AT VI 81

OPTICS

DISCOURSE ONE: LIGHT

The conduct of our life depends entirely on our senses, and since sight is the noblest and most comprehensive of the senses, inventions which serve to increase its power are undoubtedly among the most useful there can be. And it is difficult to find any such inventions which do more to increase the power of sight than those wonderful telescopes which, though in use for only a short time, have already revealed a greater number of new stars and other new objects above the earth than we had seen there before. Carrying our vision much further than our forebears could normally extend their imagination, these telescopes seem to have opened the way for us to attain a knowledge of nature much greater and
(82) more perfect than they possessed . . . But inventions of any complexity do not reach their highest degree of perfection right away, and this one is still sufficiently problematical to give me cause to write about it. And since the construction of the things of which I shall speak must depend on the skill of craftsmen, who usually have little formal education, I shall try
83 to make myself intelligible to everyone; and I shall try not to omit anything, or to assume anything that requires knowledge of other sciences. This is why I shall begin by explaining light and light-rays; then, having briefly described the parts of the eye, I shall give a detailed account of how vision comes about; and, after noting all the things which are capable of making vision more perfect, I shall show how they can be aided by the inventions which I shall describe.

Now since my only reason for speaking of light here is to explain how its rays enter into the eye, and how they may be deflected by the various bodies they encounter, I need not attempt to say what is its true nature. It will, I think, suffice if I use two or three comparisons in order to facilitate that conception of light which seems most suitable for explaining all those of its properties that we know through experience and then for deducing all the others that we cannot observe so easily. In this I am imitating the astronomers, whose assumptions are almost all false or uncertain, but who nevertheless draw many very true and certain

consequences from them because they are related to various observations they have made.

No doubt you have had the experience of walking at night over rough ground without a light, and finding it necessary to use a stick in order to
guide yourself. You may then have been able to notice that by means of 84
this stick you could feel the various objects situated around you, and that you could even tell whether they were trees or stones or sand or water or grass or mud or any other such thing. It is true that this kind of sensation is somewhat confused and obscure in those who do not have long practice with it. But consider it in those born blind, who have made use of it all their lives: with them, you will find, it is so perfect and so exact that one might almost say that they see with their hands, or that their stick is the organ of some sixth sense given to them in place of sight. In order to draw a comparison from this, I would have you consider the light in bodies we call 'luminous' to be nothing other than a certain movement, or very rapid and lively action, which passes to our eyes through the medium of the air and other transparent bodies, just as the movement or resistance of the bodies encountered by a blind man passes to his hand by means of his stick. In the first place this will prevent you from finding it strange that this light can extend its rays instantaneously from the sun to us. For you know that the action by which we move one end of a stick must pass instantaneously to the other end, and that the action of light would have to pass from the heavens to the earth in the same way, even though the distance in this case is much greater than that between the ends of a stick. Nor will you find it strange that by means of
this action we can see all sorts of colours. You may perhaps even be 85
prepared to believe that in the bodies we call 'coloured' the colours are nothing other than the various ways in which the bodies receive light and reflect it against our eyes. You have only to consider that the differences a blind man notes between trees, rocks, water and similar things by means of his stick do not seem any less to him than the differences between red, yellow, green and all the other colours seem to us. And yet in all those bodies the differences are nothing other than the various ways of moving the stick or of resisting its movements. Hence you will have reason to conclude that there is no need to suppose that something material passes from objects to our eyes to make us see colours and light, or even that there is something in the objects which resembles the ideas or sensations that we have of them. In just the same way, when a blind man feels bodies, nothing has to issue from the bodies and pass along his stick to his hand; and the resistance or movement of the bodies, which is the sole cause of the sensations he has of them, is nothing like the ideas he forms of them. By this means, your mind will be delivered from all those little

images flitting through the air, called 'intentional forms',[1] which so exercise the imagination of the philosophers. You will even find it easy to settle the current philosophical debate concerning the origin of the action which causes visual perception. For, just as our blind man can feel the
86 bodies around him not only through the action of these bodies when they move against his stick, but also through the action of his hand when they do nothing but resist the stick, so we must acknowledge that the objects of sight can be perceived not only by means of the action in them which is directed towards our eyes, but also by the action in our eyes which is directed towards them. Nevertheless, because the latter action is nothing other than light, we must note that it is found only in the eyes of those creatures which can see in the dark, such as cats, whereas a man normally sees only through the action which comes from the objects. For experience shows us that these objects must be luminous or illuminated in order to be seen, and not that our eyes must be luminous or illuminated in order to see them. But because our blind man's stick differs greatly from the air and the other transparent bodies through the medium of which we see, I must make use of yet another comparison.

Consider a wine-vat at harvest time, full to the brim with half-pressed grapes, in the bottom of which we have made one or two holes through which the unfermented wine can flow.[2] Now observe that, since there is no vacuum in nature (as nearly all philosophers acknowledge), and yet
87 there are many pores in all the bodies we perceive around us (as experience can show quite clearly), it is necessary that these pores be filled with some very subtle and very fluid matter, which extends without interruption from the heavenly bodies to us. Now, if you compare this subtle matter with the wine in the vat, and compare the less fluid or coarser parts of the air and the other transparent bodies with the bunches of grapes which are mixed in with the wine, you will readily understand the following. The parts of wine at one place tend to go down in a straight line through one hole at the very instant it is opened, and at the same time through the other hole, while the parts at other places also tend at the same time to go down through these two holes, without these actions being impeded by each other or by the resistance of the bunches of grapes in the vat. This happens even though the bunches support each other and so do not tend in the least to go down through the holes, as does the wine, and at the same time they can even be moved in many other ways by the bunches which press upon them. In the same way, all the parts of the subtle matter in contact with the side of the sun facing us

1 A reference to the scholastic doctrine that material objects transmit to the soul 'forms' or 'images' (Fr. *espèces*, Lat. *species*) resembling them.

