Leonardo da Vinci

The Notebooks of Leonardo da Vinci – Complete

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The Notebooks of Leonardo Da Vinci – Complete:

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Leonardo da Vinci
The Notebooks of Leonardo Da Vinci – Complete

The Notebooks of Leonardo Da Vinci Volume 1

Translated by Jean Paul Richter

1888

PREFACE

A singular fatality has ruled the destiny of nearly all the most famous of Leonardo da Vinci's works. Two of the three most important were never completed, obstacles having arisen during his life-time, which obliged him to leave them unfinished; namely the Sforza Monument and the Wall-painting of the Battle of Anghiari, while the third—the picture of the Last Supper at Milan—has suffered irremediable injury from decay and the repeated restorations to which it was recklessly subjected during the XVIIth and XVIIIth centuries. Nevertheless, no other picture of the Renaissance has become so wellknown and popular through copies of every description.

Vasari says, and rightly, in his Life of Leonardo, "that he laboured much more by his word than in fact or by deed", and the biographer evidently had in his mind the numerous works in Manuscript which have been preserved to this day. To us, now, it seems almost inexplicable that these valuable and interesting original texts should have remained so long unpublished, and indeed forgotten. It is certain that during the XVIth and XVIIth centuries their exceptional value was highly appreciated. This is proved not merely by the prices which they commanded, but also by the exceptional interest which has been attached to the change of ownership of merely a few pages of Manuscript.

That, notwithstanding this eagerness to possess the

Manuscripts, their contents remained a mystery, can only be accounted for by the many and great difficulties attending the task of deciphering them. The handwriting is so peculiar that it requires considerable practice to read even a few detached phrases, much more to solve with any certainty the numerous difficulties of alternative readings, and to master the sense as a connected whole. Vasari observes with reference to Leonardos writing: "he wrote backwards, in rude characters, and with the left hand, so that any one who is not practised in reading them, cannot understand them". The aid of a mirror in reading reversed handwriting appears to me available only for a first experimental reading. Speaking from my own experience, the persistent use of it is too fatiguing and inconvenient to be practically advisable, considering the enormous mass of Manuscripts to be deciphered. And as, after all, Leonardo's handwriting runs backwards just as all Oriental character runs backwards—that is to say from right to left—the difficulty of reading direct from the writing is not insuperable. This obvious peculiarity in the writing is not, however, by any means the only obstacle in the way of mastering the text. Leonardo made use of an orthography peculiar to himself; he had a fashion of amalgamating several short words into one long one, or, again, he would quite arbitrarily divide a long word into two separate halves; added to this there is no punctuation whatever to regulate the division and construction of the sentences, nor are there any accents—and the reader may imagine that such difficulties were almost sufficient to make the task seem a desperate one to a beginner. It is therefore not surprising that the good intentions of some of Leonardo s most reverent admirers should have failed.

Leonardos literary labours in various departments both of Art and of Science were those essentially of an enquirer, hence the analytical method is that which he employs in arguing out his investigations and dissertations. The vast structure of his scientific theories is consequently built up of numerous separate researches, and it is much to be lamented that he should never have collated and arranged them. His love for detailed research—as it seems to me—was the reason that in almost all the Manuscripts, the different paragraphs appear to us to be in utter confusion; on one and the same page, observations on the most dissimilar subjects follow each other without any connection. A page, for instance, will begin with some principles of astronomy, or the motion of the earth; then come the laws of sound, and finally some precepts as to colour. Another page will begin with his investigations on the structure of the intestines, and end with philosophical remarks as to the relations of poetry to painting; and so forth.

Leonardo himself lamented this confusion, and for that reason I do not think that the publication of the texts in the order in which they occur in the originals would at all fulfil his intentions. No reader could find his way through such a labyrinth; Leonardo himself could not have done it.

Added to this, more than half of the five thousand manuscript pages which now remain to us, are written on loose leaves, and at present arranged in a manner which has no justification beyond the fancy of the collector who first brought them together to make volumes of more or less extent. Nay, even in the volumes, the pages of which were numbered by Leonardo himself, their order, so far as the connection of the texts was concerned, was obviously a matter of indifference to him. The only point he seems to have kept in view, when first writing down his notes, was that each observation should be complete to the end on the page on which it was begun. The exceptions to this rule are extremely few, and it is certainly noteworthy that we find in such cases, in bound volumes with his numbered pages, the written observations: "turn over", "This is the continuation of the previous page", and the like. Is not this sufficient to prove that it was only in quite exceptional cases that the writer intended the consecutive pages to remain connected, when he should, at last, carry out the often planned arrangement of his writings?

What this final arrangement was to be, Leonardo has in most cases indicated with considerable completeness. In other cases this authoritative clue is wanting, but the difficulties arising from this are not insuperable; for, as the subject of the separate paragraphs is always distinct and well defined in itself, it is quite possible to construct a well-planned whole, out of the scattered materials of his scientific system, and I may venture to state that I have devoted especial care and thought to the due execution of this responsible task.

The beginning of Leonardo's literary labours dates from about his thirty-seventh year, and he seems to have carried them on without any serious interruption till his death. Thus the Manuscripts that remain represent a period of about thirty years. Within this space of time his handwriting altered so little that it is impossible to judge from it of the date of any particular text. The exact dates, indeed, can only be assigned to certain note-books in which the year is incidentally indicated, and in which the order of the leaves has not been altered since Leonardo used them. The assistance these afford for a chronological arrangement of the Manuscripts is generally self evident. By this clue I have assigned to the original Manuscripts now scattered through England, Italy and France, the order of their production, as in many matters of detail it is highly important to be able to verify the time and place at which certain observations were made and registered. For this purpose the Bibliography of the Manuscripts given at the end of Vol. II, may be regarded as an Index, not far short of complete, of all Leonardo s literary works now extant. The consecutive numbers (from 1 to 1566) at the head of each passage in this work, indicate their logical sequence with reference to the subjects; while the letters and figures to the left of each paragraph refer to the original Manuscript and number of the page, on which that particular passage is to be found. Thus the reader, by referring to the List of Manuscripts at the beginning of Volume I, and to the Bibliography at the end of Volume II, can, in every instance, easily ascertain, not merely the period to which the passage belongs, but also exactly where it stood in the original document. Thus, too, by following the sequence of the numbers in the Bibliographical index, the reader may reconstruct the original order of the Manuscripts and recompose the various texts to be found on the original sheets—so much of it, that is to say, as by its subject-matter came within the scope of this work. It may, however, be here observed that Leonardo s Manuscripts contain, besides the passages here printed, a great number of notes and dissertations on Mechanics, Physics, and some other subjects, many of which could only be satisfactorily dealt with by specialists. I have given as complete a review of these writings as seemed necessary in the Bibliographical notes.

In 1651, Raphael Trichet Dufresne, of Paris, published a selection from Leonardo's writings on painting, and this treatise became so popular that it has since been reprinted about two-and-twenty times, and in six different languages. But none of these editions were derived from the original texts, which were supposed to have been lost, but from early copies, in which Leonardo's text had been more or less mutilated, and which were all fragmentary. The oldest and on the whole the best copy of Leonardo's essays and precepts on Painting is in the Vatican Library; this has been twice printed, first by Manzi, in 1817, and secondly by Ludwig, in 1882. Still, this ancient copy, and the published editions of it, contain much for which it would be rash to hold Leonardo responsible, and some portions—such as the very important rules for the proportions of the human figure

—are wholly wanting; on the other hand they contain passages which, if they are genuine, cannot now be verified from any original Manuscript extant. These copies, at any rate neither give us the original order of the texts, as written by Leonardo, nor do they afford any substitute, by connecting them on a rational scheme; indeed, in their chaotic confusion they are anything rather than satisfactory reading. The fault, no doubt, rests with the compiler of the Vatican copy, which would seem to be the source whence all the published and extensively known texts were derived; for, instead of arranging the passages himself, he was satisfied with recording a suggestion for a final arrangement of them into eight distinct parts, without attempting to carry out his scheme. Under the mistaken idea that this plan of distribution might be that, not of the compiler, but of Leonardo himself, the various editors, down to the present day, have very injudiciously continued to adopt this order—or rather disorder.

I, like other enquirers, had given up the original Manuscript of the Trattato della Pittura for lost, till, in the beginning of 1880, I was enabled, by the liberality of Lord Ashburnham, to inspect his Manuscripts, and was so happy as to discover among them the original text of the best-known portion of the Trattato in his magnificent library at Ashburnham Place. Though this discovery was of a fragment only—but a considerable fragment—inciting me to further search, it gave the key to the mystery which had so long enveloped the first origin of all the known copies of the Trattato. The extensive researches I was subsequently enabled to prosecute, and the results of which are combined in this work, were only rendered possible by the unrestricted permission granted me to investigate all the Manuscripts by Leonardo dispersed throughout Europe, and to reproduce the highly important original sketches they contain, by the process of "photogravure". Her Majesty the Queen graciously accorded me special permission to copy for publication the Manuscripts at the Royal Library at Windsor. The Commission Centrale Administrative de l'Institut de France, Paris, gave me, in the most liberal manner, in answer to an application from Sir Frederic Leighton, P. R. A., Corresponding member of the Institut, free permission to work for several months in their private collection at deciphering the Manuscripts preserved there. The same favour which Lord Ashburnham had already granted me was extended to me by the Earl of Leicester, the Marchese Trivulsi, and the Curators of the Ambrosian Library at Milan, by the Conte Manzoni at Rome and by other private owners of Manuscripts of Leonardo's; as also by the Directors of the Louvre at Paris; the Accademia at Venice; the Uffizi at Florence; the Royal Library at Turin; and the British Museum, and the South Kensington Museum. I am also greatly indebted to the Librarians of these various collections for much assistance in my labours; and more particularly to Monsieur Louis Lalanne, of the Institut de France, the Abbate Ceriani, of the Ambrosian Library, Mr. Maude Thompson, Keeper of Manuscripts at the British Museum, Mr. Holmes, the Queens Librarian at Windsor, the Revd Vere Bayne, Librarian of Christ Church College at Oxford, and the Revd A. Napier, Librarian to the Earl of Leicester at Holkham Hall.

In correcting the Italian text for the press, I have had the advantage of valuable advice from the Commendatore Giov. Morelli, Senatore del Regno, and from Signor Gustavo Frizzoni, of Milan. The translation, under many difficulties, of the Italian text into English, is mainly due to Mrs. R. C. Bell; while the rendering of several of the most puzzling and important passages, particularly in the second half of Vol. I, I owe to the indefatigable interest taken in this work by Mr. E. J. Poynter R. A. Finally I must express my thanks to Mr. Alfred Marks, of Long Ditton, who has most kindly assisted me throughout in the revision of the proof sheets.

The notes and dissertations on the texts on Architecture in Vol. II I owe to my friend Baron Henri de Geymuller, of Paris.

I may further mention with regard to the illustrations, that the negatives for the production of the "photo-gravures" by Monsieur Dujardin of Paris were all taken direct from the originals.

It is scarcely necessary to add that most of the drawings here reproduced in facsimile have never been published before. As I am now, on the termination of a work of several years' duration, in a position to review the general tenour of Leonardos writings, I may perhaps be permitted to add a word as to my own estimate of the value of their contents. I have already shown that it is due to nothing but a fortuitous succession of unfortunate circumstances, that we should not, long since, have known Leonardo, not merely as a Painter, but as an Author, a Philosopher, and a Naturalist. There can be no doubt that in more than one department his principles and discoveries were infinitely more in accord with the teachings of modern science, than with the views of his contemporaries. For this reason his extraordinary gifts and merits are far more likely to be appreciated in our own time than they could have been during the preceding centuries. He has been unjustly accused of having squandered his powers, by beginning a variety of studies and then, having hardly begun, throwing them aside. The truth is that the labours of three centuries have hardly sufficed for the elucidation of some of the problems which occupied his mighty mind.

Alexander von Humboldt has borne witness that "he was the first to start on the road towards the point where all the impressions of our senses converge in the idea of the Unity of Nature" Nay, yet more may be said. The very words which are inscribed on the monument of Alexander von Humboldt himself, at Berlin, are perhaps the most appropriate in which we can sum up our estimate of Leonardo's genius:

"Majestati naturae par ingenium."

LONDON, April 1883.

F. P. R.

The author's intention to publish his MSS

1

How by a certain machine many may stay some time under water. And how and wherefore I do not describe my method of remaining under water and how long I can remain without eating. And I do not publish nor divulge these, by reason of the evil nature of men, who would use them for assassinations at the bottom of the sea by destroying ships, and sinking them, together with the men in them. Nevertheless I will impart others, which are not dangerous because the mouth of the tube through which you breathe is above the water, supported on air sacks or cork.

[Footnote: The leaf on which this passage is written, is headed with the words *Casi* 39, and most of these cases begin with the word '*Come*', like the two here given, which are the 26th and 27th. 7. *Sughero*. In the Codex Antlanticus 377a; 1170a there is a sketch, drawn with the pen, representing a man with a tube in his mouth, and at the farther end of the tube a disk. By the tube the word '*Channa*' is written, and by the disk the word '*sughero*'.]

The preparation of the MSS. for publication.

2

When you put together the science of the motions of water, remember to include under each proposition its application and use, in order that this science may not be useless.—

[Footnote: A comparatively small portion of Leonardo's notes on water-power was published at Bologna in 1828, under the title: "*Del moto e misura dell'Acqua, di L. da Vinci*".]

Admonition to readers.

3

Let no man who is not a Mathematician read the elements of my work.

The disorder in the MSS.

