tually to distinguish the true motions of particular bodies from the apparent, because the parts of that immovable space in which those motions are performed do by no means come under the observation of our senses. Yet the thing is not altogether desperate; for we have some arguments to guide us, partly from the apparent motions, which are the differences of the true motions; partly from the forces, which are the causes and effects of the true motions. For instance, if two globes, kept at a given distance one from the other by means of a cord that connects them, were revolved about their common center of gravity, we might, from the tension of the cord, discover the endeavor of the globes to recede from the axis of their motion, and from thence we might compute the quantity of their circular motions. And then if any equal forces should be impressed at once on the alternate faces of the globes to augment or diminish their circular motions, from the increase or decrease of the tension of the cord we might infer the increment or decrement of their motions, and thence would be found on what faces those forces ought to be impressed that the motions of the globes might be most augmented; that is, we might discover their hindmost faces, or those which, in the circular motion, do follow. But the faces which follow being known, and consequently the opposite ones that precede, we should likewise know the determination of their motions. And thus we might find both the quantity and the determination of this circular motion, even in an immense vacuum, where there was nothing external or sensible with which the globes could be compared. But now, if in that space some remote bodies were placed that kept always a given position one to another, as the fixed stars do in our regions, we could not indeed determine from the relative translation of the globes among those bodies whether the motion did belong to the globes or to the bodies. But if we observed the cord and found that its tension was that very tension which the motions of the globes required, we might conclude the motion to be in the globes and the bodies to be at rest; and then, lastly, from the translation of the globes among the bodies, we should find the determination of their motions. But how we are to obtain the true motions from their causes, effects, and apparent differences, and the converse, shall be



explained more at large in the following treatise. For to this end it was that I composed it.

## 3. AXIOMS, OR LAWS OF MOTION [d]

### LAW I

*Every body continues in its state of rest or of uniform motion in a right line unless it is compelled to change that state by forces impressed upon it.*

Projectiles continue in their motions, so far as they are not retarded by the resistance of the air or impelled downward by the force of gravity. A top, whose parts by their cohesion are continually drawn aside from rectilinear motions, does not cease its rotation otherwise than as it is retarded by the air. The greater bodies of the planets and comets, meeting with less resistance in freer spaces, preserve their motions both progressive and circular for a much longer time.

### LAW II

*The change of motion is proportional to the motive force impressed and is made in the direction of the right line in which that force is impressed.*

If any force generates a motion, a double force will generate double the motion, a triple force triple the motion, whether that force be impressed altogether and at once or gradually and successively. And this motion (being always directed the same way with the generating force), if the body moved before, is added to or subtracted from the former motion, according as they directly conspire with or are directly contrary to each other; or obliquely joined, when they are oblique, so as to produce a new motion compounded from the determination of both.

[d] [*Principia*, Bk. I.]

## LAW III

*To every action there is always opposed an equal reaction; or, the mutual actions of two bodies upon each other are always equal and directed to contrary parts.*

Whatever draws or presses another is as much drawn or pressed by that other. If you press a stone with your finger, the finger is also pressed by the stone. If a horse draws a stone tied to a rope, the horse (if I may so say) will be equally drawn back toward the stone; for the distended rope, by the same endeavor to relax or unbend itself, will draw the horse as much toward the stone as it does the stone toward the horse and will obstruct the progress of the one as much as it advances that of the other. If a body impinge upon another and by its force change the motion of the other, that body also (because of the equality of the mutual pressure) will undergo an equal change in its own motion, toward the contrary part. The changes made by these actions are equal, not in the velocities but in the motions of bodies; that is to say, if the bodies are not hindered by any other impediments. For, because the motions are equally changed, the changes of the velocities made toward contrary parts are inversely proportional to the bodies. This law takes place also in attractions, as will be proved in the next scholium.