2 A diagram of the wine-vat is omitted here.

tend in a straight line towards our eyes at the very instant they are opened, without these parts impeding each other, and even without their being impeded by the coarser parts of the transparent bodies which lie between them. This happens whether these bodies move in other ways – like the air which is almost always agitated by some wind – or are
motionless – say, like glass or crystal. And note here that it is necessary to 88
distinguish between the movement and the action or the tendency to move. For we may very easily conceive that the parts of wine at one place should tend towards one hole and at the same time towards the other, even though they cannot actually move towards both holes at the same time, and that they should tend exactly in a straight line towards one and towards the other, even though they cannot move exactly in a straight line because of the bunches of grapes which are between them. In the same way, considering that the light of a luminous body must be regarded as being not so much its movement as its action, you must think of the rays of light as nothing other than the lines along which this action tends. Thus there is an infinity of such rays which come from all the points of a luminous body towards all the points of the bodies it illuminates, just as you can imagine an infinity of straight lines along which the 'actions' coming from all the points of the surface of the wine tend towards one hole, and an infinity of others along which the 'actions' coming from the same points tend also towards the other hole, without either impeding the other.

Moreover, these rays must always be imagined to be exactly straight when they pass through a single transparent body which is uniform throughout. But when they meet certain other bodies, they are liable to be deflected by them, or weakened, in the same way that the movement
of a ball or stone thrown into the air is deflected by the bodies it 89
encounters. For it is very easy to believe that the action or tendency to move (which, I have said, should be taken for light) must in this respect obey the same laws as motion itself. In order that I may give a complete account of this third comparison, consider that a ball passing through the air may encounter bodies that are soft or hard or fluid. If these bodies are soft, they completely stop the ball and check its movement, as when it strikes linen sheets or sand or mud. But if they are hard, they send the ball in another direction without stopping it, and they do so in many different ways. For their surface may be quite even and smooth, or rough and uneven; if even, either flat or curved; if uneven, its unevenness may consist merely in its being composed of many variously curved parts, each quite smooth in itself, or also in its having many different angles or points, or some parts harder than others, or parts which are moving (their movements being varied in a thousand imaginable ways). And it must be noted that the ball, besides moving in the simple and ordinary way which

takes it from one place to another, may move in yet a second way, turning on its axis, and that the speed of the latter movement may have many different relations with that of the former. Thus, when many balls coming from the same direction meet a body whose surface is completely
90 smooth and even, they are reflected uniformly and in the same order, so that if this surface is completely flat they keep the same distance between them after having met it as they had beforehand; and if it is curved inward or outward they come towards each other or go away from each
(91) other in the same order, more or less, on account of this curvature . . . It is necessary to consider, in the same manner, that there are bodies which break up the light-rays that meet them and take away all their force (*viz.*, bodies called 'black', which have no colour other than that of shadows); and there are others which cause the rays to be reflected, some in the same order as they receive them (*viz.* bodies with highly polished surfaces, which can serve as mirrors, both flat and curved), and others in
92 many directions in complete disarray. Among the latter, again, some bodies cause the rays to be reflected without bringing about any other change in their action (*viz.* bodies we call 'white'), and others bring about an additional change similar to that which the movement of a ball undergoes when we graze it (*viz.* bodies which are red, or yellow, or blue or some other such colour). For I believe I can determine the nature of each of these colours, and reveal it experimentally; but this goes beyond the limits of my subject.[1] All I need to do here is to point out that the light-rays falling on bodies which are coloured and not polished are usually reflected in every direction even if they come from only a single direction . . . Finally, consider that the rays are also deflected, in the same
93 way as the ball just described, when they fall obliquely on the surface of a transparent body and penetrate this body more or less easily than the body from which they come. This mode of deflection is called 'refraction'.

DISCOURSE TWO: REFRACTION

Later on we shall need to know how to determine exactly the quantity of this refraction, and since the comparison I have just used enables this to be understood quite easily, I think it appropriate for me to try to explain it here without more ado. I shall speak first about reflection, in order to make it easier to understand refraction. Let us suppose that a ball impelled by a tennis racquet from A to B meets at point B the surface of the ground CBE, which stops its further passage and causes it to be deflected; and let us see in what direction it will go [Fig. 1]. To avoid

1 Cf. *Description of the Human Body*, p. 323 below.

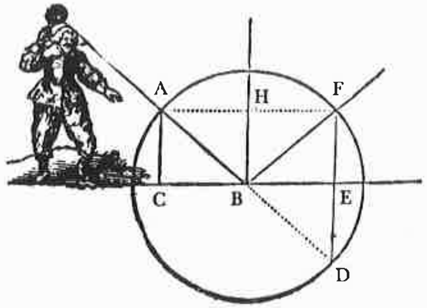

Fig. 1

getting involved in new difficulties, let us assume that the ground is perfectly flat and hard, and that the ball always travels at a constant speed, both in its downward passage and in rebounding, leaving aside entirely the question of the power which continues to move it when it is 94
no longer in contact with the racquet, and without considering any effect of its weight, size or shape. For there is no point in going into such details here, since none of these factors is involved in the action of light to which the present inquiry must be related. It is only necessary to note that the power, whatever it may be, which causes the ball to continue moving is different from that which determines it to move in one direction rather than another. It is very easy to recognize this from the fact that the movement of the ball depends upon the force with which it has been impelled by the racquet, and this same force could have made it move in any other direction as easily as towards B; whereas the ball's tending towards B is determined by the position of the racquet, which could have determined the ball in the same way even if a different force had moved it. This shows already that it is not impossible for the ball to be deflected by its encounter with the ground, and hence that there could be a change in its determination to tend towards B without any change in the force of its movement, since these are two different things. Consequently we must not imagine, as many of our philosophers do, that it is necessary for the ball to stop at point B for a moment before returning towards F. For if its motion were once interrupted by such a halt, no cause could be found which would make it start up again afterwards. Moreover, it must be noted that not only the determination to move in a certain direction but 95
also the motion itself, and in general any sort of quantity, can be divided into all the parts of which we can imagine that it is composed. And we can easily imagine that the determination of the ball to move from A towards B is composed of two others, one making it descend from line AF towards line CE and the other making it at the same time go from the