4

Begun at Florence, in the house of Piero di Braccio Martelli, on the 22nd day of March 1508. And this is to be a collection without order, taken from many papers which I have copied here, hoping to arrange them later each in its place, according to the subjects of which they may treat. But I believe that before I am at the end of this [task] I shall have to repeat the same things several times; for which, O reader! do not blame me, for the subjects are many and memory cannot retain them [all] and say: 'I will not write this because I wrote it before.' And if I wished to avoid falling into this fault, it would be necessary in every case when I wanted to copy [a passage] that, not to repeat myself, I should read over all that had gone before; and all the more since the intervals are long between one time of writing and the next.

> [Footnote: 1. In the history of Florence in the early part of the XVIth century *Piero di Braccio Martelli* is frequently mentioned as *Commissario della Signoria*. He was famous for his learning and at his death left four books on Mathematics ready for the press; comp. LITTA, *Famiglie celebri Italiane*, *Famiglia Martelli di Firenze*.— In the Official Catalogue of MSS. in the Brit. Mus., New Series Vol. I., where this passage is printed, *Barto* has been wrongly given for Braccio.

2. *addi 22 di marzo 1508*. The Christian era was computed

in Florence at that time from the Incarnation (Lady day, March 25th). Hence this should be 1509 by our reckoning.

3. *racolto tratto di molte carte le quali io ho qui copiate*. We must suppose that Leonardo means that he has copied out his own MSS. and not those of others. The first thirteen leaves of the MS. in the Brit. Mus. are a fair copy of some notes on physics.]

Suggestions for the arrangement of MSS treating of particular subjects.(5-8).

5

Of digging a canal. Put this in the Book of useful inventions and in proving them bring forward the propositions already proved. And this is the proper order; since if you wished to show the usefulness of any plan you would be obliged again to devise new machines to prove its utility and thus would confuse the order of the forty Books and also the order of the diagrams; that is to say you would have to mix up practice with theory, which would produce a confused and incoherent work.

6

I am not to blame for putting forward, in the course of my work on science, any general rule derived from a previous conclusion.

7

The Book of the science of Mechanics must precede the Book of useful inventions.—Have your books on anatomy bound! [Footnote: 4. The numerous notes on anatomy written on loose leaves and now in the Royal collection at Windsor can best be classified in four Books, corresponding to the different character and size of the paper. When Leonardo speaks of '*li tua libri di notomia*', he probably means the MSS. which still exist; if this hypothesis is correct the present condition of these leaves might seem to prove that he only carried out his purpose with one of the Books on anatomy. A borrowed book on Anatomy is mentioned in F.O.]

8

The order of your book must proceed on this plan: first simple beams, then (those) supported from below, then suspended in part, then wholly [suspended]. Then beams as supporting other weights [Footnote: 4. Leonardo's notes on Mechanics are extraordinarily numerous; but, for the reasons assigned in my introduction, they have not been included in the present work.].

General introductions to the book on Painting (9-13).

INTRODUCTION.

Seeing that I can find no subject specially useful or pleasing —since the men who have come before me have taken for their own every useful or necessary theme—I must do like one who, being poor, comes last to the fair, and can find no other way of providing himself than by taking all the things already seen by other buyers, and not taken but refused by reason of their lesser value. I, then, will load my humble pack with this despised and rejected merchandise, the refuse of so many buyers; and will go about to distribute it, not indeed in great cities, but in the poorer towns, taking such a price as the wares I offer may be worth. [Footnote: It need hardly be pointed out that there is in this 'Proemio' a covert irony. In the second and third prefaces, Leonardo characterises his rivals and opponents more closely. His protest is directed against Neo-latinism as professed by most of the humanists of his time; its futility is now no longer questioned.]

INTRODUCTION.

I know that many will call this useless work [Footnote: 3. questa essere opera inutile. By opera we must here understand libro di pittura and particularly the treatise on Perspective.]; and they will be those of whom Demetrius [Footnote: 4. Demetrio. "With regard to the passage attributed to Demetrius", Dr. H. MÜLLER STRÜBING writes, "I know not what to make of it. It is certainly not Demetrius Phalereus that is meant and it can hardly be Demetrius Poliorcetes. Who then can it be—for the name is a very common one? It may be a clerical error for Demades and the maxim is quite in the spirit of his writings I have not however been able to find any corresponding passage either in the 'Fragments' (C. MULLER, *Orat. Att.*, II. 441) nor in the Supplements collected by DIETZ (*Rhein. Mus.*, vol. 29, p. 108)."

The same passage occurs as a simple Memorandum in the MS. Tr. 57, apparently as a note for this '*Proemio*' thus affording some data as to the time where these introductions were written.] declared that he took no more account of the wind that came out their mouth in words, than of that they expelled from their lower parts: men who desire nothing but material riches and are absolutely devoid of that of wisdom, which is the food and the only true riches of the mind. For so much more worthy as the soul is than the body, so much more noble are the possessions of the soul than those of the body. And often, when I see one of these men take this work in his hand, I wonder that he does not put it to his nose, like a monkey, or ask me if it is something good to eat.

[Footnote: In the original, the Proemio dĕ prospettiva cioč dell'uffitio dell'occhio (see No. 21) stands between this and the preceding one, No. 9.]

INTRODUCTION.

I am fully concious that, not being a literary man, certain presumptuous persons will think that they may reasonably blame me; alleging that I am not a man of letters. Foolish folks! do they not know that I might retort as Marius did to the Roman Patricians [Footnote 21: *Come Mario disse ai patriti Romani*. "I am unable to find the words here attributed by Leonardo to Marius, either in Plutarch's Life of Marius or in the Apophthegmata (*Moralia*, p.202). Nor do they occur in the writings of Valerius Maximus (who frequently mentions Marius) nor in Velleius Paterculus (II, 11 to 43), Dio Cassius, Aulus Gellius, or Macrobius. Professor E. MENDELSON of Dorpat, the editor of Herodian, assures me that no such passage is the found in that author" (communication from Dr. MULLER STRUBING). Leonardo evidently meant to allude to some well known incident in Roman history and the mention of Marius is the result probably of some confusion. We may perhaps read, for Marius, Menenius Agrippa, though in that case it is true we must alter Patriti to Plebei. The change is a serious one. but it would render the passage perfectly clear.] by saying: That they, who deck themselves out in the labours of others will not allow me my own. They will say that I, having no literary skill, cannot properly express that which I desire to treat of [Footnote 26: *le mie cose .... che d'altra parola*. This can hardly be reconciled with Mons. RAVAISSON'S estimate of L. da Vinci's learning. "*Leonard de Vinci etait un admirateur et un disciple des anciens, aussi bien dans l'art que dans la science et il tenait a passer pour tel meme aux yeux de la posterite.*" _Gaz. des Beaux arts. Oct. 1877.]; but they do not know that my subjects are to be dealt with by experience rather than by words [Footnote 28: See Footnote 26]; and [experience] has been the mistress of those who wrote well. And so, as mistress, I will cite her in all cases.

11

Though I may not, like them, be able to quote other authors, I shall rely on that which is much greater and more worthy:—on experience, the mistress of their Masters. They go about puffed up and pompous, dressed and decorated with [the fruits], not of their own labours, but of those of others. And they will not allow me my own. They will scorn me as an inventor; but how much more might they—who are not inventors but vaunters and declaimers of the works of others—be blamed.

INTRODUCTION.

And those men who are inventors and interpreters between Nature and Man, as compared with boasters and declaimers of the works of others, must be regarded and not otherwise esteemed than as the object in front of a mirror, when compared with its image seen in the mirror. For the first is something in itself, and the other nothingness.—Folks little indebted to Nature, since it is only by chance that they wear the human form and without it I might class them with the herds of beasts.

12

Many will think they may reasonably blame me by alleging that my proofs are opposed to the authority of certain men held in the highest reverence by their inexperienced judgments; not considering that my works are the issue of pure and simple experience, who is the one true mistress. These rules are sufficient to enable you to know the true from the false—and this aids men to look only for things that are possible and with due moderation—and not to wrap yourself in ignorance, a thing which can have no good result, so that in despair you would give yourself up to melancholy.

13

Among all the studies of natural causes and reasons Light chiefly delights the beholder; and among the great features of Mathematics the certainty of its demonstrations is what preeminently (tends to) elevate the mind of the investigator. Perspective, therefore, must be preferred to all the discourses and systems of human learning. In this branch [of science] the beam of light is explained on those methods of demonstration which form the glory not so much of Mathematics as of Physics and are graced with the flowers of both [Footnote: 5. Such of Leonardo's notes on Optics or on Perspective as bear exclusively on Mathematics or Physics could not be included in the arrangement of the *libro di pittura* which is here presented to the reader. They are however but few.]. But its axioms being laid down at great length, I shall abridge them to a conclusive brevity, arranging them on the method both of their natural order and of mathematical demonstration; sometimes by deduction of the effects from the causes, and sometimes arguing the causes from the effects; adding also to my own conclusions some which, though not included in them, may nevertheless be inferred from them. Thus, if the Lord—who is the light of all things—vouchsafe to enlighten me, I will treat of Light; wherefore I will divide the present work into 3 Parts [Footnote: 10. In the middle ages—for instance, by ROGER BACON, by VITELLONE, with whose works Leonardo was certainly familiar, and by all the writers of the Renaissance Perspective and Optics were not regarded as distinct sciences. Perspective, indeed, is in its widest application the science of seeing. Although to Leonardo the two sciences were clearly separate, it is not so as to their names; thus we find axioms in Optics under the heading Perspective. According to this arrangement of the materials for the theoretical portion of the *libro di pittura* propositions in Perspective and in Optics stand side by side or occur alternately. Although this particular chapter deals only with Optics, it is not improbable that the words *partirň la presente opera in 3 parti* may refer to the same division into three sections which is spoken of in chapters 14 to 17.].

The plan of the book on Painting (14—17).

14

ON THE THREE BRANCHES OF PERSPECTIVE.

There are three branches of perspective; the first deals with the reasons of the (apparent) diminution of objects as they recede from the eye, and is known as Diminishing Perspective.—The second contains the way in which colours vary as they recede from the eye. The third and last is concerned with the explanation of how the objects [in a picture] ought to be less finished in proportion as they are remote (and the names are as follows):

Linear Perspective. The Perspective of Colour. The Perspective of Disappearance.

[Footnote: 13. From the character of the handwriting I infer that this passage was written before the year 1490.].

15

ON PAINTING AND PERSPECTIVE.

The divisions of Perspective are 3, as used in drawing; of these, the first includes the diminution in size of opaque objects; the second treats of the diminution and loss of outline in such opaque objects; the third, of the diminution and loss of colour at long distances.

[Footnote: The division is here the same as in the previous chapter No. 14, and this is worthy of note when we connect it with the fact that a space of about 20 years must have intervened between the writing of the two passages.]

16

THE DISCOURSE ON PAINTING.

Perspective, as bearing on drawing, is divided into three principal sections; of which the first treats of the diminution in the size of bodies at different distances. The second part is that which treats of the diminution in colour in these objects. The third [deals with] the diminished distinctness of the forms and outlines displayed by the objects at various distances.

17

ON THE SECTIONS OF [THE BOOK ON] PAINTING.

The first thing in painting is that the objects it represents should appear in relief, and that the grounds surrounding them at different distances shall appear within the vertical plane of the foreground of the picture by means of the 3 branches of Perspective, which are: the diminution in the distinctness of the forms of the objects, the diminution in their magnitude; and the diminution in their colour. And of these 3 classes of Perspective the first results from [the structure of] the eye, while the other two are caused by the atmosphere which intervenes between the eye and the objects seen by it. The second essential in painting is appropriate action and a due variety in the figures, so that the men may not all look like brothers, &c.

[Footnote: This and the two foregoing chapters must have been written in 1513 to 1516. They undoubtedly indicate the scheme which Leonardo wished to carry out in arranging his researches on Perspective as applied to Painting. This is important because it is an evidence against the supposition of H. LUDWIG and others, that Leonardo had collected his principles of Perspective in one book so early as before 1500; a Book which, according to the hypothesis, must have been lost at a very early period, or destroyed possibly, by the French (!) in 1500 (see H.

LUDWIG. L. da Vinci: *Das Buch van der Malerei*. Vienna 1882 III, 7 and 8).]

The use of the book on Painting.

18

These rules are of use only in correcting the figures; since every man makes some mistakes in his first compositions and he who knows them not, cannot amend them. But you, knowing your errors, will correct your works and where you find mistakes amend them, and remember never to fall into them again. But if you try to apply these rules in composition you will never make an end, and will produce confusion in your works.

These rules will enable you to have a free and sound judgment; since good judgment is born of clear understanding, and a clear understanding comes of reasons derived from sound rules, and sound rules are the issue of sound experience—the common mother of all the sciences and arts. Hence, bearing in mind the precepts of my rules, you will be able, merely by your amended judgment, to criticise and recognise every thing that is out of proportion in a work, whether in the perspective or in the figures or any thing else.

Necessity of theoretical knowledge (19. 20).

19

OF THE MISTAKES MADE BY THOSE WHO PRACTISE WITHOUT KNOWLEDGE.

Those who are in love with practice without knowledge are like the sailor who gets into a ship without rudder or compass and who never can be certain whether he is going. Practice must always be founded on sound theory, and to this Perspective is the guide and the gateway; and without this nothing can be done well in the matter of drawing.

20

The painter who draws merely by practice and by eye, without any reason, is like a mirror which copies every thing placed in front of it without being conscious of their existence.

The function of the eye (21-23).

21

INTRODUCTION TO PERSPECTIVE:—THAT IS OF THE FUNCTION OF THE EYE.

Behold here O reader! a thing concerning which we cannot trust our forefathers, the ancients, who tried to define what the Soul and Life are—which are beyond proof, whereas those things, which can at any time be clearly known and proved by experience, remained for many ages unknown or falsely understood. The eye, whose function we so certainly know by experience, has, down to my own time, been defined by an infinite number of authors as one thing; but I find, by experience, that it is quite another. [Footnote 13: Compare the note to No. 70.]

