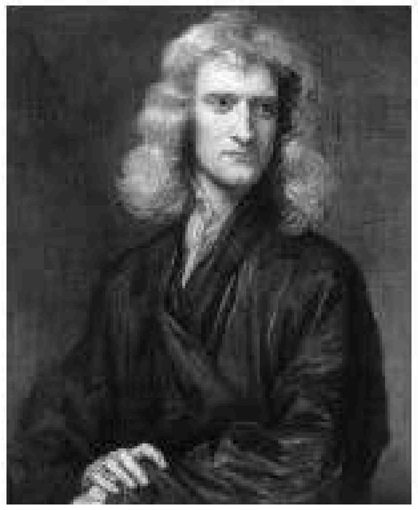
CHAPTER 3

Isaac Newton

What a Color Is



Isaac Newton, by Sir Godfrey Kneller, 1689

> The truth is, the Science of Nature has been already too long made only a work of the *Brain* and the *Fancy:* It is now high time that it should return to the plainness and soundness of *Observations* on *material* and *obvious* things.
>
> —Robert Hooke, *Micrographia*

As you enter the tomb of Isaac Newton, your gaze is swept upward by the vast curved spaces of the vaulted marble ceiling and the massive supporting columns that keep it from succumbing to gravity. Weighing just as heavily is the silence, broken only by the echo of your footsteps ascending the stairs toward the scientist's urn.

It will be then that you notice the light beam. Entering through a tiny hole, perhaps twenty feet above the floor, it shoots down at an angle and ricochets off a mirror mounted on an ornate stand. From there it travels across the room, through a prism, and is transformed into the familiar arpeggio that manifests itself in nature: red, orange, yellow, green, blue, indigo, and violet.

This pantheon exists only in a painting, *An Allegorical Monument to Sir Isaac Newton,* completed by the Venetian artist Giovanni Battista Pittoni in 1729, not long after Newton died. (He is actually buried in Westminster Abbey.) It was something of a departure for Pittoni, who is better known for religious and mythological themes (*The Holy Family, The Sacrifice of Polyxena*). But it was also unusual in another way.

Newton would become known to the ages (along with Leibniz) for his invention of calculus—the "method of fluxions"—which made sense of a concept that had eluded Galileo: how an accelerating object becomes infinitesimally faster during each of an infinity of infinitesimal moments of time. In his later triumph, the *Principia Mathematica,* he described the motions of the heavens and showed that the same gravity that causes an apple to fall holds the planets around the sun. But Pittoni's painting was celebrating something different—not Newton the theorist, giver of laws, but Newton the experimenter.

An Allegorical Monument to Sir Isaac Newton, by Giovanni Battista Pittoni

He was barely out of school, having graduated from Trinity College, Cambridge, in 1665, when the Great Plague forced an exodus to the countryside. Trapped at the family farm in Woolsthorpe, he closeted himself in his study, working out some ideas about mathematics and motion and contemplating the peculiarities of color and light.

Plato and some of the Presocratics believed that light beams emanated from the eyes, sweeping the world like searchlights. Aristotle, who rejected that idea, taught that colors are a mixture of light and darkness. Yellow, after all, is nearly white, and blue is almost black. By Newton's time a clearer picture was emerging, and philosophers were developing a precise science of optics.

When light strikes a mirror, they had learned, the angle of incidence equals the angle of reflection. And when it passes through a transparent medium and back into the air, it is bent or refracted—that is why your leg looks broken when you step into a pool of water. The degree of the refraction could be predicted by something that became known as Snell's law. While investigating rainbows, René Descartes, the French philosopher and scientist, had gazed into a giant droplet—a glass sphere filled with water—and studied the colors inside, so much like those that appeared when soap bubbles, flakes of mica, fish scales, and insect wings shimmer in the sunlight. In 1637, in an essay called *Dioptrics,* he tried to account for the origin of color, speculating that it was produced by spinning globules of aether—the faster the rotation, the redder the light.

But no one really knew. Somehow pure white light became stained in its collisions with matter—when it bounced off a colored object or passed through a tinted liquid or piece of glass. A generation after Descartes three of Europe's greatest scientists—Christiaan Huygens, Robert Boyle, and Robert Hooke—were still putting forth theories. None of them had any reason to know about Isaac Newton. Hooke, in particular, would come to wish he had never heard Newton's name.