left AC towards the right FE, so that these two determinations joined together direct it to B along the straight line AB. And then it is easy to understand that its encounter with the ground can prevent only one of these two determinations, leaving the other quite unaffected. For it must indeed prevent the one which made the ball descend from AF towards CE, because the ground occupies all the space below CE. But why should it prevent the other, which made the ball move to the right, seeing that it is not at all opposed to the determination in that direction? So, to discover in precisely what direction the ball must rebound, let us describe a circle, with its centre at B, which passes through point A; and let us say that in as much time as the ball will take to move from A to B, it must inevitably return from B to a certain point on the circumference of the circle. This holds in so far as the circumference contains all the points
96 which are as far from B as A is, and the ball is supposed to be moving always at a constant speed. Next, in order to determine precisely to which point on the circumference the ball must return, let us draw three straight lines AC, HB, and FE, perpendicular to CE, so that the distance between AC and HB is neither greater nor less than that between HB and FE. And let us say that in as much time as the ball took to move towards the right side from A (one of the points on the line AC) to B (one of those on the line HB), it must also advance from the line HB to some point on the line FE. For all the points on the line FE are equidistant from the corresponding points on HB, as are those on line AC; and also the ball is as much determined to advance towards that side as it was before. So it is that the ball cannot arrive simultaneously both at some point on the line FE and at some point on the circumference of the circle AFD, unless this point is either D or F, as these are the only two points where the circumference and the line intersect. Accordingly, since the ground prevents the ball from passing towards D, it is necessary to conclude that it must inevitably go towards F. And so you can easily see how reflection takes place, namely at an angle always equal to the one we call the angle of incidence. In the same way, if a light-ray coming from point A falls at point B on the surface of a flat mirror CBE, it is reflected towards F in such manner that the angle of reflection FBE is neither greater nor less than the angle of incidence ABC.

97 We come now to refraction. First let us suppose that a ball impelled from A towards B encounters at point B not the surface of the earth, but a linen sheet CBE which is so thin and finely woven that the ball has enough force to puncture it and pass right through, losing only some of its speed (say, a half) in doing so. Now given this, in order to know what path it must follow, let us consider again that its motion is entirely different from its determination to move in one direction rather than another – from which it follows that the quantity of these two factors must be examined separately. And let us also consider that, of the two parts of which we can imagine this determination to be composed, only the one which was making the ball tend in a downward direction can be changed in any way through its colliding with the sheet, while the one which was making the ball tend to the right must always remain the same as it was, because the sheet offers no opposition at all to the determination in this direction. Then, having described the circle AFD with its centre at B [Fig. 2], and having drawn at right angles to CBE the three straight lines AC, HB, FE so that the distance between FE and HB is twice that between HB and AC, we shall see that the ball must tend towards the point I. For, since the ball loses half its speed in passing through the sheet CBE, it must take twice as much time to descend from B to some point on 98
the circumference of the circle AFD as it took to go from A to B above the sheet. And since it loses none of its former determination to advance to the right, in twice the time it took to pass from the line AC to HB it must cover twice the distance in the same direction, and consequently it must arrive at some point on the straight line FE simultaneously with its reaching some point on the circumference of the circle AFD. This would be impossible if it did not go towards I, as this is the only point below the sheet CBE where the circle AFD and the straight line FE intersect.

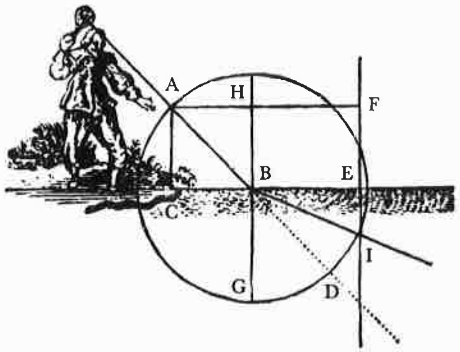

Fig. 2

Now let us suppose that the ball coming from A towards D does not strike a sheet at point B, but rather a body of water, the surface of which reduces its speed by exactly a half, as did the sheet. The other conditions being given as before, I say that this ball must pass from B in a straight line not towards D, but towards I. For, in the first place, it is certain that the surface of the water must deflect it towards that point in the same

way as the sheet, seeing that it reduces the force of the ball by the same amount, and that it is opposed to the ball in the same direction. Then, as for the rest of the body of water which fills all the space between B and I,
99 although it resists the ball more or less than did the air which we supposed there before, we should not say for this reason that it must deflect it more or less. For the water may open up to make way for the ball just as easily in one direction as in another, at least if we always assume, as we do, that the ball's course is not changed by its heaviness or lightness, or by its size or shape or any other such extraneous cause. And we may note here that the deflection of the ball by the surface of the water or the sheet is greater, the more oblique the angle at which it encounters it, so that if it encounters it at a right angle (as when it is impelled from H towards B) it must pass beyond in a straight line towards G without being deflected at all. But if it is impelled along a line such as AB [Fig. 3], which is so sharply inclined to the surface of the water or sheet CBE that the line FE (drawn as before) does not intersect the circle AD, the ball ought not to penetrate it at all, but ought to rebound from its surface B towards the air L, in the same way as if it had struck the earth at that point. People have sometimes experienced this to their regret when, firing artillery pieces towards the bottom of a river for fun, they have wounded those on the shore at the other side.

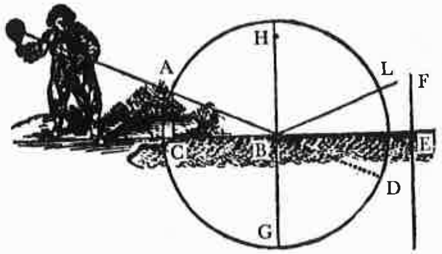

Fig. 3

But let us make yet another assumption here, and suppose that the ball,
100 having been first impelled from A to B, is again impelled at point B by the racquet CBE which increases the force of its motion, say by a third, so that it can then make as much headway in two seconds as it previously made in three. This will have the same effect as if the ball were to meet at point B a body of such nature that it could pass through its surface CBE one-third again more easily than through the air [Fig. 4]. And it follows manifestly from what has already been demonstrated that if you describe the circle AD as before, and the lines AC, HB, FE so that there is a third

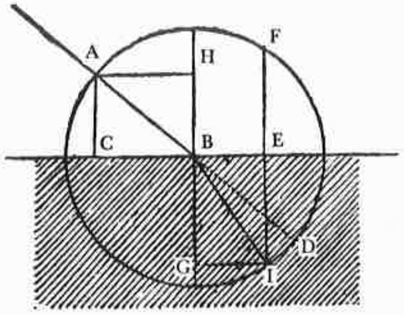

Fig. 4

less distance between FE and HB than between HB and AC, then point I, where the straight line FE and the circular line AD intersect, will indicate the position towards which the ball must be deflected when at point B.

