

# SIR ISAAC NEWTON

1642-1727

Isaac Newton was the posthumous son of a Lincolnshire farmer; as a boy, he invented machines, as an undergraduate he was making discoveries in optics and mathematics, and in 1667—aged barely twenty-five—he was elected a fellow of Trinity College, Cambridge. It would be generous to describe intellectual life in Restoration universities as “torpid,” and Newton got little in the way of stimulus from his colleagues. Even the Royal Society, after an initial burst of activity in the 1660s, sank during the latter part of the century into lethargy and triviality. But Newton was a man whose mind worked incessantly and at the very highest level of insight; apart from particular discoveries in the fields of mathematics, physics, and astronomy, he generated an entire cosmology, which was supplanted only in the twentieth century by the work of Einstein. The importance of Newton’s thought cannot be described or even indicated here: interested readers should refer to a suitable history of philosophy or scientific thought, or to a biography.

Much of Newton’s scientific work was reported in Latin, still the language of international scholarship; but when he chose, the great thinker could express himself in notably lucid and trenchant English. The earliest of his important experiments, having to do with light and color, were reported in a letter to the Royal Society, which appeared in the society’s journal, dated February 19, 1672. The experiments and reasoning are described in language of perfect clarity; and when, as the last word of his summary, he drops a very heavy word indeed, he clinches the point like a carpenter nailing shut a box.

In point of fact, not all Newton’s conclusions in the *Letter* have held absolutely solid. But for a young man just five years out of college, his command of a rigorous experimental method is extraordinary. We are, evidently, in a world diametrically different from that of Sir Thomas Browne, who also thought himself a man of science.

## *From A Letter of Mr. Isaac Newton, Professor of the Mathematics in the University of Cambridge, Containing His New Theory about Light and Colors*

*Sent by the Author to the Publisher from Cambridge, Febr. 6, 1672, in  
order to Be Communicated to the Royal Society*

Sir,

To perform my late promise to you, I shall without further ceremony acquaint you that in the beginning of the year 1666 (at which time I applied myself to

the grinding of optic glasses of other figures than spherical) I procured me a triangular glass prism to try therewith the celebrated phenomena of colors. And in order thereto having darkened my chamber and made a small hole in my window-shuts to let in a convenient quantity of the sun's light, I placed my prism at his entrance that it might be thereby refracted to the opposite wall. It was at first a very pleasing divertissement to view the vivid and intense colors produced thereby; but after a while, applying myself to consider them more circumspectly, I became surprised to see them in an *oblong* form, which according to the received laws of refraction I expected should have been *circular*.

They were terminated at the sides with straight lines, but at the ends the decay of light was so gradual that it was difficult to determine justly what was their figure; yet they seemed *semicircular*.

Comparing the length of this colored spectrum with its breadth, I found it about five times greater, a disproportion so extravagant that it excited me to a more than ordinary curiosity of examining from whence it might proceed. I could scarce think that the various thickness of the glass or the termination with shadow or darkness could have any influence on light to produce such an effect; yet I thought it not amiss first to examine those circumstances, and so tried what would happen by transmitting light through parts of the glass of divers thicknesses, or through holes in the window of divers bignesses, or by setting the prism without, so that the light might pass through it and be refracted before it was terminated by the hole. But I found none of those circumstances material. The fashion of the colors was in all these cases the same.

Then I suspected whether by any unevenness in the glass or other contingent irregularity these colors might be thus dilated. And to try this, I took another prism like the former and so placed it that the light, passing through them both, might be refracted contrary ways, and so by the latter returned into that course from which the former had diverted it. For by this means I thought the regular effects of the first prism would be destroyed by the second prism but the irregular ones more augmented by the multiplicity of refractions. The event was that the light which by the first prism was diffused into an oblong form was by the second reduced into an orbicular one with as much regularity as when it did not at all pass through them. So that, whatever was the cause of that length, 'twas not any contingent irregularity.<sup>1</sup>

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The gradual removal of these suspicions at length led me to the *experimentum crucis*,<sup>2</sup> which was this: I took two boards, and placed one of them close behind the prism at the window, so that the light might pass through a small hole made in it for the purpose and fall on the other board, which I placed at about 12 feet distance, having first made a small hole in it also, for some of that incident<sup>3</sup> light to pass through. Then I placed another prism behind this second board so that the light, trajected through both the boards, might pass through that also, and be again refracted before it arrived at the

1. Newton goes on to describe several experiments and calculations by which he disposed of alternative theories—that rays coming from different parts of the sun caused the diffusion of light into an oblong, or that the rays of light traveled in curved paths after leaving the

prism.