[Footnote: In section 13 we already find it indicated that the study of Perspective and of Optics is to be based on that of the functions of the eye. Leonardo also refers to the science of the eye, in his astronomical researches, for instance in MS. F 25b '*Ordine del provare la terra essere una stella: Imprima difinisce l'occhio'*, &c. Compare also MS. E 15b and F 60b. The principles of astronomical perspective.]

22

Here [in the eye] forms, here colours, here the character of every part of the universe are concentrated to a point; and that point is so marvellous a thing … Oh! marvellous, O stupendous Necessity—by thy laws thou dost compel every effect to be the direct result of its cause, by the shortest path. These [indeed] are miracles;…

In so small a space it can be reproduced and rearranged in its whole expanse. Describe in your anatomy what proportion there is between the diameters of all the images in the eye and the distance from them of the crystalline lens.

23

OF THE 10 ATTRIBUTES OF THE EYE, ALL CONCERNED IN PAINTING.

Painting is concerned with all the 10 attributes of sight; which are:—Darkness, Light, Solidity and Colour, Form and Position, Distance and Propinquity, Motion and Rest. This little work of mine will be a tissue [of the studies] of these attributes, reminding the painter of the rules and methods by which he should use his art to imitate all the works of Nature which adorn the world.

24

ON PAINTING.

Variability of the eye.

1st. The pupil of the eye contracts, in proportion to the increase of light which is reflected in it. 2nd. The pupil of the eye expands in proportion to the diminution in the day light, or any other light, that is reflected in it. 3rd. [Footnote: 8. The subject of this third proposition we find fully discussed in MS. G. 44a.]. The eye perceives and recognises the objects of its vision with greater intensity in proportion as the pupil is more widely dilated; and this can be proved by the case of nocturnal animals, such as cats, and certain birds—as the owl and others—in which the pupil varies in a high degree from large to small, &c., when in the dark or in the light. 4th. The eye [out of doors] in an illuminated atmosphere sees darkness behind the windows of houses which [nevertheless] are light. 5th. All colours when placed in the shade appear of an equal degree of darkness, among themselves. 6th. But all colours when placed in a full light, never vary from their true and essential hue.

25

OF THE EYE.

Focus of sight.

If the eye is required to look at an object placed too near to it, it cannot judge of it well—as happens to a man who tries to see the tip of his nose. Hence, as a general rule, Nature teaches us that an object can never be seen perfectly unless the space between it and the eye is equal, at least, to the length of the face.

Differences of perception by one eye and by both eyes (26-29).

26

OF THE EYE.

When both eyes direct the pyramid of sight to an object, that object becomes clearly seen and comprehended by the eyes.

27

Objects seen by one and the same eye appear sometimes large, and sometimes small.

28

The motion of a spectator who sees an object at rest often makes it seem as though the object at rest had acquired the motion of the moving body, while the moving person appears to be at rest.

ON PAINTING.

Objects in relief, when seen from a short distance with one eye, look like a perfect picture. If you look with the eye *a*, *b* at the spot *c*, this point *c* will appear to be at *d*, *f*, and if you look at it with the eye *g*, *h* will appear to be at *m*. A picture can never contain in itself both aspects.

29

Let the object in relief *t* be seen by both eyes; if you will look at the object with the right eye *m*, keeping the left eye *n* shut, the object will appear, or fill up the space, at *a*; and if you shut the right eye and open the left, the object (will occupy the) space *b*; and if you open both eyes, the object will no longer appear at *a* or *b*, but at *e*, *r*, *f*. Why will not a picture seen by both eyes produce the effect of relief, as [real] relief does when seen by both eyes; and why should a picture seen with one eye give the same effect of relief as real relief would under the same conditions of light and shade?

[Footnote: In the sketch, *m* is the left eye and *n* the right, while the text reverses this lettering. We must therefore suppose that the face in which the eyes *m* and *n* are placed is opposite to the spectator.]

30

The comparative size of the image depends on the amount of light (30-39).

The eye will hold and retain in itself the image of a luminous body better than that of a shaded object. The reason is that the eye is in itself perfectly dark and since two things that are alike cannot be distinguished, therefore the night, and other dark objects cannot be seen or recognised by the eye. Light is totally contrary and gives more distinctness, and counteracts and differs from the usual darkness of the eye, hence it leaves the impression of its image.

31

Every object we see will appear larger at midnight than at midday, and larger in the morning than at midday.

This happens because the pupil of the eye is much smaller at midday than at any other time.

32

The pupil which is largest will see objects the largest. This is evident when we look at luminous bodies, and particularly at those in the sky. When the eye comes out of darkness and suddenly looks up at these bodies, they at first appear larger and then diminish; and if you were to look at those bodies through a small opening, you would see them smaller still, because a smaller part of the pupil would exercise its function.

[Footnote: 9. *buso* in the Lomb. dialect is the same as *buco*.]

33

When the eye, coming out of darkness suddenly sees a luminous body, it will appear much larger at first sight than after long looking at it. The illuminated object will look larger and more brilliant, when seen with two eyes than with only one. A luminous object will appear smaller in size, when the eye sees it through a smaller opening. A luminous body of an oval form will appear rounder in proportion as it is farther from the eye.

34

Why when the eye has just seen the light, does the half light look dark to it, and in the same way if it turns from the darkness the half light look very bright?

35

ON PAINTING.

If the eye, when [out of doors] in the luminous atmosphere, sees a place in shadow, this will look very much darker than it really is. This happens only because the eye when out in the air contracts the pupil in proportion as the atmosphere reflected in it is more luminous. And the more the pupil contracts, the less luminous do the objects appear that it sees. But as soon as the eye enters into a shady place the darkness of the shadow suddenly seems to diminish. This occurs because the greater the darkness into which the pupil goes the more its size increases, and this increase makes the darkness seem less.

[Footnote 14: *La luce entrerŕ*. *Luce* occurs here in the sense of pupil of the eye as in no 51: C. A. 84b; 245a; I—5; and in many other places.]

36

ON PERSPECTIVE.

The eye which turns from a white object in the light of the sun and goes into a less fully lighted place will see everything as dark. And this happens either because the pupils of the eyes which have rested on this brilliantly lighted white object have contracted so much that, given at first a certain extent of surface, they will have lost more than 3/4 of their size; and, lacking in size, they are also deficient in [seeing] power. Though you might say to me: A little bird (then) coming down would see comparatively little, and from the smallness of his pupils the white might seem black! To this I should reply that here we must have regard to the proportion of the mass of that portion of the brain which is given up to the sense of sight and to nothing else. Or—to return—this pupil in Man dilates and contracts according to the brightness or darkness of (surrounding) objects; and since it takes some time to dilate and contract, it cannot see immediately on going out of the light and into the shade, nor, in the same way, out of the shade into the light, and this very thing has already deceived me in painting an eye, and from that I learnt it.

37

Experiment [showing] the dilatation and contraction of the pupil, from the motion of the sun and other luminaries. In proportion as the sky is darker the stars appear of larger size, and if you were to light up the medium these stars would look smaller; and this difference arises solely from the pupil which dilates and contracts with the amount of light in the medium which is interposed between the eye and the luminous body. Let the experiment be made, by placing a candle above your head at the same time that you look at a star; then gradually lower the candle till it is on a level with the ray that comes from the star to the eye, and then you will see the star diminish so much that you will almost lose sight of it.

[Footnote: No reference is made in the text to the letters on the accompanying diagram.]

38

The pupil of the eye, in the open air, changes in size with every degree of motion from the sun; and at every degree of its changes one and the same object seen by it will appear of a different size; although most frequently the relative scale of surrounding objects does not allow us to detect these variations in any single object we may look at.

39

The eye—which sees all objects reversed—retains the images for some time. This conclusion is proved by the results; because, the eye having gazed at light retains some impression of it. After looking (at it) there remain in the eye images of intense brightness, that make any less brilliant spot seem dark until the eye has lost the last trace of the impression of the stronger light.

II.
Linear Perspective

We see clearly from the concluding sentence of section 49, where the author directly addresses the painter, that he must certainly have intended to include the elements of mathematics in his Book on the art of Painting. They are therefore here placed at the beginning. In section 50 the theory of the "Pyramid of Sight" is distinctly and expressly put forward as the fundamental principle of linear perspective, and sections 52 to 57 treat of it fully. This theory of sight can scarcely be traced to any author of antiquity. Such passages as occur in Euclid for instance, may, it is true, have proved suggestive to the painters of the Renaissance, but it would be rash to say any thing decisive on this point.

Leon Battista Alberti treats of the "Pyramid of Sight" at some length in his first Book of Painting; but his explanation differs widely from Leonardo's in the details. Leonardo, like Alberti, may have borrowed the broad lines of his theory from some views commonly accepted among painters at the time; but he certainly worked out its application in a perfectly original manner.

The axioms as to the perception of the pyramid of rays are followed by explanations of its origin, and proofs of its universal application (58—69). The author recurs to the subject with endless variations; it is evidently of fundamental importance in his artistic theory and practice. It is unnecessary to discuss how far this theory has any scientific value at the present day; so much as this, at any rate, seems certain: that from the artist's point of view it may still claim to be of immense practical utility.

According to Leonardo, on one hand, the laws of perspective are an inalienable condition of the existence of objects in space; on the other hand, by a natural law, the eye, whatever it sees and wherever it turns, is subjected to the perception of the pyramid of rays in the form of a minute target. Thus it sees objects in perspective independently of the will of the spectator, since the eye receives the images by means of the pyramid of rays "just as a magnet attracts iron".

In connection with this we have the function of the eye explained by the Camera obscura, and this is all the more interesting and important because no writer previous to Leonardo had treated of this subject_ (70—73). *Subsequent passages, of no less special interest, betray his knowledge of refraction and of the inversion of the image in the camera and in the eye* (74—82).

From the principle of the transmission of the image to the eye and to the camera obscura he deduces the means of producing an artificial construction of the pyramid of rays or—which is the same thing—of the image. The fundamental axioms as to the angle of sight and the vanishing point are thus presented in a manner which is as complete as it is simple and intelligible (86

—89).

Leonardo distinguishes between simple and complex perspective (90, 91). *The last sections treat of the apparent size of objects at various distances and of the way to estimate it* (92—109).

General remarks on perspective (40-41).

40

ON PAINTING.

Perspective is the best guide to the art of Painting.

[Footnote: 40. Compare 53, 2.]

41

The art of perspective is of such a nature as to make what is flat appear in relief and what is in relief flat.

The elements of perspective—Of the Point (42-46).

42

All the problems of perspective are made clear by the five terms of mathematicians, which are:—the point, the line, the angle, the superficies and the solid. The point is unique of its kind. And the point has neither height, breadth, length, nor depth, whence it is to be regarded as indivisible and as having no dimensions in space. The line is of three kinds, straight, curved and sinuous and it has neither breadth, height, nor depth. Hence it is indivisible, excepting in its length, and its ends are two points. The angle is the junction of two lines in a point.

43

A point is not part of a line.

44

OF THE NATURAL POINT.

The smallest natural point is larger than all mathematical points, and this is proved because the natural point has continuity, and any thing that is continuous is infinitely divisible; but the mathematical point is indivisible because it has no size.

[Footnote: This definition was inserted by Leonardo on a MS. copy on parchment of the well-known *"Trattato d'Architettura civile e militare"* &c. by FRANCESCO DI GIORGIO; opposite a passage where the author says: _'In prima he da sapere che punto č quella parie della quale he nulla—Linia he luncheza senza ŕpieza; &c.]

45

1, The superficies is a limitation of the body. 2, and the limitation of a body is no part of that body. 4, and the limitation of one body is that which begins another. 3, that which is not part of any body is nothing. Nothing is that which fills no space.

If one single point placed in a circle may be the starting point of an infinite number of lines, and the termination of an infinite number of lines, there must be an infinite number of points separable from this point, and these when reunited become one again; whence it follows that the part may be equal to the whole.

46

The point, being indivisible, occupies no space. That which occupies no space is nothing. The limiting surface of one thing is the beginning of another. 2. That which is no part of any body is called nothing. 1. That which has no limitations, has no form. The limitations of two conterminous bodies are interchangeably the surface of each. All the surfaces of a body are not parts of that body.

Of the line (47-48).

47

DEFINITION OF THE NATURE OF THE LINE.

The line has in itself neither matter nor substance and may rather be called an imaginary idea than a real object; and this being its nature it occupies no space. Therefore an infinite number of lines may be conceived of as intersecting each other at a point, which has no dimensions and is only of the thickness (if thickness it may be called) of one single line.

HOW WE MAY CONCLUDE THAT A SUPERFICIES TERMINATES IN A POINT?

An angular surface is reduced to a point where it terminates in an angle. Or, if the sides of that angle are produced in a straight line, then—beyond that angle—another surface is generated, smaller, or equal to, or larger than the first.

48

OF DRAWING OUTLINE.

Consider with the greatest care the form of the outlines of every object, and the character of their undulations. And these undulations must be separately studied, as to whether the curves are composed of arched convexities or angular concavities.

49

The nature of the outline.

The boundaries of bodies are the least of all things. The proposition is proved to be true, because the boundary of a thing is a surface, which is not part of the body contained within that surface; nor is it part of the air surrounding that body, but is the medium interposted between the air and the body, as is proved in its place. But the lateral boundaries of these bodies is the line forming the boundary of the surface, which line is of invisible thickness. Wherefore O painter! do not surround your bodies with lines, and above all when representing objects smaller than nature; for not only will their external outlines become indistinct, but their parts will be invisible from distance.

50

Definition of Perspective.

