conditions is a matter of chance, and one that does not occur too frequently, we must not resort to experiments for settling such questions. So, Sarsi, if experiments are performed thousands of times at all seasons and in every place without once producing the effects mentioned by your philosophers, poets, and historians, this will mean nothing and we must believe their words rather than our own eyes? But what if I find for you a state of the air that has all the conditions you say are required, and still the egg is not cooked nor the lead ball destroyed? Alas! I should be wasting my efforts, . . . for all too prudently you have secured your position by saying that "there is needed for this effect violent motion, a great quantity of exhalations, a highly attenuated material, and whatever else conduces to it." This "whatever else" is what beats me, and gives you a blessed harbor, a sanctuary completely secure.

What I had in mind, though, was to suspend our argument and wait quietly until some new comet came along. I imagined that while this lasted you and Aristotle would grant me that since the air was then properly disposed for kindling the comet, it would likewise be suitable for melting lead balls and cooking eggs, inasmuch as you seem to require the same condition for both effects. It was then that I would have had us set to work with our slings, eggs, bows, muskets, and cannons so that we might clear up this matter for ourselves. And even without waiting for a comet we might find an opportune time when in midsummer the air flashes with heat lightning, as you assign all these "burnings" to a single cause. But I suppose that when you failed to behold a melting of lead balls or even the cooking of eggs under such conditions you would still fail to give in; you would say that this "whatever else conduces to the effect" was lacking. If you would only tell me what this "whatever else" is, I should endeavor to provide it. But if not I shall have to abandon my little scheme, though I do believe it would turn out against you. . . .

It now remains for me to tell Your Excellency, as I promised, some thoughts of mine about the proposition "motion is the cause of heat," and to show in what sense this may

be true. But first I must consider what it is that we call heat, as I suspect that people in general have a concept of this which is very remote from the truth. For they believe that heat is a real phenomenon, or property, or quality, which actually resides in the material by which we feel ourselves warmed.[19] Now I say that whenever I conceive any material or corporeal substance, I immediately feel the need to think of it as bounded, and as having this or that shape; as being large or small in relation to other things, and in some specific place at any given time; as being in motion or at rest; as touching or not touching some other body; and as being one in number, or few, or many. From these conditions I cannot separate such a substance by any stretch of my imagination. But that it must be white or red, bitter or sweet, noisy or silent, and of sweet or foul odor, my mind does not feel compelled to bring in as necessary accompaniments. Without the senses as our guides, reason or imagination unaided would probably never arrive at qualities like these. Hence I think that tastes, odors, colors, and so on are no more than mere names so far as the object in which we place them is concerned, and that they reside only in the consciousness. Hence if the living creature were removed, all these qualities would be wiped away and annihilated. But since we have imposed upon them special names, distinct from those of the other and real qualities mentioned previously, we wish to believe that they really exist as actually different from those.

[19] The ensuing passages are generally considered to entitle Galileo to credit for anticipating the fundamental concepts of the empiricist philosophy developed chiefly by John Locke at the close of the seventeenth century. The basic tenets are of course much older, belonging to the atomism of Democritus (b. 460 B.C.), a doctrine which was particularly repugnant to Aristotle. While this exposition is of no little philosophical and scientific interest (inasmuch as empiricism, rightly or wrongly, has been closely associated with the development of modern science), Galileo was no philosophical empiricist. He attached no less importance to reason than to experiment, and he had no doubt about the independent truth of mathematical propositions, the denial of which has always involved empiricist philosophers in serious difficulty with the best logicians.

