Émilie Du Châtelet, *Foundations of Physics*, 1740.
Translated by Katherine Brading *et al.*[1] at the University of Notre Dame.
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 14. Of the Phenomena of Heaviness, continued

321. We saw in the preceding Chapter that Galileo asserted that different bodies would fall equally fast toward the earth in a non-resisting medium, but he had, so to speak, guessed this truth rather than having proved it; for although the reasons upon which he relied were likely (§§300 and 301), nevertheless one could still doubt whether the species of bodies, their form, their inner contexture, etc., would not bring about some change in their gravity; for, since air resistance is always combined with the action of gravity in the fall of bodies here on earth, it was impossible to know, with precision, by means of the experiments that he had carried out in air, in what proportion this force that animates all bodies to fall toward the earth acts upon the different bodies.

322. One experiment, that was done using the vacuum pump, confirmed what Galileo had predicted; for gold, tufts of wool, feathers, lead, in fact all bodies being left to themselves, fell in the same time from the same height to the bottom of a long container purged of air.

This experiment seemed decisive; but nevertheless, since the movement of the bodies that fell in this Machine was very fast and the eye was unable to perceive the small differences in the time of their fall (supposing that there were any), one could still doubt whether perceptible bodies possess the faculty of heaviness in proportion to their mass, or indeed if the weight of different bodies follows some other proportion than that of their mass.

{Experiment of Mr. Newton on the oscillations of different pendulums. Newton, *Principia*, Book 3, Prop. 6, p. 366.} To settle this question, Mr. Newton devised an experiment suspending equal hollow wooden balls on threads of equal length, and putting in these balls equal quantities by weight of gold, wood, glass, salt, etc. Then making these pendulums oscillate freely, he investigated whether the number of their oscillations is equal in equal times; for heaviness alone causes the oscillation of pendulums (§445), and in these oscillations the smallest differences become perceptible. Mr. Newton found, by this experiment, that all the different pendulums made their oscillations in equal times; now, since the weight of these bodies was equal, this was a demonstration that the quantity of proper matter of bodies is directly

---

[1] Especially Penelope Brading, Lauren Montes, Phil Sloan, and Jeremy Steeger.

proportional to their weight (ignoring air resistance, which was equal in this experiment) and that consequently heaviness belongs to all perceptible bodies in proportion to their mass.

323. {Truths that arise from this experiment.} It follows clearly from this experiment:

1. That the force that makes bodies fall to the earth is proportional to the masses, such that it acts as one hundred upon a body with a mass of one hundred, and as one upon a body that only contains one unit of proper matter.
2. That this force acts equally on all bodies, whatever their form, their contexture, their volume, etc.
3. That all bodies on earth would fall equally fast toward the earth without the air resistance that opposes them, this resistance being more perceptible on bodies that have more volume and less mass; and that consequently air resistance is the sole cause why certain bodies fall faster than others, as Galileo had asserted.
4. **{The weight of bodies is as their mass.}** That the weight of different bodies in the vacuum is directly proportional to the quantity of proper matter that they contain; such that whatever change happens in the form of a body, its weight in the vacuum remains always the same, if its mass is not changed.

324. {Difference between the heaviness of bodies and their weight.} It is important to note here that we must distinguish with care the heaviness of bodies from their weight. Heaviness, that is to say, that force that animates bodies to descend toward the earth, acts similarly on all bodies, whatever their mass. But it is not the same with their weight: for the weight of a body is the product of the heaviness and the mass of this body. Thus, even though heaviness makes bodies of unequal mass fall equally fast in the vacuum experiment (§322), their weight is nevertheless not equal; for bodies press on the obstacle that supports them only by the effort that they make to obey the force of gravity that acts ceaselessly upon them; now this force acts as one hundred on that which has one hundred parts of proper matter, and as ten on that which has only ten parts; the body that has one hundred parts of proper matter must weigh ten times more upon the obstacle that supports it than the body that only has ten, even though these bodies fall equally as fast.

325. {Means of knowing the specific heaviness of different Bodies.} The different weight of bodies of an equal volume in the vacuum enables us to know the comparative quantity of proper matter and of pores that they contain; for if a small ball of elder, e.g. one inch in diameter, weighs one ounce in the vacuum, and if a ball of gold of the same diameter weighs 87 ounces in the vacuum, the proper matter of the gold will be to the proper matter of the elder as 87 is to one; thus, the different weight of bodies of equal volume in the vacuum is what we call *the specific heaviness of bodies*.

326. In this way, one would know with precision how much porosity and how much proper matter each body contains, if one had some mass of proper matter without pores; but as all the bodies that we know are extremely porous, and as all bodies must necessarily be so, we do not know the absolute quantity of the pores and of the proper matter that each composite body contains, and we only know only the comparative quantity thereof.