2. Crucial experiment, turning point.

3. From Latin *incidere*, to fall into or onto. Newton uses it of light striking an obstacle.

wall. This done, I took the first prism in my hand, and turned it to and fro slowly about its axis, so much as to make the several parts of the image cast on the second board successively pass through the hole in it, that I might observe to what places on the wall the second prism would refract them. And I saw by the variation of those places that the light tending to that end of the image, towards which the refraction of the first prism was made did in the second prism suffer a refraction considerably greater than the light tending to the other end. And so the true cause of the length of that image was detected to be no other than that light consists of *rays differently refrangible*, which, without any respect to a difference in their incidence, were, according to their degrees of refrangibility, transmitted towards divers parts of the wall.<sup>4</sup>

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I shall now proceed to acquaint you with another more notable difformity in its rays, wherein the *origin of colors* is unfolded: concerning which I shall lay down the doctrine first and then for its examination give you an instance or two of the experiments, as a specimen of the rest.

The doctrine you will find comprehended and illustrated in the following propositions.

1. As the rays of light differ in degrees of refrangibility, so they also differ in their disposition to exhibit this or that particular color. Colors are not qualifications of light, derived from refractions or reflections of natural bodies (as 'tis generally believed), but original and connate properties which in divers rays are divers. Some rays are disposed to exhibit a red color and no other; some a yellow and no other, some a green and no other, and so of the rest. Nor are there only rays proper and particular to the more eminent colors; but even to all their intermediate gradations.

2. To the same degree of refrangibility ever belongs the same color, and to the same color ever belongs the same degree of refrangibility. The least refrangible rays are all disposed to exhibit a red color, and contrarily those rays which are disposed to exhibit a red color are all the least refrangible. So the most refrangible rays are all disposed to exhibit a deep violet color, and contrarily those which are apt to exhibit such a violet color are all the most refrangible. And so to all the intermediate colors in a continued series belong intermediate degrees of refrangibility. And this analogy 'twixt colors and refrangibility is very precise and strict; the rays always either exactly agreeing in both or proportionally disagreeing in both.

3. The species of color and degree of refrangibility proper to any particular sort of rays is not mutable by refraction nor by reflection from natural bodies nor by any other cause that I could yet observe. When any one sort of rays hath been well parted from those of other kinds, it hath afterwards obstinately retained its color, notwithstanding my utmost endeavors to change it. I have refracted it with prisms and reflected it with bodies which in daylight were of other colors; I have intercepted it with the colored film of air interceding two compressed plates of glass; transmitted it through colored mediums and through mediums irradiated with other sorts of rays, and diversely terminated it; and yet could never produce any new color out of it. It would by contracting or

4. At this point Newton digresses to a discussion of the optical consequences of his view of light (especially for the improvement of telescopes), adding in passing that

his experiments were interrupted for two years by the plague; but at last he returns to some further and even more important characteristics of light.

dilating become more brisk or faint and by the loss of many rays in some cases very obscure and dark; but I could never see it changed *in specie*.<sup>5</sup>

4. Yet seeming transmutations of colors may be made, where there is any mixture of divers sorts of rays. For in such mixtures, the component colors appear not, but by their mutual allaying each other constitute a middling color. And therefore if by refraction or any other of the aforesaid causes the difform rays latent in such a mixture be separated, there shall emerge colors different from the color of the composition. Which colors are not new generated, but only made apparent by being parted; for if they be again entirely mixed and blended together, they will again compose that color which they did before separation. And for the same reason, transmutations made by the convening of divers colors are not real; for when the difform rays are again severed, they will exhibit the very same colors which they did before they entered the composition—as you see blue and yellow powders when finely mixed appear to the naked eye green, and yet the colors of the component corpuscles are not thereby transmuted, but only blended. For, when viewed with a good microscope, they still appear blue and yellow interspersedly.

5. There are therefore two sorts of colors: the one original and simple, the other compounded of these. The original or primary colors are red, yellow, green, blue, and a violet-purple; together with orange, indigo, and an indefinite variety of intermediate graduations.

6. The same colors *in specie* with these primary ones may be also produced by composition. For a mixture of yellow and blue makes green; of red and yellow makes orange; of orange and yellowish green makes yellow. And in general if any two colors be mixed which, in the series of those generated by the prism, are not too far distant one from another, they by their mutual alloy compound that color which in the said series appeareth in the mid-way between them. But those which are situated at too great a distance, do not so. Orange and indigo produce not the intermediate green, nor scarlet and green the intermediate yellow.