[Drawing is based upon perspective, which is nothing else than a thorough knowledge of the function of the eye. And this function simply consists in receiving in a pyramid the forms and colours of all the objects placed before it. I say in a pyramid, because there is no object so small that it will not be larger than the spot where these pyramids are received into the eye. Therefore, if you extend the lines from the edges of each body as they converge you will bring them to a single point, and necessarily the said lines must form a pyramid.]

[Perspective is nothing more than a rational demonstration applied to the consideration of how objects in front of the eye transmit their image to it, by means of a pyramid of lines. The *Pyramid* is the name I apply to the lines which, starting from the surface and edges of each object, converge from a distance and meet in a single point.]

[Perspective is a rational demonstration, by which we may practically and clearly understand how objects transmit their own image, by lines forming a Pyramid (centred) in the eye.]

Perspective is a rational demonstration by which experience confirms that every object sends its image to the eye by a pyramid of lines; and bodies of equal size will result in a pyramid of larger or smaller size, according to the difference in their distance, one from the other. By a pyramid of lines I mean those which start from the surface and edges of bodies, and, converging from a distance meet in a single point. A point is said to be that which [having no dimensions] cannot be divided, and this point placed in the eye receives all the points of the cone.

[Footnote: 50. 1-5. Compare with this the Proem. No. 21. The paragraphs placed in brackets: lines 1-9, 10-14, and 17—20, are evidently mere sketches and, as such, were cancelled by the writer; but they serve as a commentary on the final paragraph, lines 22-29.]

51

IN WHAT WAY THE EYE SEES OBJECTS PLACED IN FRONT OF IT.

The perception of the object depends on the direction of the eye.

Supposing that the ball figured above is the ball of the eye and let the small portion of the ball which is cut off by the line *s t* be the pupil and all the objects mirrored on the centre of the face of the eye, by means of the pupil, pass on at once and enter the pupil, passing through the crystalline humour, which does not interfere in the pupil with the things seen by means of the light. And the pupil having received the objects, by means of the light, immediately refers them and transmits them to the intellect by the line *a b*. And you must know that the pupil transmits nothing perfectly to the intellect or common sense excepting when the objects presented to it by means of light, reach it by the line *a b;* as, for instance, by the line *b c*. For although the lines *m n* and *f g* may be seen by the pupil they are not perfectly taken in, because they do not coincide with the line *a b*. And the proof is this: If the eye, shown above, wants to count the letters placed in front, the eye will be obliged to turn from letter to letter, because it cannot discern them unless they lie in the line *a b;* as, for instance, in the line *a c*. All visible objects reach the eye by the lines of a pyramid, and the point of the pyramid is the apex and centre of it, in the centre of the pupil, as figured above.

[Footnote: 51. In this problem the eye is conceived of as fixed and immovable; this is plain from line 11.]

Experimental proof of the existence of the pyramid of sight (52-55).

52

Perspective is a rational demonstration, confirmed by experience, that all objects transmit their image to the eye by a pyramid of lines.

By a pyramid of lines I understand those lines which start from the edges of the surface of bodies, and converging from a distance, meet in a single point; and this point, in the present instance, I will show to be situated in the eye which is the universal judge of all objects. By a point I mean that which cannot be divided into parts; therefore this point, which is situated in the eye, being indivisible, no body is seen by the eye, that is not larger than this point. This being the case it is inevitable that the lines which come from the object to the point must form a pyramid. And if any man seeks to prove that the sense of sight does not reside in this point, but rather in the black spot which is visible in the middle of the pupil, I might reply to him that a small object could never diminish at any distance, as it might be a grain of millet or of oats or of some similar thing, and that object, if it were larger than the said [black] spot would never be seen as a whole; as may be seen in the diagram below. Let *a*. be the seat of sight, *b e* the lines which reach the eye. Let *e d* be the grains of millet within these lines. You plainly see that these will never diminish by distance, and that the body *m n* could not be entirely covered by it. Therefore you must confess that the eye contains within itself one single indivisible point *a*, to which all the points converge of the pyramid of lines starting from an object, as is shown below. Let *a*. *b*. be the eye; in the centre of it is the point above mentioned. If the line *e f* is to enter as an image into so small an opening in the eye, you must confess that the smaller object cannot enter into what is smaller than itself unless it is diminished, and by diminishing it must take the form of a pyramid.

53

PERSPECTIVE.

Perspective comes in where judgment fails [as to the distance] in objects which diminish. The eye can never be a true judge for determining with exactitude how near one object is to another which is equal to it [in size], if the top of that other is on the level of the eye which sees them on that side, excepting by means of the vertical plane which is the standard and guide of perspective. Let *n* be the eye, *e f* the vertical plane above mentioned. Let *a b c d* be the three divisions, one below the other; if the lines *a n* and *c n* are of a given length and the eye *n* is in the centre, then *a b* will look as large as *b c. c d* is lower and farther off from *n*, therefore it will look smaller. And the same effect will appear in the three divisions of a face when the eye of the painter who is drawing it is on a level with the eye of the person he is painting.

54

TO PROVE HOW OBJECTS REACH THE EYE.

If you look at the sun or some other luminous body and then shut your eyes you will see it again inside your eye for a long time. This is evidence that images enter into the eye.

The relations of the distance points to the vanishing point (55-56).

55

ELEMENTS OF PERSPECTIVE.

All objects transmit their image to the eye in pyramids, and the nearer to the eye these pyramids are intersected the smaller will the image appear of the objects which cause them. Therefore, you may intersect the pyramid with a vertical plane [Footnote 4: *Pariete*. Compare the definitions in 85, 2-5, 6-27. These lines refer exclusively to the third diagram. For the better understanding of this it should be observed that *c s* must be regarded as representing the section or profile of a square plane, placed horizontally (comp. lines 11, 14, 17) for which the word *pianura* is subsequently employed (20, 22). Lines 6-13 contain certain preliminary observations to guide the reader in understanding the diagram; the last three seem to have been added as a supplement. Leonardo's mistake in writing *t denota* (line 6) for *f denota* has been rectified.] which reaches the base of the pyramid as is shown in the plane *a n*.

The eye *f* and the eye *t* are one and the same thing; but the eye *f* marks the distance, that is to say how far you are standing from the object; and the eye *t* shows you the direction of it; that is whether you are opposite, or on one side, or at an angle to the object you are looking at. And remember that the eye *f* and the eye *t* must always be kept on the same level. For example if you raise or lower the eye from the distance point *f* you must do the same with the direction point *t*. And if the point *f* shows how far the eye is distant from the square plane but does not show on which side it is placed—and, if in the same way, the point *t* shows the direction and not the distance, in order to ascertain both you must use both points and they will be one and the same thing. If the eye *f* could see a perfect square of which all the sides were equal to the distance between *s* and *c*, and if at the nearest end of the side towards the eye a pole were placed, or some other straight object, set up by a perpendicular line as shown at *r s*—then, I say, that if you were to look at the side of the square that is nearest to you it will appear at the bottom of the vertical plane *r s*, and then look at the farther side and it would appear to you at the height of the point *n* on the vertical plane. Thus, by this example, you can understand that if the eye is above a number of objects all placed on the same level, one beyond another, the more remote they are the higher they will seem, up to the level of the eye, but no higher; because objects placed upon the level on which your feet stand, so long as it is flat—even if it be extended into infinity—would never be seen above the eye; since the eye has in itself the point towards which all the cones tend and converge which convey the images of the objects to the eye. And this point always coincides with the point of diminution which is the extreme of all we can see. And from the base line of the first pyramid as far as the diminishing point

[Footnote: The two diagrams above the chapter are explained by the first five lines. They have, however, more letters than are referred to in the text, a circumstance we frequently find occasion to remark.]

there are only bases without pyramids which constantly diminish up to this point. And from the first base where the vertical plane is placed towards the point in the eye there will be only pyramids without bases; as shown in the example given above. Now, let *a b* be the said vertical plane and *r* the point of the pyramid terminating in the eye, and *n* the point of diminution which is always in a straight line opposite the eye and always moves as the eye moves—just as when a rod is moved its shadow moves, and moves with it, precisely as the shadow moves with a body. And each point is the apex of a pyramid, all having a common base with the intervening vertical plane. But although their bases are equal their angles are not equal, because the diminishing point is the termination of a smaller angle than that of the eye. If you ask me: "By what practical experience can you show me these points?" I reply—so far as concerns the diminishing point which moves with you —when you walk by a ploughed field look at the straight furrows which come down with their ends to the path where you are walking, and you will see that each pair of furrows will look as though they tried to get nearer and meet at the [farther] end.

[Footnote: For the easier understanding of the diagram and of its connection with the preceding I may here remark that the square plane shown above in profile by the line *c s* is here indicated by *e d o p*. According to lines 1, 3 *a b* must be imagined as a plane of glass placed perpendicularly at *o p*.]

57

How to measure the pyramid of vision.

As regards the point in the eye; it is made more intelligible by this: If you look into the eye of another person you will see your own image. Now imagine 2 lines starting from your ears and going to the ears of that image which you see in the other man's eye; you will understand that these lines converge in such a way that they would meet in a point a little way beyond your own image mirrored in the eye. And if you want to measure the diminution of the pyramid in the air which occupies the space between the object seen and the eye, you must do it according to the diagram figured below. Let *m n* be a tower, and *e f* a, rod, which you must move backwards and forwards till its ends correspond with those of the tower [Footnote 9: *I sua stremi .. della storre* (its ends … of the tower) this is the case at *e f*.]; then bring it nearer to the eye, at *c d* and you will see that the image of the tower seems smaller, as at *r o*. Then [again] bring it closer to the eye and you will see the rod project far beyond the image of the tower from *a* to *b* and from *t* to *b*, and so you will discern that, a little farther within, the lines must converge in a point.

The Production of pyramid of Vision (58-60).

58

PERSPECTIVE.

The instant the atmosphere is illuminated it will be filled with an infinite number of images which are produced by the various bodies and colours assembled in it. And the eye is the target, a loadstone, of these images.

59

The whole surface of opaque bodies displays its whole image in all the illuminated atmosphere which surrounds them on all sides.

60

That the atmosphere attracts to itself, like a loadstone, all the images of the objects that exist in it, and not their forms merely but their nature may be clearly seen by the sun, which is a hot and luminous body. All the atmosphere, which is the all-pervading matter, absorbs light and heat, and reflects in itself the image of the source of that heat and splendour and, in each minutest portion, does the same. The Northpole does the same as the loadstone shows; and the moon and the other planets, without suffering any diminution, do the same. Among terrestrial things musk does the same and other perfumes.

All bodies together, and each by itself, give off to the surrounding air an infinite number of images which are all-pervading and each complete, each conveying the nature, colour and form of the body which produces it.

It can clearly be shown that all bodies are, by their images, all-pervading in the surrounding atmosphere, and each complete in itself as to substance form and colour; this is seen by the images of the various bodies which are reproduced in one single perforation through which they transmit the objects by lines which intersect and cause reversed pyramids, from the objects, so that they are upside down on the dark plane where they are first reflected. The reason of this is—

[Footnote: The diagram intended to illustrate the statement (Pl. II No. i) occurs in the original between lines 3 and 4. The three circles must be understood to represent three luminous bodies which transmit their images through perforations in a wall into a dark chamber, according to a law which is more fully explained in 75?81. So far as concerns the present passage the diagram is only intended to explain that the images of the three bodies may be made to coalesce at any given spot. In the circles are written, giallo —yellow, biŕcho—white, rosso—red.

The text breaks off at line 8. The paragraph No.40 follows here in the original MS.]

62

Every point is the termination of an infinite number of lines, which diverge to form a base, and immediately, from the base the same lines converge to a pyramid [imaging] both the colour and form. No sooner is a form created or compounded than suddenly infinite lines and angles are produced from it; and these lines, distributing themselves and intersecting each other in the air, give rise to an infinite number of angles opposite to each other. Given a base, each opposite angle, will form a triangle having a form and proportion equal to the larger angle; and if the base goes twice into each of the 2 lines of the pyramid the smaller triangle will do the same.

63

Every body in light and shade fills the surrounding air with infinite images of itself; and these, by infinite pyramids diffused in the air, represent this body throughout space and on every side. Each pyramid that is composed of a long assemblage of rays includes within itself an infinite number of pyramids and each has the same power as all, and all as each. A circle of equidistant pyramids of vision will give to their object angles of equal size; and an eye at each point will see the object of the same size. The body of the atmosphere is full of infinite pyramids composed of radiating straight lines, which are produced from the surface of the bodies in light and shade, existing in the air; and the farther they are from the object which produces them the more acute they become and although in their distribution they intersect and cross they never mingle together, but pass through all the surrounding air, independently converging, spreading, and diffused. And they are all of equal power [and value]; all equal to each, and each equal to all. By these the images of objects are transmitted through all space and in every direction, and each pyramid, in itself, includes, in each minutest part, the whole form of the body causing it.

64

The body of the atmosphere is full of infinite radiating pyramids produced by the objects existing in it. These intersect and cross each other with independent convergence without interfering with each other and pass through all the surrounding atmosphere; and are of equal force and value—all being equal to each, each to all. And by means of these, images of the body are transmitted everywhere and on all sides, and each receives in itself every minutest portion of the object that produces it.

Proof by experiment (65-66).

65

PERSPECTIVE.