Now we can also draw the converse of this conclusion and say that since the ball which comes in a straight line from A to B is deflected when at point B and moves on towards I, this means that the force or ease with which it penetrates the body CBEI is related to that with which it leaves the body ACBE as the distance between AC and HB is related to that between HB and FI – that is, as the line CB is to BE.

Finally, in so far as the action of light in this respect obeys the same laws as the movement of the ball, it must be said that when its rays pass obliquely from one transparent body into another, which they penetrate
more or less easily than the first, they are deflected in such a way that 101
their inclination to the surface between these bodies is always less sharp on the side of the more easily penetrated body, and the degree of this inclination varies exactly in proportion to the varying degrees of penetrability of the respective bodies.[1] Only it must be noted carefully that this inclination has to be measured by the quantity of the straight lines (CB or AH, EB or IG, and the like) compared to each other, not by that of angles such as ABH or GBI, and still less by that of angles like DBI which we call 'angles of refraction'. For the ratio or proportion between these angles varies with all the different inclinations of the rays, whereas that between the lines AH and IG, or the like, remains the same in all refractions caused by the same bodies. Thus, for example [Fig. 5], suppose a ray passes through the air from A towards B and, meeting the surface of a lens CBR at point B, is deflected towards I in this lens; and

1 Without stating it explicitly, Descartes here enunciates the law now known as Snell's Law, according to which $\sin i = n \sin r$, where i is the angle of incidence, r the angle of refraction, and n a constant specific to the refractive medium. Cf. letter to Mersenne, June 1632.

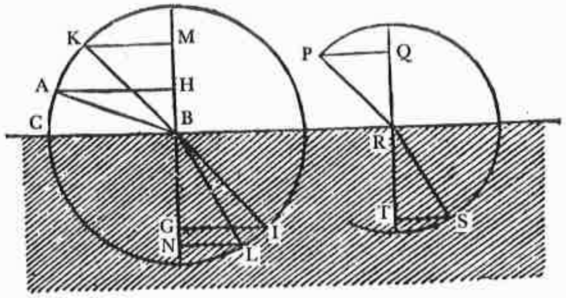

Fig. 5

suppose another ray coming from K towards B is deflected towards L, and another coming from P towards R is deflected towards S. In this case there must be the same proportion between the lines KM and LN, or PQ and ST, as between AH and IG, but not the same between the angles KBM and LBN, or PRQ and SRT, as between ABH and IBG.

102 So now you see the way in which refractions have to be measured. Although we need to refer to experience in order to determine their quantity, in so far as it depends on the particular nature of the bodies in which they occur, nonetheless we can do this easily enough and with sufficient certainty since all refractions are reduced in this way to a common measure. In fact, to discover all the refractions occurring at a given surface, it suffices to examine only those of a single ray, and we can avoid every error if in addition we examine the refractions in several other rays. So, if we wish to know the quantity of the refractions which occur at the surface CBR, separating the air AKP from the lens LIS, we need only determine the refraction of the ray ABI by examining the proportion between lines AH and IG. Then, if we suspect we have failed in this experiment, we must determine the refraction in several other rays, like KBL or PRS; and if we find the same proportion between KM and LN, and between PQ and ST, as between AH and IG, we shall have no further cause to doubt the truth of our observation.

When you make these observations, however, you will perhaps be amazed to find that light-rays are more sharply inclined in air than in water, at the surfaces where their refraction occurs, and still more in water than in glass; while just the opposite occurs in the case of a ball,
103 which is inclined more sharply in water than in air, and which cannot pass through glass at all. For example [Fig. 6], if a ball impelled through the air from A towards B meets a surface of water CBE at point B, it will be deflected from B towards V; and in the case of a ray, it will go in quite a different direction, from B towards I. You will no longer find this strange, however, if you recall the nature that I ascribed to light, when I

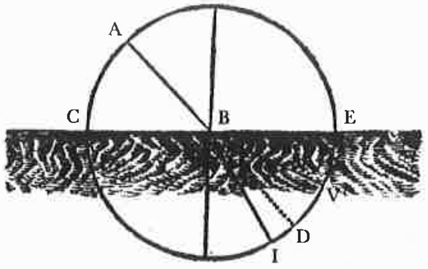

Fig. 6

said it is nothing but a certain movement or an action received in a very subtle matter which fills the pores of other bodies. And you should consider too that, just as a ball loses more of its motion in striking a soft body than a hard one and rolls less easily on a carpet than on a completely bare table, so the action of this subtle matter can be impeded much more by the parts of the air (which, being as it were soft and badly joined, do not offer it much resistance) than by those of water, which offer it more resistance; and still more by those of water than by those of glass, or of crystal. Thus, in so far as the minute parts of a transparent body are harder and firmer, the more easily they allow the light to pass; for the light does not have to drive any of them out of their places, as a ball must expel the parts of water in order to find a passage through them.

Moreover, knowing in this way the cause of the refractions which 104
occur in water and glass and generally in all the other transparent bodies around us, we can note that the refractions occurring when the rays emerge from these bodies must be wholly similar to those occurring when they enter them. So, if the ray coming from A towards B is deflected from B towards I in passing from the air into a lens, the one which returns from I towards B must also be deflected from B towards A. Nevertheless other bodies may well be found (chiefly in the sky) in which refractions result from other causes, and so are not reciprocal in this way. And certain cases may also be found in which the rays must be curved, though they merely pass through a single transparent body, just as the motion of a ball is often curved because it is deflected in one direction by its weight and in another by the action with which we have impelled it, or for various other reasons. For in the end, I venture to say, the three comparisons which I have just used are so appropriate that all the particular features which may be observed in them correspond to certain features which prove to be entirely similar in the case of light; but I have tried to explain only those which have the most bearing on my subject. And I do not wish to have you consider anything else here, except that

the surfaces of transparent bodies which are curved deflect the rays
105 passing through each of their points in the same way as would the flat surfaces that we can imagine touching these bodies at the same points. So, for example [Fig. 7], the refractions of the rays AB, AC, AD, which