327. The discoveries of which I have just given an account in these two Chapters had shown the proportion in which falling bodies accelerate. One knows from the discoveries of Galileo that they traverse unequal spaces in equal times, and that these spaces are as the squares of the times. The experiment on the fall of bodies in the vacuum, and especially that on pendulums carried out by Mr. Newton, had shown that the force that makes bodies fall is proportional to their mass. But we do not yet know, let alone with certainty, what space this force made them traverse at the commencement of their fall, in a given time; we know only that whatever this space may be in the first moment, it is three times in the second, five times in the third, and so on (§306).

328. No one doubts that heaviness is not the only cause of the oscillations of a pendulum. Now, one can demonstrate by a Theorem that I will presuppose here, and that you will see some day in the excellent Treatise *Horologio oscillatorio* by Mr. Huygens **{*Horol. oscill.,* pag. 87, 178, & 183.}**[2], that the time of one oscillation is to the time of the vertical fall, for the half period of the pendulum, as the circumference of a circle is to its diameter, or as 355 is to 113, and I suppose here, for convenience, that this is as 3 to 1. Now the length of the pendulum that beats the seconds in Paris has been found by means of astronomical observations to be 3 feet 8½ lines, thereabouts.[3] So, if we take one third of one second, or of 60 tierces[4], that is to say 20 tierces, the body would traverse in its vertical fall during the time of 20 tierces, 18 inches and 4 lines, which is half the length of the pendulum. But the spaces traversed are as the squares of the times taken to traverse them. Thus, as the square of 20 tierces (the time of the vertical fall) along half the length of the pendulum is to the square of 60 tierces (the time of the entire oscillation), that is to say as 400 is to 3600, so 18 inches 4 lines (which is the vertical fall) is to a fourth term that will mark the space traversed during the entire oscillation. And the fourth term is found to be about 15 Paris feet; I say ‘about’, for I have disregarded the fractions to make use of the nearest round numbers.[5] **{What is the Space is that bodies traverse on earth in falling in the first second?}**

---

[2] Christiaan Huygens, Horologium oscillatorium sive de motu pendulorum ad horologia aptato demonstrationes geometricae (Paris, 1673). Available online at https://archive.org/details/bub_gb_e_VXcl87u6AC.

[3] A “line” is an historic unit of length in France, approximately 2.256mm (https://en.wikipedia.org/wiki/Units_of_measurement_in_France_before_the_French_Revolution#Length). The “thereabouts” applies to the fraction of the line; see Chapter 18, §481 (second paragraph with this number).

[4] There are 60 tierces in one second.

[5] The fourth term, s_2, is given by $s_1(t_2^2/t_1^2) \simeq 18''(3600/400) = 15$ feet.

Thus, Mr. Huygens found by this means that bodies on earth traverse about 15 Paris feet in the first second when they fall toward the earth by the force of gravity alone.

In this way one can carry out far more exact experiments on the heights fallen than if one undertook to determine these heights directly; for the smallest differences are perceptible in pendulums. Thus, to say that a pendulum of 3 feet, 8 lines oscillates in Paris in one second, or to say that bodies fall vertically about 15 feet in the first second, at this latitude, is to say the same thing.

But in order for this calculation to serve for all latitudes, three things would be needed.

1. That heaviness was the same in all Regions of the earth. 2. That the space that bodies traverse in falling in the first moment of their fall was equal, whatever the height from which they fell. And 3. That air does not perceptibly resist them.

We will see in what follows that the two first suppositions are false, and that heaviness varies in different latitudes and at different heights.

As regards the third supposition, that is to say, the non-resistance of the air, one can make this without error; for this resistance is imperceptible in the vibrations of pendulums, since pendulums that are the same length but that describe very different arcs describe them nevertheless in a perceptibly equal time: and in the vacuum of Boyle, according to the experiments carried out by Mr. Derham (§460) **{Trans. Phil. N. 294}**[6], the motion of the pendulum accelerates only about four seconds in an hour.

{Air retards the fall of all bodies.} But the resistance of air, whose effect is almost imperceptible on pendulums, because of their weight and the small heights from which they fall, becomes very considerable on moving bodies that fall from a height, and it is even more perceptible when the falling bodies have more volume and less mass.