The air is filled with endless images of the objects distributed in it; and all are represented in all, and all in one, and all in each, whence it happens that if two mirrors are placed in such a manner as to face each other exactly, the first will be reflected in the second and the second in the first. The first being reflected in the second takes to it the image of itself with all the images represented in it, among which is the image of the second mirror, and so, image within image, they go on to infinity in such a manner as that each mirror has within it a mirror, each smaller than the last and one inside the other. Thus, by this example, it is clearly proved that every object sends its image to every spot whence the object itself can be seen; and the converse: That the same object may receive in itself all the images of the objects that are in front of it. Hence the eye transmits through the atmosphere its own image to all the objects that are in front of it and receives them into itself, that is to say on its surface, whence they are taken in by the common sense, which considers them and if they are pleasing commits them to the memory. Whence I am of opinion: That the invisible images in the eyes are produced towards the object, as the image of the object to the eye. That the images of the objects must be disseminated through the air. An instance may be seen in several mirrors placed in a circle, which will reflect each other endlessly. When one has reached the other it is returned to the object that produced it, and thence—being diminished—it is returned again to the object and then comes back once more, and this happens endlessly. If you put a light between two flat mirrors with a distance of 1 braccio between them you will see in each of them an infinite number of lights, one smaller than another, to the last. If at night you put a light between the walls of a room, all the parts of that wall will be tinted with the image of that light. And they will receive the light and the light will fall on them, mutually, that is to say, when there is no obstacle to interrupt the transmission of the images. This same example is seen in a greater degree in the distribution of the solar rays which all together, and each by itself, convey to the object the image of the body which causes it. That each body by itself alone fills with its images the atmosphere around it, and that the same air is able, at the same time, to receive the images of the endless other objects which are in it, this is clearly proved by these examples. And every object is everywhere visible in the whole of the atmosphere, and the whole in every smallest part of it; and all the objects in the whole, and all in each smallest part; each in all and all in every part.

66

The images of objects are all diffused through the atmosphere which receives them; and all on every side in it. To prove this, let *a c e* be objects of which the images are admitted to a dark chamber by the small holes *n p* and thrown upon the plane *f i* opposite to these holes. As many images will be produced in the chamber on the plane as the number of the said holes.

67

General conclusions.

All objects project their whole image and likeness, diffused and mingled in the whole of the atmosphere, opposite to themselves. The image of every point of the bodily surface, exists in every part of the atmosphere. All the images of the objects are in every part of the atmosphere. The whole, and each part of the image of the atmosphere is [reflected] in each point of the surface of the bodies presented to it. Therefore both the part and the whole of the images of the objects exist, both in the whole and in the parts of the surface of these visible bodies. Whence we may evidently say that the image of each object exists, as a whole and in every part, in each part and in the whole interchangeably in every existing body. As is seen in two mirrors placed opposite to each other.

That the contrary is impossible.

It is impossible that the eye should project from itself, by visual rays, the visual virtue, since, as soon as it opens, that front portion [of the eye] which would give rise to this emanation would have to go forth to the object and this it could not do without time. And this being so, it could not travel so high as the sun in a month's time when the eye wanted to see it. And if it could reach the sun it would necessarily follow that it should perpetually remain in a continuous line from the eye to the sun and should always diverge in such a way as to form between the sun and the eye the base and the apex of a pyramid. This being the case, if the eye consisted of a million worlds, it would not prevent its being consumed in the projection of its virtue; and if this virtue would have to travel through the air as perfumes do, the winds would bent it and carry it into another place. But we do [in fact] see the mass of the sun with the same rapidity as [an object] at the distance of a braccio, and the power of sight is not disturbed by the blowing of the winds nor by any other accident.

[Footnote: The view here refuted by Leonardo was maintained among others by Bramantino, Leonardo's Milanese contemporary. LOMAZZO writes as follows in his Trattato dell' Arte della pittura &c. (Milano 1584. Libr. V cp. XXI): Sovviemmi di aver giŕ letto in certi

> scritti alcune cose di Bramantino milanese, celebratissimo pittore, attenente alla prospettiva, le quali ho voluto riferire, e quasi intessere in questo luogo, affinchč sappiamo qual fosse l'opinione di cosi chiaro e famoso pittore intorno alla prospettiva . . Scrive Bramantino che la prospettiva č una cosa che contrafŕ il naturale, e che ciň si fa in tre modi

Circa il primo modo che si fa con ragione, per essere la cosa in poche parole conclusa da Bramantino in maniera che giudico non potersi dir meglio, contenendovi si tutta Parte del principio al fine, io riferirň per appunto le proprie parole sue (cp. XXII, Prima prospettiva di Bramantino). La prima prospettiva fa le cose di punto, e l'altra non mai, e la terza piů appresso. Adunque la prima si dimanda prospettiva, cioč ragione, la quale fa l'effetto dell' occhio, facendo crescere e calare secondo gli effetti degli occhi. Questo crescere e calare non procede della cosa propria, che in se per esser lontana, ovvero vicina, per quello effetto non puň crescere e sminuire, ma procede dagli effetti degli occhi, i quali sono piccioli, e perciň volendo vedere tanto gran cosa_, bisogna che mandino fuora la virtů visiva, *la quale si dilata in tanta larghezza, che piglia tutto quello che vuoi vedere, ed* arrivando a quella cosa la vede dove č: *e da lei agli occhi per quello circuito fino all' occhio, e tutto quello termine č pieno di quella cosa*.

It is worthy of note that Leonardo had made his memorandum refuting this view, at Milan in 1492]

69

A parallel case.

Just as a stone flung into the water becomes the centre and cause of many circles, and as sound diffuses itself in circles in the air: so any object, placed in the luminous atmosphere, diffuses itself in circles, and fills the surrounding air with infinite images of itself. And is repeated, the whole every-where, and the whole in every smallest part. This can be proved by experiment, since if you shut a window that faces west and make a hole [Footnote: 6. Here the text breaks off.] . .

[Footnote: Compare LIBRI, *Histoire des sciences mathématiques en Italie*. Tome III, p. 43.]

The function of the eye as explained by the camera obscura (70. 71).

If the object in front of the eye sends its image to the eye, the eye, on the other hand, sends its image to the object, and no portion whatever of the object is lost in the images it throws off, for any reason either in the eye or the object. Therefore we may rather believe it to be the nature and potency of our luminous atmosphere which absorbs the images of the objects existing in it, than the nature of the objects, to send their images through the air. If the object opposite to the eye were to send its image to the eye, the eye would have to do the same to the object, whence it might seem that these images were an emanation. But, if so, it would be necessary [to admit] that every object became rapidly smaller; because each object appears by its images in the surrounding atmosphere. That is: the whole object in the whole atmosphere, and in each part; and all the objects in the whole atmosphere and all of them in each part; speaking of that atmosphere which is able to contain in itself the straight and radiating lines of the images projected by the objects. From this it seems necessary to admit that it is in the nature of the atmosphere, which subsists between the objects, and which attracts the images of things to itself like a loadstone, being placed between them.

PROVE HOW ALL OBJECTS, PLACED IN ONE POSITION, ARE ALL EVERYWHERE AND ALL IN

EACH PART.

I say that if the front of a building—or any open piazza or field—which is illuminated by the sun has a dwelling opposite to it, and if, in the front which does not face the sun, you make a small round hole, all the illuminated objects will project their images through that hole and be visible inside the dwelling on the opposite wall which may be made white; and there, in fact, they will be upside down, and if you make similar openings in several places in the same wall you will have the same result from each. Hence the images of the illuminated objects are all everywhere on this wall and all in each minutest part of it. The reason, as we clearly know, is that this hole must admit some light to the said dwelling, and the light admitted by it is derived from one or many luminous bodies. If these bodies are of various colours and shapes the rays forming the images are of various colours and shapes, and so will the representations be on the wall.

[Footnote: 70. 15—23. This section has already been published in the "*Saggio delle Opere di Leonardo da Vinci*" Milan 1872, pp. 13, 14. G. Govi observes upon it, that Leonardo is not to be regarded as the inventor of the Camera obscura, but that he was the first to explain by it the structure of the eye. An account of the Camera obscura first occurs in CESARE CESARINI's Italian version of Vitruvius, pub. 1523, four years after Leonardo's death. Cesarini expressly names Benedettino Don Papnutio as the inventor of the Camera obscura. In his explanation of the function of the eye by a comparison with the Camera obscura Leonardo was the precursor of G. CARDANO, Professor of Medicine at Bologna (died 1576) and it appears highly probable that this is, in fact, the very discovery which Leonardo ascribes to himself in section 21 without giving any further details.]

71

HOW THE IMAGES OF OBJECTS RECEIVED BY THE EYE INTERSECT WITHIN THE CRYSTALLINE HUMOUR OF THE EYE.

An experiment, showing how objects transmit their images or pictures, intersecting within the eye in the crystalline humour, is seen when by some small round hole penetrate the images of illuminated objects into a very dark chamber. Then, receive these images on a white paper placed within this dark room and rather near to the hole and you will see all the objects on the paper in their proper forms and colours, but much smaller; and they will be upside down by reason of that very intersection. These images being transmitted from a place illuminated by the sun will seem actually painted on this paper which must be extremely thin and looked at from behind. And let the little perforation be made in a very thin plate of iron. Let *a b e d e* be the object illuminated by the sun and *o r* the front of the dark chamber in which is the said hole at *n m*. Let *s t* be the sheet of paper intercepting the rays of the images of these objects upside down, because the rays being straight, *a* on the right hand becomes *k* on the left, and *e* on the left becomes *f* on the right; and the same takes place inside the pupil.

[Footnote: This chapter is already known through a translation into French by VENTURI. Compare his '*Essai* *sur les ouvrages physico-mathématiques de L. da Vinci avec des fragments tirés de ses Manuscrits, apportés de l'Italie. Lu a la premiere classe de l'Institut national des Sciences et Arts.' Paris, An V* (1797).]

The practice of perspective (72. 73).

72

In the practice of perspective the same rules apply to light and to the eye.

73

The object which is opposite to the pupil of the eye is seen by that pupil and that which is opposite to the eye is seen by the pupil.

Refraction of the rays falling upon the eye (74. 75)

74

The lines sent forth by the image of an object to the eye do not reach the point within the eye in straight lines.

75

If the judgment of the eye is situated within it, the straight lines of the images are refracted on its surface because they pass through the rarer to the denser medium. If, when you are under water, you look at objects in the air you will see them out of their true place; and the same with objects under water seen from the air.

The intersection of the rays (76-82).

76

The inversion of the images.

All the images of objects which pass through a window [glass pane] from the free outer air to the air confined within walls, are seen on the opposite side; and an object which moves in the outer air from east to west will seem in its shadow, on the wall which is lighted by this confined air, to have an opposite motion.

77

THE PRINCIPLE ON WHICH THE IMAGES OF BODIES PASS IN BETWEEN THE MARGINS OF THE OPENINGS BY WHICH THEY ENTER.

What difference is there in the way in which images pass through narrow openings and through large openings, or in those which pass by the sides of shaded bodies? By moving the edges of the opening through which the images are admitted, the images of immovable objects are made to move. And this happens, as is shown in the 9th which demonstrates: [Footnote 11: *per la 9a che dicie*. When Leonardo refers thus to a number it serves to indicate marginal diagrams; this can in some instances be distinctly proved. The ninth sketch on the page W. L. 145 b corresponds to the middle sketch of the three reproduced.] the images of any object are all everywhere, and all in each part of the surrounding air. It follows that if one of the edges of the hole by which the images are admitted to a dark chamber is moved it cuts off those rays of the image that were in contact with it and gets nearer to other rays which previously were remote from it &c.

OF THE MOVEMENT OF THE EDGE AT THE RIGHT OR LEFT, OR THE UPPER, OR LOWER EDGE.

If you move the right side of the opening the image on the left will move [being that] of the object which entered on the right side of the opening; and the same result will happen with all the other sides of the opening. This can be proved by the 2nd of this which shows: all the rays which convey the images of objects through the air are straight lines. Hence, if the images of very large bodies have to pass through very small holes, and beyond these holes recover their large size, the lines must necessarily intersect.

[Footnote: 77. 2. In the first of the three diagrams Leonardo had drawn only one of the two margins, et *m*.]

78

Necessity has provided that all the images of objects in front of the eye shall intersect in two places. One of these intersections is in the pupil, the other in the crystalline lens; and if this were not the case the eye could not see so great a number of objects as it does. This can be proved, since all the lines which intersect do so in a point. Because nothing is seen of objects excepting their surface; and their edges are lines, in contradistinction to the definition of a surface. And each minute part of a line is equal to a point; for *smallest* is said of that than which nothing can be smaller, and this definition is equivalent to the definition of the point. Hence it is possible for the whole circumference of a circle to transmit its image to the point of intersection, as is shown in the 4th of this which shows: all the smallest parts of the images cross each other without interfering with each other. These demonstrations are to illustrate the eye. No image, even of the smallest object, enters the eye without being turned upside down; but as it penetrates into the crystalline lens it is once more reversed and thus the image is restored to the same position within the eye as that of the object outside the eye.

79

OF THE CENTRAL LINE OF THE EYE.

Only one line of the image, of all those that reach the visual virtue, has no intersection; and this has no sensible dimensions because it is a mathematical line which originates from a mathematical point, which has no dimensions.

According to my adversary, necessity requires that the central line of every image that enters by small and narrow openings into a dark chamber shall be turned upside down, together with the images of the bodies that surround it.

80

AS TO WHETHER THE CENTRAL LINE OF THE IMAGE CAN BE INTERSECTED, OR NOT, WITHIN THE OPENING.

It is impossible that the line should intersect itself; that is, that its right should cross over to its left side, and so, its left side become its right side. Because such an intersection demands two lines, one from each side; for there can be no motion from right to left or from left to right in itself without such extension and thickness as admit of such motion. And if there is extension it is no longer a line but a surface, and we are investigating the properties of a line, and not of a surface. And as the line, having no centre of thickness cannot be divided, we must conclude that the line can have no sides to intersect each other. This is proved by the movement of the line *a f* to *a b* and of the line *e b* to *e f*, which are the sides of the surface *a f e b*. But if you move the line *a b* and the line *e f*, with the frontends *a e*, to the spot *c*, you will have moved the opposite ends *f b* towards each other at the point *d*. And from the two lines you will have drawn the straight line *c d* which cuts the middle of the intersection of these two lines at the point *n* without any intersection. For, you imagine these two lines as having breadth, it is evident that by this motion the first will entirely cover the other—being equal with it—without any intersection, in the position *c d*. And this is sufficient to prove our proposition.

