Nicholas Copernicus*, On the Revolution of Heavenly Spheres*

Nicholas Copernicus began a revolution in astronomy when he argued that the sun and not the earth was at the center of the universe. Expecting controversy and scorn, Copernicus hesitated to publish the work in which he put forth his heliocentric theory. He finally relented, however, and managed to see a copy of it just before he died.

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| For a long time, then, I reflected on this confusion in the astronomical traditions concerning the derivation of the motions of the universe's spheres. I began to be annoyed that the movements of the world machine, created for our sake by the best and most systematic Artisan of all [God], were not understood with greater certainty by the philosophers, who otherwise examined so precisely the most insignificant trifles of this world. For this reason I undertook the task of rereading the works of all the philosophers which I could obtain to learn whether anyone had ever proposed other motions of the universe's spheres than those expounded by the teachers of astronomy in the schools. And in fact first I found in Cicero that Hicetas supposed the earth to move. Later I also discovered in Plutarch that certain others were of this opinion. I have decided to set his words down here, so that they may be available to everybody:  Some think that the earth remains at rest. But Philolaus the Pythagorean believes that, like the sun and moon, it revolves around the fire in an oblique circle. Heraclides of Pontus, and Ecphantus the Pythagorean make the earth move, not in a progressive motion, but like a wheel in a rotation from west to east about its own center.  Therefore, having obtained the opportunity from these sources, I too began to consider the mobility of the earth. And even though the idea seemed absurd, nevertheless I knew that others before me had been granted the freedom to imagine any circles whatever for the purpose of explaining the heavenly phenomena. Hence I thought that I too would be readily permitted to ascertain whether  explanations sounder than those of my predecessors could be found for the revolution of the celestial spheres on the assumption of some motion of the earth.  Having thus assumed the motions which I ascribe to the earth later on in the volume, by long and intense study I finally found that if the motions of the other planets are correlated with the orbiting of the earth, and are computed for the revolution of each planet, not only do their phenomena follow therefrom but also the order and size of all the planets and spheres, and heaven itself is so linked together that in no portion of it can anything be shifted without disrupting the remaining parts and the universe as a whole…  Hence I feel no shame in asserting that this whole region engirdled by the moon, and the center of the earth, traverse this grand circle amid the rest of the planets in an annual revolution around the sun. Near the sun is the center of the universe. Moreover, since the sun remains stationary, whatever appears as a motion of the sun is really due rather to the motion of the Earth. |

Galileo Galilei, *The Starry Messenger*

The Italian Galileo Galilei was the first European to use a telescope to make systematic observations of the heavens. His observations, as reported in The Starry Messenger in 1610, stunned European intellectuals by revealing that the celestial bodies were not perfect and immutable but rather composed of material substances similar to that of the earth. In this selection, Galileo describes how he devised a telescope and what he saw with it.

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| About ten months ago a report reached my ears that a certain Fleming had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. Of this truly remarkable effect several experiences were related, to which some persons gave credence while others denied them. A few days later the report was confirmed to me in a letter from a noble Frenchman at Paris, Jacques Badovere, which caused me to apply myself wholeheartedly to inquire into the means by which I might arrive at the invention of a similar instrument. This I did shortly afterwards, my basis being the theory of refraction. First I prepared a tube of lead, at the ends of which I fitted two glass lenses, both plane on one side while on the other side one was spherically convex and the other concave. Then placing my eye near the concave lens I perceived objects satisfactorily large and near, for they appeared three times closer and nine times larger than when seen with the naked eye alone. Next I constructed another one, more accurate, which represented objects as enlarged more than sixty times. Finally, sparing neither labor nor expense, I succeeded in constructing for myself so excellent an instrument that objects seen by means of it appeared nearly one thousand times larger and over thirty times closer than when regarded with our natural vision.  It would be superfluous to enumerate the number and importance of the advantages of such an instrument at sea as well as on land. But forsaking terrestrial observations, I turned to celestial ones, and first I saw the moon from as near at hand as if it were scarcely two terrestrial radii away. After that I observed often with wondering delight both the planets and the fixed stars, and since I saw these latter to be very crowded, I began to seek (and eventually found) a method by which I might measure their distances apart…  Now let us review the observations made during the past two months, once more inviting the attention of all who are eager for true philosophy to the first steps of such important contemplations. Let us speak first of that surface of the moon which faces us. For greater clarity I distinguish two parts of this surface, a lighter and a darker; the lighter part seems to surround and to pervade the whole hemisphere, while the darker part discolors the moon’s surface like a kind of cloud, and makes it appear covered with spots… From observations of these spots repeated many times I have been led to the opinion and conviction that the surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and the other heavenly bodies) to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the earth, relieved by chains of mountains and deep valleys. |

Isaac Newton, *Rules of Reasoning in Philosophy*

In 1687, Isaac Newton published his masterpiece, the *Mathematical Principles of Natural Philosophy*, or Principia. In this work, Newton demonstrated the mathematical proofs for his universal law of gravitation and completed the new cosmology begun by Copernicus, Kepler, and Galileo. He also described the rules of reasoning by which he arrived at his universal law.

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| Rule 1  *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 2  *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 3  *The qualities of bodies, which admit neither intension 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  Rule 4  *In experimental philosophy we are to look upon propositions collected 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. |

Margaret Cavendish, “The Philosophical and Physical Opinions”

Margaret Cavendish, who came from an aristocratic background, was not a popularizer of science for women, but she was crucial in the scientific debates of her time. Her husband, who was thirty years her senior, encouraged her to pursue her literary interests. In addition to her scientific works, she wrote plays, an autobiography, and a biography of her husband titled *The Life of the Thrice Noble, High and Puissant Prince William Cavendish, Duke Marquess and Earl of Newcastle.* The autobiography and biography led one male critic to call her “a mad, conceited and ridiculous woman.” In an essay titled, “The Philosophical and Physical Opinions”, she discussed the constraints placed upon women, including education.

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| But to answer those objections that are made against me, as first how should I come by so much experience as I have expressed in my several books to have? I answer: I have had by relation the long and much experience of my lord, who hath lived to see and be in many changes of fortune and to converse with many men of sundry nations, ages, qualities, tempers, capacities, abilities, wits, humors, fashions, and customs.  And as many others, especially wives, go from church to church, from ball to ball,… gossiping from house to house, so when my lord admits to me his company I listen with attention to his edifying discourse and I govern myself by his doctrine: I dance a measure with the muses, feast with sciences, or sit and discourse with the arts.  The second is that, since I am no scholar, I cannot know the names and terms of art and the divers and several opinions of several authors. I answer: that I must have been a natural fool if I had not known and learnt from them, for they are customarily taught all children from the nurses breast, being ordinarily discoursed of in every family that is of quality, and the family from whence I sprung are neither natural idiots or ignorant fools, but the contrary, for they were rational, learned, understanding and witty…  But as I have said my head was so full of my own natural fantasies, as it had not room for strangers to bore therein, and certainly natural reason is a better tutor than education. For though education doth help natural reason to a more sudden maturity, yet natural reason was the first educator: for natural reason did first compose commonwealths, invented arts and science, and if natural reason hath composed, invented and discovered, I know no reason but natural reason may find out what natural reason hath composed, invented and discovered with the help of education… |