§329. {Phil. Trans. N. 362. Experiment of Doctor Desaguliers on the fall of bodies in air.}[7] Doctor Desaguliers carried out some experiments on the resistance that air brings to the fall of the bodies, and on the retardations that this resistance brings to their fall, experiments the precision of which, and the witnesses before whom they were carried out, made very famous. He let fall from the lantern that is at the top of the cupola of St. Paul's in London, which is 272 feet high, in the presence of Messrs. Newton, Halley, Derham, and several other scholars of the first order, moveable bodies of all types, from Spheres of lead two inches in diameter to Spheres made from dried pig bladders and inflated with air, of about five inches in diameter. The lead took 4½ seconds to traverse the 272 feet, and the Spheres made with the bladders took about 18½ seconds, so that the lead had traversed the 272 feet about 14 seconds sooner than the bladders.

---

[6] William Derham, "Experiments About the Motion Pendulums in Vacuo," Philosophical Transactions of the Royal Society of London 24, No. 294 (1705): 1785-89.

[7] J. T. Desaguliers, "An Account of Some Experiments Made on the 27th Day of April, 1719 to Find How Much the Resistance of the Air Retards Falling Bodies," Philosophical Transactions of the Royal Society of London 30, No. 362 (1719): 1071-1078.

The lead Spheres that had fallen 272 feet in 4½ seconds should have fallen, according to Galileo's theory, from 324 feet in the 4½ seconds, calculating the initial fall according to Huygens's calculation (§328) of about 16 English feet in the first second. But one must subtract from these 324 feet that they should have traversed (according to the calculations of Huygens and of Galileo) in 4½ seconds, 35 feet, those which they must have fallen in the last quarter of a second of their fall, because one calculates the end of the fall of this ball from the instant at which one heard from the top of the dome the noise that it made on falling,[8] and that the time that the sound takes to traverse 272 feet is a about a quarter of a second. Thus, these 35 feet for the time of the motion of the sound, being subtracted from 324, leaves 289 feet that these lead Spheres would have traversed in the vacuum in the 4½ seconds of their fall. But they traversed only 272 feet. The air by its resistance thus slowed their fall by about 17 feet in 4½ seconds.

A cardboard Sphere 5 inches in diameter took 6½ seconds to fall the 272 feet, and one finds by a similar calculation to the preceding one that the resistance of the air subtracted 53 feet from it.

A bucketful of water thrown from the top of the dome where these experiments were being carried out fell as a very light rain because of the resistance that it encountered in the air in falling from this height.

It is essential to note that the Barometer was at about 30 inches when these experiments were carried out.

330. {Experiments of Mr. Mariotte on the same matter. Mar. Traité de la Perc., p. 116}[9]
Mr. Mariotte also carried out several experiments on the fall of bodies from the top of the platform of the Observatory of Paris. But as its height is only 166 feet, I will not relate them, I will be content with one remark that he made, and that seems very curious to me; it is that a cannonball and a bowling ball[10] of the same size traversed a space of about 25 feet with perceptibly equal speeds: then the cannonball advanced ahead of the bowling ball, and finally reached the bottom when the bowling ball was still 4 feet away. The same equality in the beginning of the fall was found between bodies that had very different diameters, for a ball of wax three inches in diameter and one of six inches fell 30 feet at an equal speed; but at the end of the fall, the large ball preceded the small one by 6 or 7 feet.

331. {Mariotte, *idem.*} This same Mr. Mariotte reports that according to his experiments, a ball of lead 6 lines in diameter seemed to traverse about 14 feet in the first second; consequently air resistance made it lose one foot in the first second: but it seems very difficult to be able to

---

[8] That is, on hitting the ground.

[9] Edme Mariotte, Traité de la percussion des corps, Experiment Three, p. 116 in Vol. 1, Oeuvres de Mariotte, 2 Vols. Leiden 1717. Online at https://babel.hathitrust.org/cgi/pt?id=nyp.33433084031396;view=1up;seq=135.

[10] We have translated "boule de mail" as "bowling ball".

perceive this difference. The total difference that is found at the end of the fall between the space traversed by the body and that which it would have traversed in the vacuum is, it seems to me, the only thing of which we can be certain. And this total difference gives the initial difference by conjecture only; the equality, or at least the perceptible equality, that Mr. Mariotte says he has found in the speed of the fall of a bowling ball and a cannonball in traversing the first 25 feet, could perhaps even make one believe that this diminution is not as great in the first second.

332. {Bodies falling in air do not ceaselessly accelerate their motion.} What is very certain by all the experiments is that air slows the fall of all bodies, and that it slows them all the more when they have more surface area in relation to their mass; now since air slows the fall of all bodies, bodies that fall in air cannot ceaselessly accelerate their motion; for air, like all Fluids, resists all the more as it is cleaved with greater speed, so its resistance must in the end counteract the acceleration of gravity, when bodies fall from a height. Galileo had already discovered this truth and gave a demonstration of it in the 13th theorem of his third dialogue.[11]

333. Bodies therefore descend in air in a uniform motion, after having acquired a certain degree of speed that we call *their complete speed*, and this speed is as much greater, at equal height, as the bodies have more mass within the same volume.