81

HOW THE INNUMERABLE RAYS FROM INNUMERABLE IMAGES CAN CONVERGE TO A POINT.

Just as all lines can meet at a point without interfering with each other—being without breadth or thickness—in the same way all the images of surfaces can meet there; and as each given point faces the object opposite to it and each object faces an opposite point, the converging rays of the image can pass through the point and diverge again beyond it to reproduce and re-magnify the real size of that image. But their impressions will appear reversed—as is shown in the first, above; where it is said that every image intersects as it enters the narrow openings made in a very thin substance.

Read the marginal text on the other side.

In proportion as the opening is smaller than the shaded body, so much less will the images transmitted through this opening intersect each other. The sides of images which pass through openings into a dark room intersect at a point which is nearer to the opening in proportion as the opening is narrower. To prove this let *a b* be an object in light and shade which sends not its shadow but the image of its darkened form through the opening *d e* which is as wide as this shaded body; and its sides *a b*, being straight lines (as has been proved) must intersect between the shaded object and the opening; but nearer to the opening in proportion as it is smaller than the object in shade. As is shown, on your right hand and your left hand, in the two diagrams *a b c n m o* where, the right opening *d e*, being equal in width to the shaded object *a b*, the intersection of the sides of the said shaded object occurs half way between the opening and the shaded object at the point *c*. But this cannot happen in the left hand figure, the opening *o* being much smaller than the shaded object *n m*.

It is impossible that the images of objects should be seen between the objects and the openings through which the images of these bodies are admitted; and this is plain, because where the atmosphere is illuminated these images are not formed visibly.

When the images are made double by mutually crossing each other they are invariably doubly as dark in tone. To prove this let *d e h* be such a doubling which although it is only seen within the space between the bodies in *b* and *i* this will not hinder its being seen from *f g* or from *f m*; being composed of the images *a b i k* which run together in *d e h*.

[Footnote: 81. On the original diagram at the beginning of this chapter Leonardo has written "*azurro*" (blue) where in the facsimile I have marked *A*, and "*giallo*" (yellow) where *B* stands.]

[Footnote: 15—23. These lines stand between the diagrams I and III.]

[Footnote: 24—53. These lines stand between the diagrams I and II.]

[Footnote: 54—97 are written along the left side of diagram I.]

82

An experiment showing that though the pupil may not be moved from its position the objects seen by it may appear to move from their places.

If you look at an object at some distance from you and which is below the eye, and fix both your eyes upon it and with one hand firmly hold the upper lid open while with the other you push up the under lid—still keeping your eyes fixed on the object gazed at—you will see that object double; one [image] remaining steady, and the other moving in a contrary direction to the pressure of your finger on the lower eyelid. How false the opinion is of those who say that this happens because the pupil of the eye is displaced from its position.

How the above mentioned facts prove that the pupil acts upside down in seeing.

> [Footnote: 82. 14—17. The subject indicated by these two headings is fully discussed in the two chapters that follow them in the original; but it did not seem to me appropriate to include them here.]

Demostration of perspective by means of a vertical glass plane (83-85).

83

OF THE PLANE OF GLASS.

Perspective is nothing else than seeing place [or objects] behind a plane of glass, quite transparent, on the surface of which the objects behind that glass are to be drawn. These can be traced in pyramids to the point in the eye, and these pyramids are intersected on the glass plane.

84

Pictorial perspective can never make an object at the same distance, look of the same size as it appears to the eye. You see that the apex of the pyramid *f c d* is as far from the object *c d* as the same point *f* is from the object *a b*; and yet *c d*, which is the base made by the painter's point, is smaller than *a b* which is the base of the lines from the objects converging in the eye and refracted at *s t*, the surface of the eye. This may be proved by experiment, by the lines of vision and then by the lines of the painter's plumbline by cutting the real lines of vision on one and the same plane and measuring on it one and the same object.

85

PERSPECTIVE.

The vertical plane is a perpendicular line, imagined as in front of the central point where the apex of the pyramids converge. And this plane bears the same relation to this point as a plane of glass would, through which you might see the various objects and draw them on it. And the objects thus drawn would be smaller than the originals, in proportion as the distance between the glass and the eye was smaller than that between the glass and the objects.

PERSPECTIVE.

The different converging pyramids produced by the objects, will show, on the plane, the various sizes and remoteness of the objects causing them.

PERSPECTIVE.

All those horizontal planes of which the extremes are met by perpendicular lines forming right angles, if they are of equal width the more they rise to the level of eye the less this is seen, and the more the eye is above them the more will their real width be seen.

PERSPECTIVE.

The farther a spherical body is from the eye the more you will see of it.

The angle of sight varies with the distance (86-88)

86

A simple and natural method; showing how objects appear to the eye without any other medium.

The object that is nearest to the eye always seems larger than another of the same size at greater distance. The eye *m*, seeing the spaces *o v x*, hardly detects the difference between them, and the. reason of this is that it is close to them [Footnote 6: It is quite inconceivable to me why M. RAVAISSON, in a note to his French translation of this simple passage should have remarked: *Il est clair que c'est par erreur que Leonard a čcrit* per esser visino *au lieu de* per non esser visino. (See his printed ed. of MS. A. p. 38.)]; but if these spaces are marked on the vertical plane *n o* the space *o v* will be seen at *o r*, and in the same way the space *v x* will appear at *r q*. And if you carry this out in any place where you can walk round, it will look out of proportion by reason of the great difference in the spaces *o r* and *r q*. And this proceeds from the eye being so much below [near] the plane that the plane is foreshortened. Hence, if you wanted to carry it out, you would have [to arrange] to see the perspective through a single hole which must be at the point *m*, or else you must go to a distance of at least 3 times the height of the object you see. The plane *o p* being always equally remote from the eye will reproduce the objects in a satisfactory way, so that they may be seen from place to place.

87

How every large mass sends forth its images, which may diminish through infinity.

The images of any large mass being infinitely divisible may be infinitely diminished.

88

Objects of equal size, situated in various places, will be seen by different pyramids which will each be smaller in proportion as the object is farther off.

89

Perspective, in dealing with distances, makes use of two opposite pyramids, one of which has its apex in the eye and the base as distant as the horizon. The other has the base towards the eye and the apex on the horizon. Now, the first includes the [visible] universe, embracing all the mass of the objects that lie in front of the eye; as it might be a vast landscape seen through a very small opening; for the more remote the objects are from the eye, the greater number can be seen through the opening, and thus the pyramid is constructed with the base on the horizon and the apex in the eye, as has been said. The second pyramid is extended to a spot which is smaller in proportion as it is farther from the eye; and this second perspective [= pyramid] results from the first.

SIMPLE PERSPECTIVE.

Simple perspective is that which is constructed by art on a vertical plane which is equally distant from the eye in every part. Complex perspective is that which is constructed on a ground-plan in which none of the parts are equally distant from the eye.

91

PERSPECTIVE.

No surface can be seen exactly as it is, if the eye that sees it is not equally remote from all its edges.

92

WHY WHEN AN OBJECT IS PLACED CLOSE TO THE EYE ITS EDGES ARE INDISTINCT.

When an object opposite the eye is brought too close to it, its edges must become too confused to be distinguished; as it happens with objects close to a light, which cast a large and indistinct shadow, so is it with an eye which estimates objects opposite to it; in all cases of linear perspective, the eye acts in the same way as the light. And the reason is that the eye has one leading line (of vision) which dilates with distance and embraces with true discernment large objects at a distance as well as small ones that are close. But since the eye sends out a multitude of lines which surround this chief central one and since these which are farthest from the centre in this cone of lines are less able to discern with accuracy, it follows that an object brought close to the eye is not at a due distance, but is too near for the central line to be able to discern the outlines of the object. So the edges fall within the lines of weaker discerning power, and these are to the function of the eye like dogs in the chase which can put up the game but cannot take it. Thus these cannot take in the objects, but induce the central line of sight to turn upon them, when they have put them up. Hence the objects which are seen with these lines of sight have confused outlines.

The relative size of objects with regard to their distance from the eye (93-98).

93

PERSPECTIVE.

Small objects close at hand and large ones at a distance, being seen within equal angles, will appear of the same size.

94

PERSPECTIVE.

There is no object so large but that at a great distance from the eye it does not appear smaller than a smaller object near.

95

Among objects of equal size that which is most remote from the eye will look the smallest. [Footnote: This axiom, sufficiently clear in itself, is in the original illustrated by a very large diagram, constructed like that here reproduced under No. 108.

The same idea is repeated in C. A. I a; I a, stated as follows: *Infra le cose d'equal grandeza quella si dimostra di minor figura che sara piů distante dall' ochio*.—]

96

Why an object is less distinct when brought near to the eye, and why with spectacles, or without the naked eye sees badly either close or far off [as the case may be].

97

PERSPECTIVE.

Among objects of equal size, that which is most remote from the eye will look the smallest.

PERSPECTIVE.

No second object can be so much lower than the first as that the eye will not see it higher than the first, if the eye is above the second.

PERSPECTIVE.

And this second object will never be so much higher than the first as that the eye, being below them, will not see the second as lower than the first.

PERSPECTIVE.

If the eye sees a second square through the centre of a smaller one, that is nearer, the second, larger square will appear to be surrounded by the smaller one.

PERSPECTIVE—PROPOSITION.

Objects that are farther off can never be so large but that those in front, though smaller, will conceal or surround them.

DEFINITION.

This proposition can be proved by experiment. For if you look through a small hole there is nothing so large that it cannot be seen through it and the object so seen appears surrounded and enclosed by the outline of the sides of the hole. And if you stop it up, this small stopping will conceal the view of the largest object.

The apparent size of objects defined by calculation (99-105)

OF LINEAR PERSPECTIVE.

Linear Perspective deals with the action of the lines of sight, in proving by measurement how much smaller is a second object than the first, and how much the third is smaller than the second; and so on by degrees to the end of things visible. I find by experience that if a second object is as far beyond the first as the first is from the eye, although they are of the same size, the second will seem half the size of the first and if the third object is of the same size as the 2nd, and the 3rd is as far beyond the second as the 2nd from the first, it will appear of half the size of the second; and so on by degrees, at equal distances, the next farthest will be half the size of the former object. So long as the space does not exceed the length of 20 braccia. But, beyond 20 braccia figures of equal size will lose 2/4 and at 40 braccia they will lose 9/10, and 19/20 at 60 braccia, and so on diminishing by degrees. This is if the picture plane is distant from you twice your own height. If it is only as far off as your own height, there will be a great difference between the first braccia and the second.

[Footnote: This chapter is included in DUFRESNE'S and MANZI'S editions of the Treatise on Painting. H. LUDWIG, in his commentary, calls this chapter "*eines der wichtigsten im ganzen Tractat*", but at the same time he asserts that its substance has been so completely disfigured in the best MS. copies that we ought not to regard Leonardo as responsible for it. However, in the case of this chapter, the old MS. copies agree with the original as it is reproduced above. From the chapters given later in this edition, which were written at a subsequent date, it would appear that Leonardo corrected himself on these points.]

100

OF THE DIMINUTION OF OBJECTS AT VARIOUS DISTANCES.

A second object as far distant from the first as the first is from the eye will appear half the size of the first, though they be of the same size really.

OF THE DEGREES OF DIMINUTION.

If you place the vertical plane at one braccio from the eye, the first object, being at a distance of 4 braccia from your eye will diminish to 3/4 of its height at that plane; and if it is 8 braccia from the eye, to 7/8; and if it is 16 braccia off, it will diminish to 15/16 of its height and so on by degrees, as the space doubles the diminution will double.

101

Begin from the line *m f* with the eye below; then go up and do the same with the line *n f*, then with the eye above and close to the 2 gauges on the ground look at *m n*; then as *c m* is to *m n* so will *n m* be to *n s*.

If *a n* goes 3 times into *f b*, *m p* will do the same into *p g*. Then go backwards so far as that *c d* goes twice into *a n* and *p g* will be equal to *g h*. And *m p* will go into *h p* as often as *d c* into *o p*.

[Footnote: The first three lines are unfortunately very obscure.]

102

I GIVE THE DEGREES OF THE OBJECTS SEEN BY THE EYE AS THE MUSICIAN DOES THE NOTES HEARD BY THE EAR.

Although the objects seen by the eye do, in fact, touch each other as they recede, I will nevertheless found my rule on spaces of 20 braccia each; as a musician does with notes, which, though they can be carried on one into the next, he divides into degrees from note to note calling them 1st, 2nd, 3rd, 4th, 5th; and has affixed a name to each degree in raising or lowering the voice.

103

PERSPECTIVE.

Let *f* be the level and distance of the eye; and *a* the vertical plane, as high as a man; let *e* be a man, then I say that on the plane this will be the distance from the plane to the 2nd man.

104

The differences in the diminution of objects of equal size in consequence of their various remoteness from the eye will bear among themselves the same proportions as those of the spaces between the eye and the different objects.

Find out how much a man diminishes at a certain distance and what its length is; and then at twice that distance and at 3 times, and so make your general rule.

105

The eye cannot judge where an object high up ought to descend.

106

PERSPECTIVE.

If two similar and equal objects are placed one beyond the other at a given distance the difference in their size will appear greater in proportion as they are nearer to the eye that sees them. And conversely there will seem to be less difference in their size in proportion as they are remote from the eve.