A stooped troll of a man, Hooke was so well known for his elegant manipulations of nature that he served as the first curator of experiments for the Royal Society of London, which was beginning its emergence as a powerhouse of the scientific revolution. One of the first great microscopists, Hooke produced meticulous drawings—a flea and a louse magnified into monsters, molds as extravagant as flowers in a tropical rain forest—that filled the pages of his celebrated book *Micrographia.* Focusing his lenses on a piece of cork, he explored the labyrinth of empty chambers and was the first to call them cells. An ingenious inventor, he designed an air pump and assisted Boyle in discovering the inverse relationship between the volume and pressure of a gas, Boyle's law. There is a Hooke's law as well, precisely describing the nature of elasticity: the amount a solid object can be stretched is proportional to the force that is applied. Or as Hooke himself put it, "ceiiinosssttuv," which unscrambles into *Ut tensio sic vis,* "As the extension, so the force." (To establish priority and avoid intellectual property theft, he first published the law as a Latin anagram.)

Viewed under a microscope, "a small white spot of hairy mould." From Robert Hooke, *Micrographia*

Hooke was certain he had also figured out color and light. White was fundamental, and colors were aberrations: "Blue is an impression on the Retina of an oblique and confus'd pulse of light, whose weakest part precedes, and whose strongest follows," he obscurely wrote. Red was the opposite—a misshapen pulse "whose strongest part precedes, and whose weakest follows." Red and blue could be mixed and diluted to form mongrel hues. Huygens and Boyle had their own theories, but they all came down to the same bedrock—color as stained light.

STARTING from scratch, Newton carefully reviewed what others before him had found and added some observations of his own. A piece of gold leaf, thin enough to be almost transparent, reflects yellow light. But hold it "twixt your eye & a candle," he noted, and the light passing through is blue. The opposite effect could be had from a wood called *lignum nephriticum,* sold by druggists as a kidney treatment. When it was sliced into thin pieces and infused in water "the liquor (looked on in a cleare violl) reflects blew rays & transmits yellow ones." The same was true for certain pieces of flat glass: they "appeare of one colour when looked upon & of another colour when looked through." But these were aberrations. "Generally bodys which appeare of any colour to the eye, appeare of the same colour in all positions."

Shut away from the plague, he studied the world with the eyes of a blind man suddenly able to see. Dark or translucent substances ground into a powder or shaved with a knife become lighter in appearance—for the mangling creates a "multitude of reflecting surface" that didn't exist before. By contrast substances soaked in water become darker, "for the water fills up the reflecting pores."

He also played with plates of glass, mounting a flat lens sandwichlike against one with a gentle spherical curve. Shining a light beam at the surface he beheld a mesmerizing pattern of colorful swirls. Newton's rings. "Accordingly as the glasses are pressed more or lesse together the coloured circles doe become greater or less. & as they are pressed more & more together new circles doe arrive in the midst." Taking the apparatus into a dark room he exposed it to a blue ray emitted by a prism. This time he saw a monochromatic target of dark and light circles. Red light produced a similar pattern.

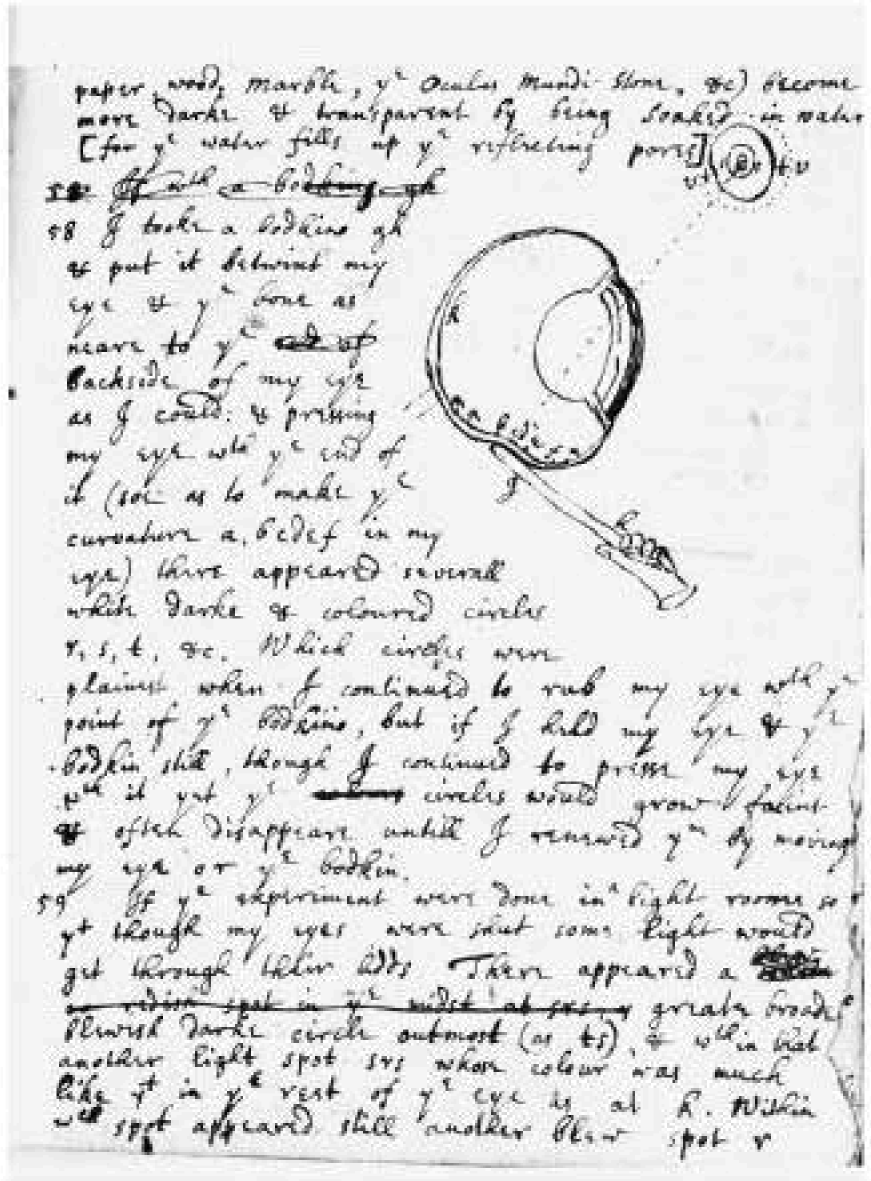
Hooke had already described the phenomenon—interference—in *Micrographia,* but Newton plumbed its depths and made it his own.