# 4. THE MOTIONS OF BODIES[e]

## COROLLARY I

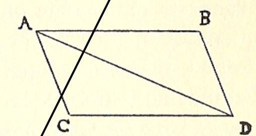
*A body, acted on by two forces simultaneously, will describe the diagonal of a parallelogram in the same time as it would describe the sides by those forces separately.*

If a body in a given time, by the force M impressed apart in the place A, should with a uniform motion be carried from A to B,

[e] [*Principia,* Bk. I. Corollaries I, II, IV, V, VI, and Scholium to Corollary VI following the laws of motion.]



and by the force N impressed apart in the same place, should be carried from A to C, let the parallelogram ABCD be completed; and by both forces acting together, it will in the same time be carried in the diagonal from A to D. For since the force N acts in the direction of the line AC, parallel to BD, this force (by the Second Law) will not at all alter the velocity generated by the other force M, by which the body is carried toward the line BD. The body therefore will arrive at the line BD in the same time, whether the force N be impressed or not; and therefore at the end of that time it will be found somewhere in the line BD. By the same argument, at the end of the same time it will be found somewhere in the line CD. Therefore it will be found in the point D, where both lines meet. But it will move in a right line from A to D, by Law I.




## COROLLARY II

*And hence is explained the composition of any one direct force AD out of any two oblique forces AC and CD; and, on the contrary, the resolution of any one direct force AD into two oblique forces AC and CD: which composition and resolution are abundantly confirmed from mechanics.*

## COROLLARY IV

*The common center of gravity of two or more bodies does not alter its state of motion or rest by the actions of the bodies among themselves, and therefore the common center of gravity of all bodies acting upon each other (excluding external actions and impediments) is either at rest or moves uniformly in a right line.*

For if two points proceed with a uniform motion in right lines, and their distance be divided in a given ratio, the dividing point will be either at rest or proceed uniformly in a right line. This is demonstrated hereafter in Lemma XXIII and Corollary, when the historian would all do well to read what Newton himself said. The present selection has been made with a view to the interests of all of them. The scientist may complain that little of Newton's mathematical demonstration is included. If he has looked into the *Principia Mathematica,* he will realize that even with the notation modernized, as in Cajori, that book is one of the most difficult of all the scientific classics. Only a hardened reader of Great Books would venture upon it without guidance. Newton expressed himself so elliptically, with such lack of concern for the ordinary reader who could not fill in the missing steps for himself, that one is inclined to sympathize with the non-mathematically-minded John Locke, who, on the appearance of the *Principia,* was forced to ask his mathematical friends whether Newton's demonstrations could be relied upon, and when assured that they could, painfully tried to puzzle out the conclusions for himself. The editors have resolved to appeal to readers with the mathematical competence of Locke, who after all as a physician could claim respectability as a scientist. Readers who demand more can turn to Cajori, or, if they command Latin, to the earlier admirable editions of the Jesuits.

Newton was, as the phrase goes, a "seminal thinker." If we have here been more concerned to comment on the harvest than on the seed and its provenance, readers may exercise their own wits and their knowledge of the history of thought on the "sources" of his major ideas. Such an inquiry will take them far afield, and will lead to men like William of Ockham, Francesco Patrizzi, and Bernardino Telesio, as well as to sober scientists like Galileo. Newton being what he is, what started him off is of undying fascination. But still more important is what Newton himself started. It is the hope of the editors that those who properly appreciate what Newton started will be glad to learn just how he started it, by reading his own words—often a disconcerting process with a thinker whose originality and historical limitations have been so long buried under the easy disguise of Newton the symbol.

JOHN HERMAN RANDALL, JR.

COLUMBIA UNIVERSITY
*September, 1952*

# SELECTIONS FROM NEWTON

*Natural philosophy consists in discovering the frame and operations of nature, and reducing them, as far as may be, to general rules or laws—establishing these rules by observations and experiments, and thence deducing the causes and effects of things. . . .*

NEWTON

# I. The Method of Natural Philosophy [a]

## 1. RULES OF REASONING IN PHILOSOPHY [b]

### RULE I

*We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.*

To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity and affects not the pomp of superfluous causes.

### RULE II

*Therefore to the same natural effects we must, as far as possible, assign the same causes.*

As to respiration in a man and in a beast, the descent of stones in Europe and in America, the light of our culinary fire and of the sun, the reflection of light in the earth and in the planets.

### RULE III

*The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.*

For since the qualities of bodies are only known to us by experiments, we are to hold for universal all such as universally agree with experiments, and such as are not liable to diminution can never be quite taken away. We are certainly not to relinquish the

[a] [Also on method, see the latter parts of Queries 28 and 29, in the Questions from the *Optics*, Part V.]