334. The time after which the accelerated motion of moveable bodies is changed into a uniform motion when falling in air, is different according to the surface and the weight of the moveable body, and according to the height from which it falls; thus, this time cannot be determined in general.

335. {Experiment of Mr. de Frenicle which proves it. Hist. de Du Hamel, p. 86.}[12] In 1669, at the birth of the Academy of Sciences, Mr. de Frenicle carried out several experiments to determine the space that bodies traverse in falling in air before having acquired their complete speed, that is to say, before the resistance of the air has changed the accelerated motion into uniform motion.

This Philosopher found, through these experiments, that a small ball of soft elder that was four lines in diameter, acquired its complete speed after having traversed about 20 feet, and that

---

[11] This seems to be a reference to the 13th proposition in Day Two, not Day Three. See Galileo Galilei, Two New Sciences, 2nd ed., trans. Stillman Drake (Toronto: Wall and Emerson, 1989), p. 187.

[12] Jean Baptiste DuHamel, Regiae scientiarum Academiae historia, 2nd ed. (Paris, 1701), Bk. I, p. 87. Online at https://books.google.com/books?id=7EgAAAAQAAJ&pg=PA595&lpg=PA595&dq=Gallica+Regi%C3%A6+scientiarum+Academi%C3%A6+historia++Gallica&source=bl&ots=NJibOyqh22&sig=0tcPz9XaeP2McWzH8QFVVm6cbjQ&hl=en&sa=X&ved=0ahUKEwiIgtXD3pHZAhUOzFMKHe7fBLsQ6AEILzAC#v=onepage&q=Gallica%20Regi%C3%A6%20scientiarum%20Academi%C3%A6%20historia%20%20Gallica&f=false.

the small bladder of an Indian rooster inflated with air acquired its complete speed after having traversed only 12 feet.

Thus, the more surface the bodies have in relation to their solidity, the sooner they acquire their complete speed in falling in the air; this is why one can only do these experiments with very light bodies, because of the small heights that we can attain.

336. {Error of Mr. de Frenicle on the time of fall of different bodies. Hist. de Du Hamel p. 87.} The same Mr. de Frenicle was deceived about the time of fall of bodies of different mass and of the same volume in air. He asserted that in a closed space, a ball of lead and a ball of wood, of the same diameter, would fall in the same time from 147 feet high, which is entirely false: a badly done experiment had thrown him into error. This example shows us that we must be all the more circumspect concerning the experiments that we do, because self love always speaks to us in their favor.

337. {Calculation of Mr.Pitot which shows how rain can fall on the earth without any damage. Mem. de l'Acad. Year 1728, p. 376.}[13] Mr. Pitot calculated that a drop of water that would be the 10,000,000,000th part of a cubic inch of water would fall in perfectly calm air at 4.7 inches per second in uniform motion, and that consequently it would fall 235 fathoms per hour. One sees by this example that light bodies that fall to earth from high in our atmosphere, do not fall to the earth with an accelerated motion, as they would fall in the vacuum by the force of heaviness; but that the acceleration that heaviness imprints upon them is soon counteracted by air resistance. Without this, the lightest rain would cause infinite damage: and far from fertilizing the earth, it would destroy the flowers and the fruits; Providence has foreseen this by the resistance of the air that surrounds us.

338. {Bodies fall perpendicularly to the surface of the earth.} Bodies left to themselves fall toward the earth, along a line perpendicular to the horizon; for it is constant from experiment that the line of the direction of heavy bodies is perpendicular to the surface of the water. Now the earth being certainly spherical, as all geographical and astronomical observations demonstrate, the point of the horizon toward which heavy bodies are directed in their fall, can always be considered as the extremity of one of the radii of this sphere. **{And tend, as a consequence, to its center.}** Thus, if the line along which the bodies fall toward the earth was prolonged, it would pass through its center, supposing that the earth was perfectly spherical. But the earth, instead of being a perfect Sphere, is a spheroid flattened toward the poles and raised toward the equator, according to the measurements by which Messrs. Maupertuis, Clairaut and the other Academicians who have been to the pole, came to fix its shape (§383). So the line of direction

---

[13] Henri Pitot, "Remarques sur les rapports des Surfaces des grands & des petits Corps," Histoire de l'Académie royale des sciences (1728), pp. 369-377. Online at https://www.biodiversitylibrary.org/item/88100#page/552/mode/1up.

of heavy bodies does not tend directly to the center of the earth; *the place toward which they tend* is found to be to a certain space around this center. Nevertheless, one ordinarily assumes that falling bodies tend directly to the center of the earth, because this supposition can be made without perceptible error, their direction being always perpendicular to the surface.