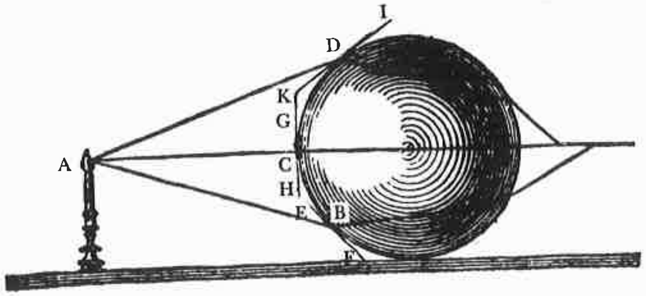

Fig. 7

come from the flame A and fall on the curved surface of the crystal ball BCD, must be regarded in the same way as if AB fell on flat surface EBF, AC on GHC, and AD on IDK, and likewise for the others. From this you can see that these rays may be variously focussed or dispersed, according as they fall on surfaces which are differently curved. But now it is time for me to begin describing the structure of the eye, so as to enable you to understand how the rays which enter it are so disposed there as to cause visual perception . . .[1]

109 DISCOURSE FOUR: THE SENSES IN GENERAL

Now I must tell you something about the nature of the senses in general, the more easily to explain that of sight in particular. We know for certain that it is the soul which has sensory perceptions, and not the body. For when the soul is distracted by an ecstasy or deep contemplation, we see that the whole body remains without sensation, even though it has various objects touching it. And we know that it is not, properly speaking, because of its presence in the parts of the body which function as organs of the external senses that the soul has sensory perceptions, but because of its presence in the brain, where it exercises the faculty called the 'common' sense.[2] For we observe injuries and diseases which attack the brain alone and impede all the senses generally, even though the rest of the body continues to be animated. We know, lastly, that it is through

1 Discourse Three, on the eye, is omitted here. For an English version of this and material omitted below, see *Descartes: Discourse on Method, Optics, Geometry and Meteorology*, tr. P. J. Olscamp (Indianapolis: Bobbs-Merrill, 1965).

2 Cf. *Rules*, p. 41 above, and *Passions*, pp. 341ff below.

the nerves that the impressions formed by objects in the external parts of the body reach the soul in the brain. For we observe various accidents which cause injury only to a nerve, and destroy sensation in all the parts of the body to which this nerve sends its branches, without causing it to diminish elsewhere . . .[1] We must take care not to assume – as our (112)
philosophers commonly do – that in order to have sensory perceptions the soul must contemplate certain images[2] transmitted by objects to the brain; or at any rate we must conceive the nature of these images in an entirely different manner from that of the philosophers. For since their conception of the images is confined to the requirement that they should resemble the objects they represent, the philosophers cannot possibly show us how the images can be formed by the objects, or how they can be received by the external sense organs and transmitted by the nerves to the brain. Their sole reason for positing such images was that they saw how easily a picture can stimulate our mind to conceive the objects depicted in it, and so it seemed to them that, in the same way, the mind must be stimulated, by little pictures formed in our head, to conceive the objects that affect our senses. We should, however, recall that our mind can be stimulated by many things other than images – by signs and words, for example, which in no way resemble the things they signify. And if, in order to depart as little as possible from accepted views, we prefer to maintain that the objects which we perceive by our senses really send images of themselves to the inside of our brain, we must at least 113
observe that in no case does an image have to resemble the object it represents in all respects, for otherwise there would be no distinction between the object and its image. It is enough that the image resembles its object in a few respects. Indeed the perfection of an image often depends on its not resembling its object as much as it might. You can see this in the case of engravings: consisting simply of a little ink placed here and there on a piece of paper, they represent to us forests, towns, people, and even battles and storms; and although they make us think of countless different qualities in these objects, it is only in respect of shape that there is any real resemblance. And even this resemblance is very imperfect, since engravings represent to us bodies of varying relief and depth on a surface which is entirely flat. Moreover, in accordance with the rules of perspective they often represent circles by ovals better than by other circles, squares by rhombuses better than by other squares, and similarly for other shapes. Thus it often happens that in order to be more perfect as

1 There follows an account of the function of the nerves and animal spirits in producing sensation and movement. Cf. *Treatise on Man*, AT XI 132ff and *Passions*, pp. 331–8 below.

2 See footnote 1, p. 154 above.

an image and to represent an object better, an engraving ought not to resemble it. Now we must think of the images formed in our brain in just the same way, and note that the problem is to know simply how they can enable the soul to have sensory perceptions of all the various qualities of the objects to which they correspond – not to know how they can
114 resemble these objects. For instance, when our blind man touches bodies with his stick, they certainly do not transmit anything to him except in so far as they cause his stick to move in different ways according to the different qualities in them, thus likewise setting in motion the nerves in his hand, and then the regions of his brain where these nerves originate. This is what occasions his soul to have sensory perception of just as many different qualities in these bodies as there are differences in the movements caused by them in his brain.

DISCOURSE FIVE: THE IMAGES WHICH ARE FORMED ON THE BACK OF THE EYE

You see, then, that in order to have sensory perceptions the soul does not need to contemplate any images resembling the things which it perceives. And yet, for all that, the objects we look at do imprint quite perfect images of themselves on the back of our eyes. This has been very ingeniously explained by the following comparison. Suppose a chamber is all shut up apart from a single hole, and a glass lens is placed in front of this hole with a white sheet stretched at a certain distance behind it so that the light coming from objects outside forms images on the sheet.
115 Now it is said that the room represents the eye; the hole, the pupil; the lens, the crystalline humour, or rather all the parts of the eye which cause some refraction; and the sheet, the internal membrane, which is composed of the optic nerve-endings.

But you may become more certain of this if, taking the eye of a newly dead person (or failing that, the eye of an ox or some other large animal), you carefully cut away the three surrounding membranes at the back so as to expose a large part of the humour without spilling any. Then cover the hole with some white body thin enough to let light pass through (e.g. a piece of paper or an egg-shell), and put this eye in the hole of a specially made shutter so that its front faces a place where there are various objects lit up by the sun, and its back faces the inside of the room where you are standing. (No light must enter the room except what comes through this eye, all of whose parts you know to be entirely transparent.) Having done this, if you look at the white body you will see there, not perhaps without wonder and pleasure, a picture representing in natural perspective all the
116 objects outside – at any rate you will if you ensure that the eye keeps its

natural shape, according to the distance of the objects (for if you squeeze 117
it just a little more or less than you ought, the picture becomes less distinct) . . .[1]

Now, when you have seen this picture in the eye of a dead animal, and (124)
considered its causes, you cannot doubt that a quite similar picture is formed in the eye of a living person, on the internal membrane for which we substituted the white body – indeed, a much better one is formed there since the humours in this eye are full of animal spirits and so are more transparent and more exactly of the shape necessary for this to occur. (And also, perhaps in the eye of an ox the shape of the pupil, which is not round, prevents the picture from being so perfect.) . . .