[b] [Rules of Reasoning in Philosophy. *Philosophiae Naturalis Principia Mathematica*, Bk. III, 1686.]

evidence of experiments for the sake of dreams and vain fictions of our own devising; nor are we to recede from the analogy of Nature, which is wont to be simple and always consonant to itself. We in no other way know the extension of bodies than by our senses, nor do these reach it in all bodies; but because we perceive extension in all that are sensible, therefore we ascribe it universally to all others also. That abundance of bodies are hard we learn by experience; and because the hardness of the whole arises from the hardness of the parts, we therefore justly infer the hardness of the undivided particles, not only of the bodies we feel, but of all others. That all bodies are impenetrable, we gather not from reason, but from sensation. The bodies which we handle we find impenetrable, and thence conclude impenetrability to be a universal property of all bodies whatsoever. That all bodies are movable and endowed with certain powers (which we call the inertia) of persevering in their motion, or in their rest, we only infer from the like properties observed in the bodies which we have seen. The extension, hardness, impenetrability, mobility, and inertia of the whole result from the extension, hardness, impenetrability, mobility, and inertia of the parts; and hence we conclude the least particles of all bodies to be also all extended, and hard and impenetrable, and movable, and endowed with their proper inertia. And this is the foundation of all philosophy. Moreover, that the divided but contiguous particles of bodies may be separated from one another is a matter of observation; and, in the particles that remain undivided, our minds are able to distinguish yet lesser parts, as is mathematically demonstrated. But whether the parts so distinguished and not yet divided may, by the powers of Nature, be actually divided and separated from one another we cannot certainly determine. Yet had we the proof of but one experiment that any undivided particle, in breaking a hard and solid body, suffered a division, we might by virtue of this rule conclude that the undivided as well as the divided particles may be divided and actually separated to infinity.

Lastly, if it universally appears, by experiments and astronomical observations, that all bodies about the earth gravitate toward the earth, and that in proportion to the quantity of matter which



they severally contain; that the moon likewise, according to the quantity of its matter, gravitates toward the earth; that, on the other hand, our sea gravitates toward the moon; and all the planets one toward another; and the comets in like manner toward the sun: we must, in consequence of this rule, universally allow that all bodies whatsoever are endowed with a principle of mutual gravitation. For the argument from the appearances concludes with more force for the universal gravitation of all bodies than for their impenetrability, of which, among those in the celestial regions, we have no experiments nor any manner of observation. Not that I affirm gravity to be essential to bodies; by their *vis insita* I mean nothing but their inertia. This is immutable. Their gravity is diminished as they recede from the earth.

### RULE IV

*In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur by which they may either be made more accurate or liable to exceptions.*

This rule we must follow, that the argument of induction may not be evaded by hypotheses.

## 2. ON HYPOTHESES

*From a Letter to Oldenburg* [c]

. . . For the best and safest method of philosophizing seems to be, first, to inquire diligently into the properties of things and to establish those properties by experiments, and to proceed later to hypotheses for the explanation of things themselves. For hypotheses ought to be applied only in the explanation of the properties

[c] [Newton's letter to Oldenburg. London, 1672. *Isaac Newtoni Opera quae exstant Omnia*, IV, p. 314.]

of things, and not made use of in determining them; except in so far as they may furnish experiments. And if anyone offers conjectures about the truth of things from the mere possibility of hypotheses, I do not see by what stipulation anything certain can be determined in any science; since one or another set of hypotheses may always be devised which will appear to supply new difficulties. Hence I judged that one should abstain from contemplating hypotheses, as from improper argumentation. . . .[1]

### *From Letters to Cotes* [d]

I

I had yours of Feb. 18th, and the difficulty you mention which lies in these words, "since every attraction is mutual," is removed by considering that, as in geometry, the word 'hypothesis' is not taken in so large a sense as to include the axioms and postulates; so, in experimental philosophy, it is not to be taken in so large a sense as to include the first principles or axioms, which I call the laws of motion. These principles are deduced from phenomena and made general by induction, which is the highest evidence that a proposition can have in this philosophy. And the word 'hypothesis' is here used by me to signify only such a proposition as is not a phenomenon nor deduced from any phenomena, but assumed or supposed—without any experimental proof. Now the mutual and mutually equal attraction of bodies is a branch of the third law of motion, and how this branch is deduced from phenomena you may see at the end of the corollaries of the laws of motion. . . . If a body attracts another contiguous to it and is not mutually attracted by the other, the attracted body will drive the other before it, and both will go away together with an accelerated motion *in infinitum,* as it were, by a self-moving principle, contrary to the first law of motion, whereas there is no such phenomenon in all nature.