7. But the most surprising and wonderful composition was that of whiteness. There is no one sort of rays which alone can exhibit this. 'Tis ever compounded, and to its composition are requisite all the aforesaid primary colors, mixed in a due proportion: I have often with admiration beheld that, all the colors of the prism being made to converge and thereby to be again mixed as they were in the light before it was incident upon the prism; reproduced light, entirely and perfectly white, and not at all sensibly differing from a direct light of the sun, unless when the glasses I used were not sufficiently clear; for then they would a little incline it to *their* color.

8. Hence therefore it comes to pass that whiteness is the usual color of light, for light is a confused aggregate of rays endued with all sorts of colors, as they are promiscuously darted from the various parts of luminous bodies. And of such a confused aggregate, as I said, is generated whiteness; if there be a due proportion of the ingredients; but if any one predominate, the light must incline to that color, as it happens in the blue flame of brimstone, the yellow flame of a candle, and the various colors of the fixed stars.

9. These things considered, the manner how colors are produced by the prism is evident. For of the rays constituting the incident light, since those

5. In kind.

which differ in color proportionally differ in refrangibility, they by their unequal refractions must be severed and dispersed into an oblong form in an orderly succession from the least refracted scarlet to the most refracted violet. And for the same reason it is that objects, when looked upon through a prism, appear colored. For the difform rays, by their unequal refractions, are made to diverge towards several parts of the retina, and there express the images of things colored, as in the former case they did the sun's image upon a wall. And by this inequality of refractions they become not only colored, but also very confused and indistinct.

10. Why the colors of the rainbow appear in falling drops of rain is also from hence evident. For those drops which refract the rays disposed to appear purple in greatest quantity to the spectator's eye, refract the rays of other sorts so much less as to make them pass beside it;<sup>6</sup> and such are the drops on the inside of the primary bow and on the outside of the secondary or exterior one. So those drops which refract in greatest plenty the rays apt to appear red toward the spectator's eye, refract those of other sorts so much more as to make them pass beside it; and such are the drops on the exterior part of the primary and interior part of the secondary bow.

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13. I might add more instances of this nature, but I shall conclude with this general one, that the colors of all natural bodies have no other origin than this, that they are variously qualified to reflect one sort of light in greater plenty than another. And this I have experimented in a dark room by illuminating those bodies with uncompounded light of divers colors. For by that means any body may be made to appear of any color. They have there no appropriate color, but ever appear of the color of the light cast upon them, but yet with this difference, that they are most brisk and vivid in the light of their own daylight color. *Minium*<sup>7</sup> appeareth there of any color indifferently with which 'tis illustrated, but yet most luminous in red, and so *Bise*<sup>8</sup> appeareth indifferently of any color with which 'tis illustrated, but yet most luminous in blue. And therefore *minium* reflecteth rays of any color, but most copiously those endued with red; and consequently when illustrated with daylight, that is, with all sorts of rays promiscuously blended, those qualified with red shall abound most in the reflected light, and by their prevalence cause it to appear of that color. And for the same reason *bise*, reflecting blue most copiously, shall appear blue by the excess of those rays in its reflected light; and the like of other bodies. And that this is the entire and adequate cause of their colors is manifest, because they have no power to change or alter the colors of any sort of rays incident apart, but put on all colors indifferently with which they are enlightened.

These things being so, it can no longer be disputed whether there be colors in the dark, nor whether they be the qualities of the objects we see, no, nor perhaps whether light be a body. For since colors are the qualities of light, having its rays for their entire and immediate subject, how can we think those rays qualities also, unless one quality may be the subject of and sustain another—which in effect is to call it substance. We should not know bodies for sub-

6. I.e., disappear alongside it.  
7. Red lead.

8. Azurite blue.

stances were it not for their sensible qualities, and the principal of those being now found due to something else, we have as good reason to believe that to be a substance also.<sup>9</sup>

Besides, who ever thought any quality to be a heterogeneous aggregate, such as light is discovered to be? But to determine more absolutely what light is, after what manner refracted, and by what modes or actions it produceth in our minds the phantasms of colors, is not so easy. And I shall not mingle conjectures with certainties.

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1672

9. I.e., the only way we know bodies are substances is light, not body; our conclusion can perfectly well be that our senses perceive their qualities. The chief of that light is a form of substance, as well as body, and these qualities, color, is now known to be a quality of that we know it to be so through its quality, color.