I may be able to make my notion clearer by means of some examples. I move my hand first over a marble statue and then over a living man. As to the effect flowing from my hand, this is the same with regard to both objects and my hand; it consists of the primary phenomena of motion and touch, for which we have no further names. But the live body which receives these operations feels different sensations according to the various places touched. When touched upon the soles of the feet, for example, or under the knee or armpit, it feels in addition to the common sensation of touch a sensation on which we have imposed a special name, "tickling." This sensation belongs to us and not to the hand. Anyone would make a serious error if he said that the hand, in addition to the properties of moving and touching, possessed another faculty of "tickling," as if tickling were a phenomenon that resided in the hand that tickled. A piece of paper or a feather drawn lightly over any part of our bodies performs intrinsically the same operations of moving and touching, but by touching the eye, the nose, or the upper lip it excites in us an almost intolerable titillation, even though elsewhere it is scarcely felt. This titillation belongs entirely to us and not to the feather; if the live and sensitive body were removed it would remain no more than a mere word. I believe that no more solid an existence belongs to many qualities which we have come to attribute to physical bodies—tastes, odors, colors, and many more.

A body which is solid and, so to speak, quite material, when moved in contact with any part of my person produces in me the sensation we call touch. This, though it exists over my entire body, seems to reside principally in the palms of the hands and in the finger tips, by whose means we sense the most minute differences in texture that are not easily distinguished by other parts of our bodies. Some of these sensations are more pleasant to us than others. . . . The sense of touch is more material than the other sense; and, as it arises from the solidity of matter, it seems to be related to the earthly element.

Perhaps the origin of two other senses lies in the fact

that there are bodies which constantly dissolve into minute particles, some of which are heavier than air and descend, while others are lighter and rise up. The former may strike upon a certain part of our bodies that is much more sensitive than the skin, which does not feel the invasion of such subtle matter. This is the upper surface of the tongue; here the tiny particles are received, and mixing with and penetrating its moisture, they give rise to tastes, which are sweet or unsavory according to the various shapes, numbers, and speeds of the particles. And those minute particles which rise up may enter by our nostrils and strike upon some small protuberances which are the instrument of smelling; here likewise their touch and passage is received to our like or dislike according as they have this or that shape, are fast or slow, and are numerous or few. The tongue and nasal passages are providently arranged for these things, as the one extends from below to receive descending particles, and the other is adapted to those which ascend. Perhaps the excitation of tastes may be given a certain analogy to fluids, which descend through air, and odors to fires, which ascend.

Then there remains the air itself, an element available for sounds, which come to us indifferently from below, above, and all sides—for we reside in the air and its movements displace it equally in all directions. The location of the ear is most fittingly accommodated to all positions in space. Sounds are made and heard by us when the air—without any special property of "sonority" or "transonority"—is ruffled by a rapid tremor into very minute waves and moves certain cartilages of a tympanum in our ear. External means capable of thus ruffling the air are very numerous, but for the most part they may be reduced to the trembling of some body which pushes the air and disturbs it. Waves are propagated very rapidly in this way, and high tones are produced by frequent waves and low tones by sparse ones.

To excite in us tastes, odors, and sounds I believe that nothing is required in external bodies except shapes, numbers, and slow or rapid movements. I think that if ears,

tongues, and noses were removed, shapes and numbers and motions would remain, but not odors or tastes or sounds. The latter, I believe, are nothing more than names when separated from living beings, just as tickling and titillation are nothing but names in the absence of such things as noses and armpits. And as these four senses are related to the four elements, so I believe that vision, the sense eminent above all others in the proportion of the finite to the infinite, the temporal to the instantaneous, the quantitative to the indivisible, the illuminated to the obscure—that vision, I say, is related to light itself. But of this sensation and the things pertaining to it I pretend to understand but little; and since even a long time would not suffice to explain that trifle, or even to hint at an explanation, I pass this over in silence.