[d] [This and the next selection are from Newton's letters to Cotes. London, 1713. J. Edleston, *Correspondence of Sir Isaac Newton and Prof. Cotes,* pp. 154-56, 156-57.]



. . . And for preventing exceptions against the use of the word 'hypothesis,' I desire you to conclude the next paragraph in this manner: "For anything which is not deduced from phenomena ought to be called a hypothesis, and hypotheses of this kind, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy, propositions are deduced from phenomena, and afterward made general by induction." . . .

II

On Saturday last I wrote to you, representing that experimental philosophy proceeds only upon phenomena and deduces general propositions from them only by induction. And such is the proof of mutual attraction. And the arguments for the impenetrability, mobility, and force of all bodies and for the laws of motion are no better. And he that in experimental philosophy would except against any of these must draw his objection from some experiment or phenomenon and not from a mere hypothesis, if the induction be of any force. . . .[2]

## 3. THE EXPERIMENTAL METHOD

### *From a letter to Oldenburg* [e]

. . . I cannot think it effectual for determining truth to examine the several ways by which phenomena may be explained, unless where there can be a perfect enumeration of all those ways. You know, the proper method for inquiring after the properties of things is to deduce them from experiments. And I told you that the theory which I propounded was evinced to me, not by inferring *'tis thus because not otherwise,* that is, not by deducing it only from a confutation of contrary suppositions, but by deriving it from experiments concluding positively and directly. The way therefore to examine it is by considering whether the experiments which I

[e] [From a letter to Oldenburg. July, 1672. *Opera Omnia* IV, pp. 320-21.]

propound do prove those parts of the theory to which they are applied, or by prosecuting other experiments which the theory may suggest for its examination.

To determine by these and such like queries seems the most proper and direct way to a conclusion. And therefore I could wish all objections were suspended from hypotheses or any other heads than these two: of showing the insufficiency of experiments to determine these queries, or prove any other parts of my theory, by assigning the flaws and defects in my conclusions drawn from them; or of producing other experiments which directly contradict me, if any such may seem to occur. For if the experiments which I urge be defective, it cannot be difficult to show the defects; but if valid, then by proving the theory, they must render all objections invalid.

# II. Fundamental Principles of Natural Philosophy

## 1. NEWTON'S PREFACE TO THE FIRST EDITION OF THE *PRINCIPIA* [a]

Since the ancients (as we are told by Pappus [b]) esteemed the science of mechanics of greatest importance in the investigation of natural things, and the moderns, rejecting substantial forms and occult qualities, have endeavored to subject the phenomena of nature to the laws of mathematics, I have in this treatise cultivated mathematics as far as it relates to philosophy. The ancients considered mechanics in a twofold respect: as rational, which proceeds accurately by demonstration, and practical. To practical mechanics all the manual arts belong, from which mechanics took its name. But as artificers do not work with perfect accuracy, it comes to pass that mechanics is so distinguished from geometry that what is perfectly accurate is called geometrical; what is less so is called mechanical. However, the errors are not in the art, but in the artificers. He that works with less accuracy is an imperfect mechanic; and if any could work with perfect accuracy, he would be the most perfect mechanic of all; for the description of right lines and circles, upon which geometry is founded, belongs to mechanics. Geometry does not teach us to draw these lines, but requires them to be drawn; for it requires that the learner should first be taught to describe these accurately before he enters upon geometry, then it shows how by these operations problems may be solved. To describe right lines and circles are problems, but not

[a] [Written at Cambridge, Trinity College, May 8, 1686, the year of publication of the first edition.]

[b] [Pappus was the author of the *Synagoge* ("Collection"), the last great treatise of the Alexandrian mathematicians, end of the third century. The *Synagoge* was a guide to the study of Greek geometry. Many important Greek mathematical results have been preserved for later ages only through the work of Pappus. The *Synagoge* was written about 320 A.D.; Latin translation, 1589.]