The images of objects are not only formed in this way at the back of (128)
the eye but also pass beyond into the brain . . .[2]

DISCOURSE SIX: VISION 130

Now, when this picture thus passes to the inside of our head, it still bears some resemblance to the objects from which it proceeds. As I have amply shown already, however, we must not think that it is by means of this resemblance that the picture causes our sensory perception of these objects – as if there were yet other eyes within our brain with which we could perceive it. Instead we must hold that it is the movements composing this picture which, acting directly upon our soul in so far as it is united to our body, are ordained by nature to make it have such sensations. I will explain this in more detail. All the qualities which we perceive in the objects of sight can be reduced to six principal ones: light, colour, position, distance, size and shape. First, regarding light and colour (the only qualities belonging properly to the sense of sight), we must suppose our soul to be of such a nature that what makes it have the sensation of light is the force of the movements taking place in the regions of the brain where the optic nerve-fibres originate, and what
makes it have the sensation of colour is the manner of these movements. 131
Likewise, the movements in the nerves leading to the ears make the soul hear sounds; those in the nerves of the tongue make it taste flavours; and, in general, movements in the nerves anywhere in the body make the soul have a tickling sensation if they are moderate, and a pain when they are too violent. But in all this there need be no resemblance between the ideas which the soul conceives and the movements which cause these ideas. You will readily grant this if you note that people struck in the eye seem to see countless sparks and flashes before them, even though they shut their

1 A diagram is omitted here and the text abridged.
2 Here Descartes repeats the account given in the *Treatise on Man*, pp. 105f above.

eyes or are in a very dark place; hence this sensation can be ascribed only to the force of the blow, which sets the optic nerve-fibres in motion as a bright light would do. The same force might make us hear a sound if it affected the ears, or feel pain if it affected some other part of the body. This is also confirmed by the fact that whenever you force your eyes to look at the sun, or at some other very bright light, they retain its impression for a short time afterwards, so that even with your eyes shut you seem to see various colours which change and pass from one to another as they fade away. This can only result from the fact that the optic nerve-fibres have been set in motion with extraordinary force, and cannot come to rest as soon as they usually can. But the agitation
132 remaining in them when the eyes are shut is not great enough to represent the bright light that caused it, and thus it represents the less vivid colours. That these colours change as they fade away shows that their nature consists simply in the diversity of the movement, exactly as I have already suggested. And finally this is evidenced by the frequent appearance of colours in transparent bodies, for it is certain that nothing can cause this except the various ways in which the light-rays are received there. One example is the appearance of a rainbow in the clouds, and a still clearer example is the likeness of a rainbow seen in a piece of glass cut on many sides.

But we must consider in detail what determines the quantity of the light which is seen, i.e. the quantity of the force with which each of the optic nerve-fibres is moved. For it is not always equal to the light which is in the objects, but varies in proportion to their distance and the size of the pupil, and also in proportion to the area at the back of the eye which may
(133) be occupied by the rays coming from each point of the object . . . We must also consider that we cannot discriminate the parts of the bodies we are looking at except in so far as they differ somehow in colour; and distinct vision of these colours depends not only on the fact that all the rays coming from each point of the object converge in almost as many different points at the back of the eye, and on the fact that no rays reach the same points from elsewhere . . . but also on the great number of optic nerve-fibres in the area which the image occupies at the back of the eye.
134 For example, if an object is composed of ten thousand parts capable of sending rays to a certain area at the back of the eye in ten thousand different ways, and consequently of making ten thousand colours simultaneously visible, these parts nonetheless will enable the soul to discriminate only at most a thousand colours, if we suppose that in this area there are only a thousand fibres of the optic nerve. Thus ten parts of the object, acting together upon each of the fibres, can move it in just one single way made up of all the ways in which they act, so that the area

occupied by each fibre has to be regarded as if it were only a single point. This is why a field decked out in countless different colours often appears from a distance to be all white or all blue; why, in general, all bodies are seen less distinctly from a distance than close at hand; and finally why the greater the area which we can make the image of a single object occupy at the back of the eye, the more distinctly it can be seen. We shall need to take special note of this fact later on.

As regards position, i.e. the orientation of each part of an object relative to our body, we perceive it by means of our eyes exactly as we do by means of our hands. Our knowledge of it does not depend on any image, nor on any action coming from the object, but solely on the position of the tiny parts of the brain where the nerves originate. For this position changes ever so slightly each time there is a change in the position of the limbs in which the nerves are embedded. Thus it is ordained by nature to enable the soul not only to know the place 135
occupied by each part of the body it animates relative to all the others, but also to shift attention from these places to any of those lying on the straight lines which we can imagine to be drawn from the extremity of each part and extended to infinity. In the same way, when the blind man, of whom we have already spoken so much, turns his hand A towards E [Fig. 8], or again his hand C towards E, the nerves

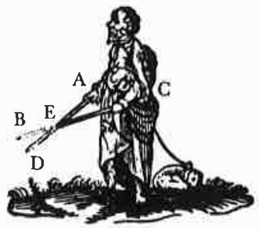

Fig. 8

embedded in that hand cause a certain change in his brain, and through this change his soul can know not only the place A or C but also all the other places located on the straight line AE or CE; in this way his soul can turn its attention to the objects B and D, and determine the places they occupy without in any way knowing or thinking of those which his hands occupy. Similarly, when our eye or head is turned in some direction, our soul is informed of this by the change in the brain which is caused by the nerves embedded in the muscles used for these movements. . . . You must not, therefore, find it strange that objects can be seen in their true position even though the picture they imprint upon the eye is 136

inverted. This is just like our blind man's being able to feel, at one and the same time, the object B (to his right) by means of his left hand, and the object D (to his left) by means of his right hand. And as the blind man does not judge a body to be double although he touches it with his two
137 hands, so too, when both our eyes are disposed in the manner required to direct our attention to one and the same place, they need only make us see a single object there, even though a picture of it is formed in each of our eyes.

