr. Bouguer; some unknown circumstances could be involved, which evade the precision and the perspicacity of the observer; in a word, Mr. Bouguer does not put forward his observations as absolutely conclusive, he presents them as needing to be repeated, with attention to the errors that could be happen again in this respect, in the measurement of the earth. But even when this observation is beyond doubt, we would still need to examine whether or not some subtle matter is the cause of this Phenomenon; **{One must search for the mechanical cause that brings about the Phenomena that we attribute to attraction.}** for nothing is less conclusive in favor of attraction than showing that this or that mechanical explanation cannot subsist: perhaps a time will come when we will explain in detail the directions, motions, and combinations of fluids that bring about the Phenomena that the Newtonians explain by attraction, and this is a quest to which all Physicists must apply themselves.