Having shown that many sensations which are supposed to be qualities residing in external objects have no real existence save in us, and outside ourselves are mere names, I now say that I am inclined to believe heat to be of this character. Those materials which produce heat in us and make us feel warmth, which are known by the general name of "fire," would then be a multitude of minute particles having certain shapes and moving with certain velocities. Meeting with our bodies, they penetrate by means of their extreme subtlety, and their touch as felt by us when they pass through our substance is the sensation we call "heat." This is pleasant or unpleasant according to the greater or smaller speed of these particles as they go pricking and penetrating; pleasant when this assists our necessary transpiration, and obnoxious when it causes too great a separation and dissolution of our substance. The operation of fire by means of its particles is merely that in moving it penetrates all bodies, causing their speedy or slow dissolution in proportion to the number and velocity of the fire-corpuscles and the density or tenuity of the bodies. Many materials are such that in their decomposition the greater part of them passes over into additional tiny corpuscles, and this dissolution continues so long as these continue to meet with further matter capable of being so resolved. I do not

believe that in addition to shape, number, motion, penetration, and touch there is any other quality in fire corresponding to "heat"; this belongs so intimately to us that when the live body is taken away, heat becomes no more than a simple name. . . .

Since the presence of fire-corpuscles alone does not suffice to excite heat, but their motion is needed also, it seems to me that one may very reasonably say that motion is the cause of heat. . . . But I hold it to be silly to accept that proposition in the ordinary way, as if a stone or piece of iron or a stick must heat up when moved. The rubbing together and friction of two hard bodies, either by resolving their parts into very subtle flying particles or by opening an exit for the tiny fire-corpuscles within, ultimately sets these in motion; and when they meet our bodies and penetrate them, our conscious mind feels those pleasant or unpleasant sensations which we have named heat, burning, and scalding. And perhaps when such attrition stops at or is confined to the smallest quanta, their motion is temporal and their action calorific only; but when their ultimate and highest resolution into truly indivisible atoms is arrived at, light is created.[20] This may have an instantaneous motion, or rather an instantaneous expansion and diffusion,[21] rendering it capable of occupying immense spaces by its—I know not whether to say its subtlety, its rarity, its immateriality, or some other property which differs from all these and is nameless.

[20] This lucky guess should entitle Galileo to consideration as having anticipated many modern scientific discoveries—in about the same sense as that in which medieval philosophers anticipated Galileo in the discovery of the principle of inertia. At present it is customary to praise their happy conjectures and to overlook his. But perhaps that is because they made so many unsupported guesses, and he so few.

[21] The erroneous view that light is transmitted instantaneously was later withdrawn by Galileo, and in the *Discourses* of 1638 he even proposed an experiment for determining the speed of light. It was, of course, too crude to succeed. Yet Galileo's discoveries played a part in its successful measurement, for this was eventually accomplished by means of observations of eclipses of the satellites of Jupiter.

I do not wish, Your Excellency, to engulf myself inadvertently in a boundless sea from which I might never get back to port, nor in trying to solve one difficulty do I wish to give rise to a hundred more, as I fear may have already happened in sailing but this little way from shore. Therefore I shall desist until some more opportune occasion.

. . . . . .

Finally I cannot resist speaking about Sarsi's amazement at my hopeless ineptitude in the employment of experiments, inasmuch as he himself errs as badly as a man can in that same activity. You, Sarsi, must show us that an interposed flame would not suffice to hide the stars. In order to convince us by experiments, you say that if we look through flames at people, firebrands, coals, printed pages, and candles, we shall see all these quite plainly. Did it never enter your head to tell us to try looking at stars? Why did you not say to us at the outset, "Interpose a flame between the eye and some star, and the star will be made neither more nor less visible"? Surely there is no lack of stars in the sky. Now is this to be a skillful and prudent experimentalist?

I ask you whether the comet's flame is like our flames, or whether it has a different nature. If its nature is different, experiments made with our flames are not conclusive. If it is like our flames, then you might have made us look at stars through our flames and left out firebrands, candle-snuffs, and such things. Instead of saying that print may be read through a candle flame, you might have said that a star may be so perceived. . . . You are obliged to kindle a very distant flame as large as a comet and to make us see stars through it. . . . But in order to put you at your ease and give you every advantage, I shall be content with much less. Instead of placing the fire as far away as a comet, I am satisfied with a distance of one hundred yards. In place of the thickness of a comet, merely ten yards will suffice. And since you say the object to be seen gains an advantage from being bright, let it be one of the stars which