This is proved by the proportions of their distances among themselves; for, if the first of these two objects were as far from the eye, as the 2nd from the first this would be called the second proportion: since, if the first is at 1 braccia from the eye and the 2nd at two braccia, two being twice as much as one, the first object will look twice as large as the second. But if you place the first at a hundred braccia from you and the second at a hundred and one, you will find that the first is only so much larger than the second as 100 is less than 101; and the converse is equally true. And again, the same thing is proved by the 4th of this book which shows that among objects that are equal, there is the same proportion in the diminution of the size as in the increase in the distance from the eye of the spectator.

On natural perspective (107—109).

107

OF EQUAL OBJECTS THE MOST REMOTE LOOK THE SMALLEST.

The practice of perspective may be divided into … parts [Footnote 4: *in … parte*. The space for the number is left blank in the original.], of which the first treats of objects seen by the eye at any distance; and it shows all these objects just as the eye sees them diminished, without obliging a man to stand in one place rather than another so long as the plane does not produce a second foreshortening.

But the second practice is a combination of perspective derived partly from art and partly from nature and the work done by its rules is in every portion of it, influenced by natural perspective and artificial perspective. By natural perspective I mean that the plane on which this perspective is represented is a flat surface, and this plane, although it is parallel both in length and height, is forced to diminish in its remoter parts more than in its nearer ones. And this is proved by the first of what has been said above, and its diminution is natural. But artificial perspective, that is that which is devised by art, does the contrary; for objects equal in size increase on the plane where it is foreshortened in proportion as the eye is more natural and nearer to the plane, and as the part of the plane on which it is figured is farther from the eye.

And let this plane be *d e* on which are seen 3 equal circles which are beyond this plane *d e*, that is the circles *a b c*. Now you see that the eye *h* sees on the vertical plane the sections of the images, largest of those that are farthest and smallest of the nearest.

Here follows what is wanting in the margin at the foot on the other side of this page.

Natural perspective acts in a contrary way; for, at greater distances the object seen appears smaller, and at a smaller distance the object appears larger. But this said invention requires the spectator to stand with his eye at a small hole and then, at that small hole, it will be very plain. But since many (men's) eyes endeavour at the same time to see one and the same picture produced by this artifice only one can see clearly the effect of this perspective and all the others will see confusion. It is well therefore to avoid such complex perspective and hold to simple perspective which does not regard planes as foreshortened, but as much as possible in their proper form. This simple perspective, in which the plane intersects the pyramids by which the images are conveyed to the eye at an equal distance from the eye is our constant experience, from the curved form of the pupil of the eye on which the pyramids are intersected at an equal distance from the visual virtue.

[Footnote 24: *la prima di sopra* i. e. the first of the three diagrams which, in the original MS., are placed in the margin at the beginning of this chapter.]

109

OF A MIXTURE OF NATURAL AND ARTIFICIAL PERSPECTIVE.

This diagram distinguishes natural from artificial perspective. But before proceeding any farther I will define what is natural and what is artificial perspective. Natural perspective says that the more remote of a series of objects of equal size will look the smaller, and conversely, the nearer will look the larger and the apparent size will diminish in proportion to the distance. But in artificial perspective when objects of unequal size are placed at various distances, the smallest is nearer to the eye than the largest and the greatest distance looks as though it were the least of all; and the cause of this is the plane on which the objects are represented; and which is at unequal distances from the eye throughout its length. And this diminution of the plane is natural, but the perspective shown upon it is artificial since it nowhere agrees with the true diminution of the said plane. Whence it follows, that when the eye is somewhat removed from the [station point of the] perspective that it has been gazing at, all the objects represented look monstrous, and this does not occur in natural perspective, which has been defined above. Let us say then, that the square *a b c d* figured above is foreshortened being seen by the eye situated in the centre of the side which is in front. But a mixture of artificial and natural perspective will be seen in this tetragon called *el main* [Footnote 20: *el main* is quite legibly written in the original; the meaning and derivation of the word are equally doubtful.], that is to say *e f g h* which must appear to the eye of the spectator to be equal to *a b c d* so long as the eye remains in its first position between *c* and *d*. And this will be seen to have a good effect, because the natural perspective of the plane will conceal the defects which would [otherwise] seem monstrous.

III.
Six books on Light and Shade

Linear Perspective cannot be immediately followed by either the "prospettiva de' perdimenti" *or the* "prospettiva de' colori" *or the aerial perspective; since these branches of the subject presuppose a knowledge of the principles of Light and Shade. No apology, therefore, is here needed for placing these immediately after Linear Perspective.*

We have various plans suggested by Leonardo for the arrangement of the mass of materials treating of this subject. Among these I have given the preference to a scheme propounded in No. III, *because, in all probability, we have here a final and definite purpose expressed. Several authors have expressed it as their opinion that the Paris Manuscript* C *is a complete and finished treatise on Light and Shade. Certainly, the Principles of Light and Shade form by far the larger portion of this MS. which consists of two separate parts; still, the materials are far from being finally arranged. It is also evident that he here investigates the subject from the point of view of the Physicist rather than from that of the Painter.*

The plan of a scheme of arrangement suggested in No. III *and adopted by me has been strictly adhered to for the first four Books. For the three last, however, few materials have come down to us;*

and it must be admitted that these three Books would find a far more appropriate place in a work on Physics than in a treatise on Painting. For this reason I have collected in Book V all the chapters on Reflections, and in Book VI I have put together and arranged all the sections of MS. C *that belong to the book on Painting, so far as they relate to Light and Shade, while the sections of the same MS. which treat of the* "Prospettiva de' perdimenti" *have, of course, been excluded from the series on Light and Shade.*

[Footnote III: This text has already been published with some slight variations in Dozio's pamphlet *Degli scritti e disegni di Leonardo da Vinci*, Milan 1871, pp. 30—31. Dozio did not transcribe it from the original MS. which seems to have remained unknown to him, but from an old copy (MS. H. 227 in the Ambrosian Library).]

GENERAL INTRODUCTION.

Prolegomena.

110

You must first explain the theory and then the practice. First you must describe the shadows and lights on opaque objects, and then on transparent bodies.

Scheme of the books on Light and shade.

111

INTRODUCTION.

[Having already treated of the nature of shadows and the way in which they are cast [Footnote 2: *Avendo io tractato.*—We may suppose that he here refers to some particular MS., possibly Paris C.], I will now consider the places on which they fall; and their curvature, obliquity, flatness or, in short, any character I may be able to detect in them.]

Shadow is the obstruction of light. Shadows appear to me to be of supreme importance in perspective, because, without them opaque and solid bodies will be ill defined; that which is contained within their outlines and their boundaries themselves will be ill-understood unless they are shown against a background of a different tone from themselves. And therefore in my first proposition concerning shadow I state that every opaque body is surrounded and its whole surface enveloped in shadow and light. And on this proposition I build up the first Book. Besides this, shadows have in themselves various degrees of darkness, because they are caused by the absence of a variable amount of the luminous rays; and these I call Primary shadows because they are the first, and inseparable from the object to which they belong. And on this I will found my second Book. From these primary shadows there result certain shaded rays which are diffused through the atmosphere and these vary in character according to that of the primary shadows whence they are derived. I shall therefore call these shadows Derived shadows because they are produced by other shadows; and the third Book will treat of these. Again these derived shadows, where they are intercepted by various objects, produce effects as various as the places where they are cast and of this I will treat in the fourth Book. And since all round the derived shadows, where the derived shadows are intercepted, there is always a space where the light falls and by reflected dispersion is thrown back towards its cause, it meets the original shadow and mingles with it and modifies it somewhat in its nature; and on this I will compose my fifth Book. Besides this, in the sixth Book I will investigate the many and various diversities of reflections resulting from these rays which will modify the original [shadow] by [imparting] some of the various colours from the different objects whence these reflected rays are derived. Again, the seventh Book will treat of the various distances that may exist between the spot where the reflected rays fall and that where they originate, and the various shades of colour which they will acquire in falling on opaque bodies.

Different principles and plans of treatment (112—116).

112

First I will treat of light falling through windows which I will call Restricted [Light] and then I will treat of light in the open country, to which I will give the name of diffused Light. Then I will treat of the light of luminous bodies.

113

OF PAINTING.

The conditions of shadow and light [as seen] by the eye are 3. Of these the first is when the eye and the light are on the same side of the object seen; the 2nd is when the eye is in front of the object and the light is behind it. The 3rd is when the eye is in front of the object and the light is on one side, in such a way as that a line drawn from the object to the eye and one from the object to the light should form a right angle where they meet.

114

OF PAINTING.

This is another section: that is, of the nature of a reflection (from) an object placed between the eye and the light under various aspects.

115

OF PAINTING.

As regards all visible objects 3 things must be considered. These are the position of the eye which sees: that of the object seen [with regard] to the light, and the position of the light which illuminates the object, *b* is the eye, *a* the object seen, *c* the light, *a* is the eye, *b* the illuminating body, *c* is the illuminated object.

116

Let *a* be the light, *b* the eye, *c* the object seen by the eye and in the light. These show, first, the eye between the light and the body; the 2nd, the light between the eye and the body; the 3rd the body between the eye and the light, *a* is the eye, *b* the illuminated object, *c* the light.

117

OF PAINTING.

OF THE THREE KINDS OF LIGHT THAT ILLUMINATE OPAQUE BODIES.

The first kind of Light which may illuminate opaque bodies is called Direct light—as that of the sun or any other light from a window or flame. The second is Diffused [universal] light, such as we see in cloudy weather or in mist and the like. The 3rd is Subdued light, that is when the sun is entirely below the horizon, either in the evening or morning.

118

OF LIGHT.

The lights which may illuminate opaque bodies are of 4 kinds. These are: diffused light as that of the atmosphere, within our horizon. And Direct, as that of the sun, or of a window or door or other opening. The third is Reflected light; and there is a 4th which is that which passes through [semi] transparent bodies, as linen or paper or the like, but not transparent like glass, or crystal, or other diaphanous bodies, which produce the same effect as though nothing intervened between the shaded object and the light that falls upon it; and this we will discuss fully in our discourse.

Definition of the nature of shadows (119—122).

119

WHAT LIGHT AND SHADOW ARE.

Shadow is the absence of light, merely the obstruction of the luminous rays by an opaque body. Shadow is of the nature of darkness. Light [on an object] is of the nature of a luminous body; one conceals and the other reveals. They are always associated and inseparable from all objects. But shadow is a more powerful agent than light, for it can impede and entirely deprive bodies of their light, while light can never entirely expel shadow from a body, that is from an opaque body.

120

Shadow is the diminution of light by the intervention of an opaque body. Shadow is the counterpart of the luminous rays which are cut off by an opaque body.

This is proved because the shadow cast is the same in shape and size as the luminous rays were which are transformed into a shadow.

121

Shadow is the diminution alike of light and of darkness, and stands between darkness and light.

A shadow may be infinitely dark, and also of infinite degrees of absence of darkness.

The beginnings and ends of shadow lie between the light and darkness and may be infinitely diminished and infinitely increased. Shadow is the means by which bodies display their form.

The forms of bodies could not be understood in detail but for shadow.

122

OF THE NATURE OF SHADOW.

Shadow partakes of the nature of universal matter. All such matters are more powerful in their beginning and grow weaker towards the end, I say at the beginning, whatever their form or condition may be and whether visible or invisible. And it is not from small beginnings that they grow to a great size in time; as it might be a great oak which has a feeble beginning from a small acorn. Yet I may say that the oak is most powerful at its beginning, that is where it springs from the earth, which is where it is largest (To return:) Darkness, then, is the strongest degree of shadow and light is its least. Therefore, O Painter, make your shadow darkest close to the object that casts it, and make the end of it fading into light, seeming to have no end.

Of the various kinds of shadows. (123-125).

123

Darkness is absence of light. Shadow is diminution of light. Primitive shadow is that which is inseparable from a body not in the light. Derived shadow is that which is disengaged from a body in shadow and pervades the air. A cast transparent shadow is that which is surrounded by an illuminated surface. A simple shadow is one which receives no light from the luminous body which causes it. A simple shadow begins within the line which starts from the edge of the luminous body *a b*.

124

A simple shadow is one where no light at all interferes with it.

A compound shadow is one which is somewhat illuminated by one or more lights.

125

WHAT IS THE DIFFERENCE BETWEEN A SHADOW THAT IS INSEPARABLE FROM A BODY AND A CAST SHADOW?

An inseparable shadow is that which is never absent from the illuminated body. As, for instance a ball, which so long as it is in the light always has one side in shadow which never leaves it for any movement or change of position in the ball. A separate shadow may be and may not be produced by the body itself. Suppose the ball to be one braccia distant from a wall with a light on the opposite side of it; this light will throw upon the wall exactly as broad a shadow as is to be seen on the side of the ball that is turned towards the wall. That portion of the cast shadow will not be visible when the light is below the ball and the shadow is thrown up towards the sky and finding no obstruction on its way is lost.

126

HOW THERE ARE 2 KINDS OF LIGHT, ONE SEPARABLE FROM, AND THE OTHER INSEPARABLE FROM BODIES.

Of the various kinds of light (126, 127).

Separate light is that which falls upon the body. Inseparable light is the side of the body that is illuminated by that light. One is called primary, the other derived. And, in the same way there are two kinds of shadow:—One primary and the other derived. The primary is that which is inseparable from the body, the derived is that which proceeds from the body conveying to the surface of the wall the form of the body causing it.

127

How there are 2 different kinds of light; one being called diffused, the other restricted. The diffused is that which freely illuminates objects. The restricted is that which being admitted through an opening or window illuminates them on that side only.

> [Footnote: At the spot marked *A* in the first diagram Leonardo wrote *lume costretto* (restricted light). At the spot *B* on the second diagram he wrote *lume libero* (diffused light).]

General remarks (128. 129).