The seeing of distance depends no more than does the seeing of position upon any images emitted from objects. Instead it depends in the first place on the shape of the body of the eye. For as we have said, for us to see things close to our eyes this shape must be slightly different from the shape which enables us to see things farther away; and as we adjust the shape of the eye according to the distance of objects, we change a certain part of our brain in a manner that is ordained by nature to make our soul perceive this distance. Ordinarily this happens without our reflecting upon it – just as, for example, when we clasp some body with our hand, we adjust our hand to its size and shape and thus feel it by means of our hand without needing to think of these movements. In the second place, we know distance by the relation of the eyes to one another. Our blind man holding the two sticks AE and CE (whose length I assume he does not know) and knowing only the distance between his two hands A and C and the size of the angles ACE and CAE, can tell from this knowledge, as if by a natural geometry, where the point E is. And similarly, when our two eyes A and B are turned towards point X, the length of the line AB and the size of the two angles XAB and XBA enable
138 us to know where the point X is. We can do the same thing also with the aid of only one eye, by changing its position.[1] Thus, if we keep it turned towards X and place it first at point A and immediately afterwards at point B, this will be enough to make our imagination contain the magnitude of the line AC together with that of the two angles XAB and XBA, and thus enable us to perceive the distance from point X. And this is done by a mental act which, though only a very simple act of the imagination, involves a kind of reasoning quite similar to that used by surveyors when they measure inaccessible places by means of two different vantage points. We have yet another way of perceiving distance, namely by the distinctness or indistinctness of the shape seen, together with the strength or weakness of the light. Thus, if we gaze fixedly towards X [Fig. 9], the rays coming from objects 10 and 12 do not converge so exactly upon R or T, at the back of our eye, as they would if

1 A diagram is omitted here.

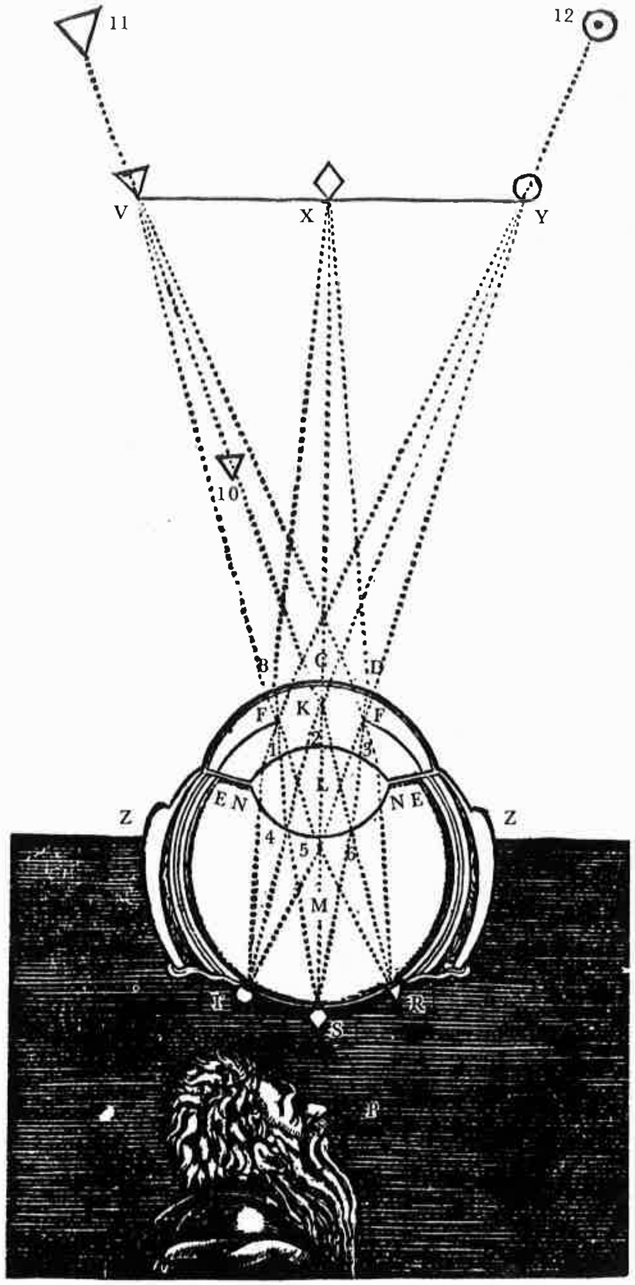

Fig. 9

these objects were at points V and Y. From this we see that they are
farther from us, or nearer to us, than X. Then, the light coming from
object 10 to our eye is stronger than it would be if that object were near
V, and from this we judge it to be nearer; and the light coming from
object 12 is weaker than it would be if it were near Y, and so we judge it
to be farther away. Finally, we may already have from another source an
image of an object's size, or its position, or the distinctness of its shape
and its colours, or merely the strength of the light coming from it; and
139 this may enable us to imagine its distance, if not actually to see it. For
140 example, when we observe from afar some body we are used to seeing
close at hand, we judge its distance much better than we would if its size
were less well known to us. If we are looking at a mountain lit up by
sunlight beyond a forest covered in shadow, it is solely the position of the
forest that makes us judge it the nearer. And when we look at two ships
out at sea, one smaller than the other but proportionately nearer so that
they appear equal in size, we can use the difference in their shapes and
colours, and in the light they send to us, to judge which is the more
distant.

Concerning the manner in which we see the size and shape of objects, I
need not say anything in particular since it is wholly included in the way
we see the distance and the position of their parts. That is, we judge their
size by the knowledge or opinion that we have of their distance,
compared with the size of the images they imprint on the back of the eye
– and not simply by the size of these images. This is sufficiently obvious
from the fact that the images imprinted by objects very close to us are a
hundred times bigger than those imprinted by objects ten times farther
away, and yet they do not make us see the objects a hundred times larger;
instead they make the objects look almost the same size, at least if their
distance does not deceive us. It is obvious too that we judge shape by the
knowledge or opinion that we have of the position of the various parts of
an object, and not by the resemblance of the pictures in our eyes. For
141 these pictures usually contain only ovals and rhombuses when they make
us see circles and squares.