A lens sandwich used to show Newton's rings

As his interests grew into an obsession, he even experimented with his own eyes, taking a thin, blunt probe—a bodkin, he called it—and carefully inserting it "betwixt my eye & the bone as neare to the Backside of my eye as I could." Pressing and rubbing the instrument against his eyeball, he saw "severall white darke & coloured circles." When he repeated the experiment in daylight, with his eyes almost closed, "There appeared a greate broade blewish darke circle" with a smaller, lighter spot inside. If he pressed hard enough, within that spot was another little circle of blue. Performing the experiment in darkness produced a different effect: "the circle apeared of a Reddish light" surrounding an inner circle of "darkish blew."

Sometimes as he poked around in his eye socket he perceived still finer distinctions: a target of colorful rings "from the center greene, blew, purple, darke purple, blew, greene, yellow, red like flame, yellow, greene, blew, broade purple, darke." Staring at the sun or its reflection, he noticed that the afterimage was red, "but if I went into a dark roome the Phantasma was blew."

From physics he occasionally detoured into anatomy. From each eye, he learned in his readings, the visual vibrations traveled through the optic nerves—"a vast multitud of these slender pipes"—and into the brain. Dissecting the tissues around an eye—an animal's, thank God, not his own—he tried to determine the nature of the substance that carried the imagery. "Water is too grosse for such subtile impressions," he concluded. A better possibility seemed to be the "animal spirits" said by the Galenists to blow through the nervous system. Newton ruled that out with an experiment: "though I tyed a peice of the optick nerve at one end & warmed it in the middle to see if any aery substance by that meanes would disclose it selfe in bubbles at the other end, I could not spy the least bubble; a little moisture only & the marrow it selfe squeezed out."

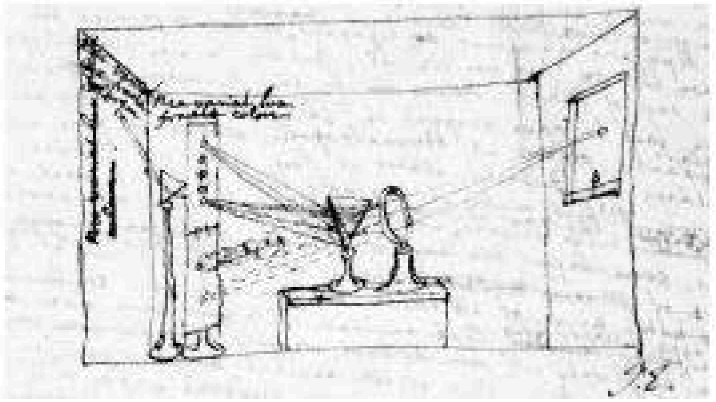


Newton's experiment with his own eye: a page from his notebooks

If that is where it all had ended—waiting for the spirits of vision to come bubbling from the optic tubules—Newton might have remained just another seventeenth-century genius confused and tantalized by light. But sometime in the midst of his investigations he became captivated by a curiosity involving prisms. Draw a line, half blue and half a "good deepe red," on a black piece of paper and the prism will make it appear skewed: "broken in two twixt the colours." The same thing happened with blue and red threads. One was offset from the other. But why were the colors treated differently by the glass?

One day, his curiosity aroused, he cut a small circular hole a quarter-inch across in his window shutter. Holding a prism in the narrow path of the sunbeam, he cast a spectrum on the far wall of the darkened room.