But in order that you may have no doubts at all that vision works as I
have explained it, I would again have you consider the reasons why it
sometimes deceives us. First, it is the soul which sees, and not the eye;
and it does not see directly, but only by means of the brain. That is why
madmen and those who are asleep often see, or think they see, various
objects which are nevertheless not before their eyes: namely, certain
vapours disturb their brain and arrange those of its parts normally
engaged in vision exactly as they would be if these objects were present.
Then, because the impressions which come from outside pass to the

'common' sense by way of the nerves, if the position of these nerves is
changed by any unusual cause, this may make us see objects in places
other than where they are ... Again, because we normally judge that the (142)
impressions which stimulate our sight come from places towards which
we have to look in order to sense them, we may easily be deceived when
they happen to come from elsewhere. Thus, those whose eyes are affected
by jaundice, or who are looking through yellow glass or shut up in a
room where no light enters except through such glass, attribute this
colour to all the bodies they look at. And the person inside the dark room
which I described earlier attributes to the white body the colours of the
objects outside because he directs his sight solely upon that body. And if
our eyes see objects through lenses and in mirrors, they judge them to be
at points where they are not and to be smaller or larger than they are, or
inverted as well as smaller (namely, when they are somewhat distant
from the eyes). This occurs because the lenses and mirrors deflect the rays
coming from the objects, so that our eyes cannot see the objects distinctly 143
except by making the adjustments necessary for looking towards the
points in question.[1] This will readily be known by those who take the
trouble to examine the matter. In the same way they will see how far the 144
ancients went wrong in their catoptrics when they tried to determine the
location of the images in concave and convex mirrors. It must also be
noted that all our methods for recognizing distance are highly unreliable.
For the shape of the eye undergoes hardly any perceptible variation when
the object is more than four or five feet away, and even when the object is
nearer the shape varies so little that no very precise knowledge can be
obtained from it. And if one is looking at an object at all far away, there
is also hardly any variation in the angles between the line joining the two
eyes (or two positions of the same eye) and the lines from the eyes to the
object. As a consequence, even our 'common' sense seems incapable of
receiving in itself the idea of a distance greater than approximately one or
two hundred feet. This can be verified in the case of the moon and the
sun. Although they are among the most distant bodies that we can see,
and their diameters are to their distances roughly as one to a hundred,
they normally appear to us as at most only one or two feet in diameter –
although we know very well by reason that they are extremely large and
extremely far away. This does not happen because we cannot conceive
them as any larger, seeing that we easily conceive towers and mountains
which are much larger. It happens, rather, because we cannot conceive
them as more than one or two hundred feet away, and consequently their
diameters cannot appear to us to be more than one or two feet. The

1 A diagram is omitted here, and the text is slightly condensed.

145 position of these bodies also helps to mislead us. For usually, when they are very high in the sky at midday, they seem smaller than they do when they are rising or setting, and we can notice their distance more easily because there are various objects between them and our eyes. And, by measuring them with their instruments, the astronomers prove clearly that they appear larger at one time than at another not because they are seen to subtend a greater angle, but because they are judged to be farther away. It follows that the axiom of the ancient optics – which says that the apparent size of objects is proportional to the size of the angle of vision – is not always true. We are also deceived because white or luminous bodies, and generally all those which have a great power to stimulate the sense of sight, always appear just a little nearer and larger than they would if they had less such power. The reason why such bodies appear nearer is that the movement with which the pupil contracts to avoid their strong light is so connected with the movement which disposes the whole eye to see near objects distinctly – a movement by which we judge the distance of such objects – that the one hardly ever takes place without the other occurring to some extent as well. (In the same way, we cannot fully close the first two fingers of our hand without the third bending a little too, as if to close with the others.) The reason why these white or
146 luminous bodies appear larger is not only that our estimation of their size depends on that of their distance, but also that they impress larger images on the back of the eye. For it must be noted that the back of the eye is covered by the ends of optic nerve-fibres which, though very small, still have some size. Thus each of them may be affected in one of its parts by one object and in other parts by other objects. But it is capable of being moved in only a single way at any given time; so when the smallest of its parts is affected by some very brilliant object, and the others by different objects that are less brilliant, the whole of it moves in accordance with the most brilliant object, presenting its image but not that of the others. Thus, suppose the ends of these little fibres are 1, 2, 3 [Fig. 10] and the rays which come, for example, from a star to trace an image on the back of the eye are spread over 1, and also slightly beyond over the six nerve-endings marked 2 (which I suppose are reached by no other rays

Fig. 10

except very weak ones from regions of the sky next to the star). In this case the image of the star will be spread over the whole area occupied by the six nerve-endings marked 2 and may even spread throughout that occupied by the twelve marked 3 if the disturbance is strong enough to be propagated to them as well. So you can see that the stars, while appearing rather small, nevertheless appear much larger than their extreme distance should cause them to appear. And even if they were not perfectly round, they could not fail to appear so – just as a square tower seen from afar 147
looks round, and all bodies that trace only very small images in the eye cannot trace there the shapes of their angles. Finally, as regards judgement of distance by size, shape, colour, or light, pictures drawn in perspective show how easy it is to make mistakes. For often the things depicted in such pictures appear to us to be farther off than they are because they are smaller, while their outlines are more blurred, and their colours darker or fainter, than we imagine they ought to be.[1]

1 The contents of the rest of the *Optics*, and of the *Meteorology* and the *Geometry*, are as follows:

Optics

Discourse Seven: The means of perfecting vision
Discourse Eight: The shapes that the transparent bodies must have in order to deflect rays through refraction in all the ways which are useful to vision
Discourse Nine: The description of telescopes
Discourse Ten: The method of cutting lenses

Meteorology

Discourse 1: The nature of terrestrial bodies
Discourse 2: Vapours and exhalations
Discourse 3: Salt
Discourse 4: Winds
Discourse 5: Clouds
Discourse 6: Snow, rain and hail
Discourse 7: Storms, lightning and all the other fires that blaze in the air
Discourse 8: The rainbow
Discourse 9: The colours of clouds and the circles or coronas that we sometimes see around the heavenly bodies
Discourse 10: The appearance of many suns

Geometry

Book 1: Problems that can be solved by constructions using only circles and straight lines
Book 2: The nature of curved lines
Book 3: Problems requiring the construction of solids and supersolids