"It was at first a very pleasing divertisement to view the vivid & intense colours," he reported: blues fading into greens then yellows into oranges and reds. But far more significant than the familiar appearance of a spectrum was its shape. It was not circular like the hole in the shutter or the image of the sun, but oblong: thirteen and one-fourth inches long, two and five-eighths inches wide. It was "a disproportion soe extravagant that it excited me to a more then ordinary curiosity of examining from whence it might proceed."



Newton's drawing of his *Experimentum Crucis*

Something was causing the colors to fan out this way. Newton doubted that the effect could be an artifact, some obscure confluence of accidental effects. But the possibility had to be ruled out. He tried holding the prism in different positions so that the light traveled "through parts of the glasse of divers thicknesses." He cut holes in the shade of "divers bignesses." He tried putting the prism outside the window, so the sunlight hit it before passing through the hole. None of that mattered. "The fashion of the colours was in all these cases the same."

Having refracted sunlight with one prism, he found that he could pass the colors through a second prism and they would recombine. The second prism undid what the first had done, leaving a colorless circle of light on the wall. The colors were not added by the prism. They had been in the light beam all along.

It was a multitude of such experiments that led him to his surprising conclusion. By the time he was ready for what he would call his *Experimentum Crucis* (borrowing the term from Hooke), he probably knew what he would find. But that barely detracts from the drama. As before, the light beam from the window passed through a prism and crossed the room, but this time it cast its spectrum on a wooden board. Through one end of the board Newton had drilled a hole, and by holding his prism just so, he could make the colors pass through the opening one by one. From there they entered a second prism before leaving an image on the wall.

What he saw that day changed forever how we think about light. Starting at the red end of the spectrum and progressing toward the blue, each color was bent a little more—an elaboration of the effect hinted at by the colored threads: "blew rays suffer a greater refraction than red ones." That was the reason for the oblong. If all colors were bent equally the spectrum would be a roundish blob. But light, as Newton put it, "consists of rayes differently refrangible."

Refrangible means refractable—both words come from the same Latin root —and Newton had discovered nothing less than what a color is: a ray of light preternaturally disposed to bend a certain way. "To the same degree of refrangibility ever belongs the same colour, & to the same colour ever belongs the same degree of refrangibility," he wrote. Color *is* refrangibility.

And there was more. Once a color was separated from the rest, it could not be further altered, no matter how hard he tried. "I have refracted it with Prismes, & reflected it with bodies which in day light were of other colours; I have intercepted it with the coloured film of air interceding two compressed plates of Glasse, transmitted it through coloured mediums & through mediums irradiated with other sort of rayes, & diversly terminated it, & yet could not produce any new colour out of it. It would by contracting or dilating become more brisk or faint, & by the losse of many rayes in some cases very obscure & dark, but I could never see it changed in Specie."

If a ray was composed of more than one color—orangish yellow, yellowish green—it could be split once again by a prism, but at some point you would reach the bottom, the fundamental components of light. "Colours are not qualifications of light derived from refractions or reflections of naturall bodies as 'tis generally beleived, but originall & connate properties."

It was white light that was the mongrel, not just another color but a combination of them all, a "heterogeneous mixture of differently refrangible rayes." As the sun shines on the world, it is not bringing out the red in an apple, the green in a leaf. The apple and the leaf are bringing the colors out of the sunlight.

Descartes had also believed that colors were not inherent in objects, but rather manifestations of how they affected light. Now Newton knew why. The world is colorful because it consists of bodies "variously qualified to reflect one sort of light in greater plenty than another."

IN EARLY September 1666, the Great Fire destroyed much of London, killing the rats and hastening the end of the plague. Setting aside optics and other scientific pursuits, Robert Hooke worked with Christopher Wren to rebuild the city. Newton moved back to Cambridge, where he rose to the position of Lucasian professor of mathematics and lectured on color and light. A reflecting telescope he invented, six inches long and more powerful than a conventional telescope ten times its size, impressed the members of the Royal

Society, and in 1672, six years after his experiments, they published his paper "New Theory About Light and Colors" in the society's *Philosophical Transactions*.

Burning with jealousy, Hooke tried to discredit the upstart, setting off a feud that would last as long as both men were alive. Hooke declared that he had already performed all these experiments himself, and that the results could be explained just as well by his own theory. (Later he would claim that Newton's *Principia* was plagiarized from him.)

Other scientists, like Huygens, also raised objections in dispatches to the journal, and Newton countered his nay-sayers with a mixture of disbelief and scorn. The merciless dissection of new ideas would become a normal part of science. But Newton, an intensely private man, felt violated. He became especially agitated by a group of English Jesuits who insisted that they could not replicate his *Experimentum Crucis* and that the spreading out of the spectrum was an artifact caused by a "bright cloud." The carping continued until 1678, when in exasperation he retreated into seclusion. He was thirty-five. There was so much still to be done.