128

Light is the chaser away of darkness. Shade is the obstruction of light. Primary light is that which falls on objects and causes light and shade. And derived lights are those portions of a body which are illuminated by the primary light. A primary shadow is that side of a body on which the light cannot fall.

The general distribution of shadow and light is that sum total of the rays thrown off by a shaded or illuminated body passing through the air without any interference and the spot which intercepts and cuts off the distribution of the dark and light rays.

And the eye can best distinguish the forms of objects when it is placed between the shaded and the illuminated parts.

129

MEMORANDUM OF THINGS I REQUIRE TO HAVE GRANTED [AS AXIOMS] IN MY EXPLANATION OF PERSPECTIVE.

I ask to have this much granted me—to assert that every ray passing through air of equal density throughout, travels in a straight line from its cause to the object or place it falls upon.

FIRST BOOK ON LIGHT AND SHADE

On the nature of light (130. 131).

130

The reason by which we know that a light radiates from a single centre is this: We plainly see that a large light is often much broader than some small object which nevertheless—and although the rays [of the large light] are much more than twice the extent [of the small body]—always has its shadow cast on the nearest surface very visibly. Let *c f* be a broad light and *n* be the object in front of it, casting a shadow on the plane, and let *a b* be the plane. It is clear that it is not the broad light that will cast the shadow *n* on the plane, but that the light has within it a centre is shown by this experiment. The shadow falls on the plane as is shown at *m o t r*.

[Footnote 13: In the original MS. no explanatory text is placed after this title-line; but a space is left for it and the text beginning at line 15 comes next.] Why, to two [eyes] or in front of two eyes do 3 objects appear as two?

Why, when you estimate the direction of an object with two sights the nearer appears confused. I say that the eye projects an infinite number of lines which mingle or join those reaching it which come to it from the object looked at. And it is only the central and sensible line that can discern and discriminate colours and objects; all the others are false and illusory. And if you place 2 objects at half an arm's length apart if the nearer of the two is close to the eye its form will remain far more confused than that of the second; the reason is that the first is overcome by a greater number of false lines than the second and so is rendered vague.

Light acts in the same manner, for in the effects of its lines (=rays), and particularly in perspective, it much resembles the eye; and its central rays are what cast the true shadow. When the object in front of it is too quickly overcome with dim rays it will cast a broad and disproportionate shadow, ill defined; but when the object which is to cast the shadow and cuts off the rays near to the place where the shadow falls, then the shadow is distinct; and the more so in proportion as the light is far off, because at a long distance the central ray is less overcome by false rays; because the lines from the eye and the solar and other luminous rays passing through the atmosphere are obliged to travel in straight lines. Unless they are deflected by a denser or rarer air, when they will be bent at some point, but so long as the air is free from grossness or moisture they will preserve their direct course, always carrying the image of the object that intercepts them back to their point of origin. And if this is the eye, the intercepting object will be seen by its colour, as well as by form and size. But if the intercepting plane has in it some small perforation opening into a darker chamber—not darker in colour, but by absence of light—you will see the rays enter through this hole and transmitting to the plane beyond all the details of the object they proceed from both as to colour and form; only every thing will be upside down. But the size [of the image] where the lines are reconstructed will be in proportion to the relative distance of the aperture from the plane on which the lines fall [on one hand] and from their origin [on the other]. There they intersect and form 2 pyramids with their point meeting [a common apex] and their bases opposite. Let *a b* be the point of origin of the lines, *d e* the first plane, and *c* the aperture with the intersection of the lines; *f g* is the inner plane. You will find that *a* falls upon the inner plane below at *g*, and *b* which is below will go up to the spot *f*; it will be quite evident to experimenters that every luminous body has in itself a core or centre, from which and to which all the lines radiate which are sent forth by the surface of the luminous body and reflected back to it; or which, having been thrown out and not intercepted, are dispersed in the air.

131

THE RAYS WHETHER SHADED OR LUMINOUS HAVE GREATER STRENGTH AND EFFECT AT THEIR POINTS THAN AT THEIR SIDES.

Although the points of luminous pyramids may extend into shaded places and those of pyramids of shadow into illuminated places, and though among the luminous pyramids one may start from a broader base than another; nevertheless, if by reason of their various length these luminous pyramids acquire angles of equal size their light will be equal; and the case will be the same with the pyramids of shadow; as may be seen in the intersected pyramids *a b c* and *d e f*, which though their bases differ in size are equal as to breadth and light.

> [Footnote: 51—55: This supplementary paragraph is indicated as being a continuation of line 45, by two small crosses.]

The difference between light and lustre (132—135).

132

Of the difference between light and lustre; and that lustre is not included among colours, but is saturation of whiteness, and derived from the surface of wet bodies; light partakes of the colour of the object which reflects it (to the eye) as gold or silver or the like.

133

OF THE HIGHEST LIGHTS WHICH TURN AND MOVE AS THE EYE MOVES WHICH SEES THE OBJECT.

Suppose the body to be the round object figured here and let the light be at the point *a*, and let the illuminated side of the object be *b c* and the eye at the point *d*: I say that, as lustre is every where and complete in each part, if you stand at the point *d* the lustre will appear at *c*, and in proportion as the eye moves from *d* to *a*, the lustre will move from *c* to *n*.

134

OF PAINTING.

Heigh light or lustre on any object is not situated [necessarily] in the middle of an illuminated object, but moves as and where the eye moves in looking at it.

135

OF LIGHT AND LUSTRE.

What is the difference between light and the lustre which is seen on the polished surface of opaque bodies?

The lights which are produced from the polished surface of opaque bodies will be stationary on stationary objects even if the eye on which they strike moves. But reflected lights will, on those same objects, appear in as many different places on the surface as different positions are taken by the eye.

WHAT BODIES HAVE LIGHT UPON THEM WITHOUT LUSTRE?

Opaque bodies which have a hard and rough surface never display any lustre in any portion of the side on which the light falls.

WHAT BODIES WILL DISPLAY LUSTRE BUT NOT LOOK ILLUMINATED?

Those bodies which are opaque and hard with a hard surface reflect light [lustre] from every spot on the illuminated side which is in a position to receive light at the same angle of incidence as they occupy with regard to the eye; but, as the surface mirrors all the surrounding objects, the illuminated [body] is not recognisable in these portions of the illuminated body.

136

The relations of luminous to illuminated bodies.

The middle of the light and shade on an object in light and shade is opposite to the middle of the primary light. All light and shadow expresses itself in pyramidal lines. The middle of the shadow on any object must necessarily be opposite the middle of its light, with a direct line passing through the centre of the body. The middle of the light will be at *a*, that of the shadow at *b*. [Again, in bodies shown in light and shade the middle of each must coincide with the centre of the body, and a straight line will pass through both and through that centre.]

[Footnote: In the original MS., at the spot marked *a* of the first diagram Leonardo wrote *primitiuo*, and at the spot marked *c*—*primitiva* (primary); at the spot marked *b* he wrote *dirivatiuo* and at *d deriuatiua* (derived).]

Experiments on the relation of light and shadow within a room (137—140).

137

SHOWS HOW LIGHT FROM ANY SIDE CONVERGES TO ONE POINT.

Although the balls *a b c* are lighted from one window, nevertheless, if you follow the lines of their shadows you will see they intersect at a point forming the angle *n*.

> [Footnote: The diagram belonging to this passage is slightly sketched on Pl. XXXII; a square with three balls below it. The first three lines of the text belonging to it are written above the sketch and the six others below it.]

138

Every shadow cast by a body has a central line directed to a single point produced by the intersection of luminous lines in the middle of the opening and thickness of the window. The proposition stated above, is plainly seen by experiment. Thus if you draw a place with a window looking northwards, and let this be *s f*, you will see a line starting from the horizon to the east, which, touching the 2 angles of the window *o f*, reaches *d*; and from the horizon on the west another line, touching the other 2 angles *r s*, and ending at *c*; and their intersection falls exactly in the middle of the opening and thickness of the window. Again, you can still better confirm this proof by placing two sticks, as shown at *g h*; and you will see the line drawn from the centre of the shadow directed to the centre *m* and prolonged to the horizon *n f*.

[Footnote: *B* here stands for *cerchio del' orizonte tramontano* on the original diagram (the circle of the horizon towards the North); *A* for *levante* (East) and *C* for *ponete* (West).]

139

Every shadow with all its variations, which becomes larger as its distance from the object is greater, has its external lines intersecting in the middle, between the light and the object. This proposition is very evident and is confirmed by experience. For, if *a b* is a window without any object interposed, the luminous atmosphere to the right hand at *a* is seen to the left at *d*. And the atmosphere at the left illuminates on the right at *c*, and the lines intersect at the point *m*.

[Footnote: *A* here stands for *levante* (East), *B* for *ponente* (West).]

140

Every body in light and shade is situated between 2 pyramids one dark and the other luminous, one is visible the other is not. But this only happens when the light enters by a window. Supposing *a b* to be the window and *r* the body in light and shade, the light to the right hand *z* will pass the object to the left and go on to *p*; the light to the left at *k* will pass to the right of the object at *i* and go on to *m* and the two lines will intersect at *c* and form a pyramid. Then again *a b* falls on the shaded body at *i g* and forms a pyramid *f i g*. *f* will be dark because the light *a b* can never fall there; *i g c* will be illuminated because the light falls upon it.

Light and shadow with regard to the position of the eye (141—145).

141

Every shaded body that is larger than the pupil and that interposes between the luminous body and the eye will be seen dark.

When the eye is placed between the luminous body and the objects illuminated by it, these objects will be seen without any shadow.

[Footnote: The diagram which in the original stands above line 1 is given on Plate II, No 2. Then, after a blank space of about eight lines, the diagram Plate II No 3 is placed in the original. There is no explanation of it beyond the one line written under it.]

142

Why the 2 lights one on each side of a body having two pyramidal sides of an obtuse apex leave it devoid of shadow.

[Footnote: The sketch illustrating this is on Plate XLI No 1.]

143

A body in shadow situated between the light and the eye can never display its illuminated portion unless the eye can see the whole of the primary light.

[Footnote: *A* stands for *corpo* (body), *B* for *lume* (light).]

144

The eye which looks (at a spot) half way between the shadow and the light which surrounds the body in shadow will see that the deepest shadows on that body will meet the eye at equal angles, that is at the same angle as that of sight.

[Footnote: In both these diagrams *A* stands for *lume* (light) *B* for *ombra* (shadow).]

145

OF THE DIFFERENT LIGHT AND SHADE IN VARIOUS ASPECTS AND OF OBJECTS PLACED IN THEM.

If the sun is in the East and you look towards the West you will see every thing in full light and totally without shadow because you see them from the same side as the sun: and if you look towards the South or North you will see all objects in light and shade, because you see both the side towards the sun and the side away from it; and if you look towards the coming of the sun all objects will show you their shaded side, because on that side the sun cannot fall upon them.

The law of the incidence of light.

146

The edges of a window which are illuminated by 2 lights of equal degrees of brightness will not reflect light of equal brightness into the chamber within.

If *b* is a candle and *a c* our hemisphere both will illuminate the edges of the window *m n*, but light *b* will only illuminate *f g* and the hemisphere *a* will light all of *d e*.

147

OF PAINTING.

That part of a body which receives the luminous rays at equal angles will be in a higher light than any other part of it.

And the part which the luminous rays strike between less equal angles will be less strongly illuminated.

SECOND BOOK ON LIGHT AND SHADE

Gradations of strength in the shadows (148. 149).

148

THAT PORTION OF A BODY IN LIGHT AND SHADE WILL BE LEAST LUMINOUS WHICH IS SEEN UNDER THE LEAST AMOUNT OF LIGHT.

That part of the object which is marked *m* is in the highest light because it faces the window *a d* by the line *a f*; *n* is in the second grade because the light *b d* strikes it by the line *b e*; *o* is in the third grade, as the light falls on it from *c d* by the line *c h*; *p* is the lowest light but one as *c d* falls on it by the line *d v*; *q* is the deepest shadow for no light falls on it from any part of the window.

In proportion as *c d* goes into *a d* so will *n r s* be darker than *m*, and all the rest is space without shadow.

[Footnote: The diagram belonging to this chapter is No. 1 on Plate III. The letters *a b e d* and *r* are not reproduced in facsimile of the original, but have been replaced by ordinary type in the margin. 5-12. The original text of these lines is reproduced within the diagram.—Compare No 275.]

149

The light which falls on a shaded body at the acutest angle receives the highest light, and the darkest portion is that which receives it at an obtuse angle and both the light and the shadow form pyramids. The angle *c* receives the highest grade of light because it is directly in front of the window *a b* and the whole horizon of the sky *m x*. The angle *a* differs but little from *c* because the angles which divide it are not so unequal as those below, and only that portion of the horizon is intercepted which lies between *y* and *x*. Although it gains as much on the other side its line is nevertheless not very strong because one angle is smaller than its fellow. The angles *e i* will have less light because they do not see much of the light *m s* and the light *v x* and their angles are very unequal. Yhe angle *k* and the angle *f* are each placed between very unequal angles and therefore have but little light, because at *k* it has only the light *p t*, and at *f* only *t q*; *o g* is the lowest grade of light because this part has no light at all from the sky; and thence come the lines which will reconstruct a pyramid that is the counterpart of the pyramid *c*; and this pyramid *l* is in the first grade of shadow; for this too is placed between equal angles directly opposite to each other on either side of a straight line which passes through the centre of the body and goes to the centre of the light. The several luminous images cast within the frame of the window at the points *a* and *b* make a light which surrounds the derived shadow cast by the solid body at the points 4 and 6. The shaded images increase from *o g* and end at 7 and 8.

[Footnote: The diagram belonging to this chapter is No. 2 on Plate III. In the original it is placed between lines 3 and 4, and in the reproduction these are shown in part. The semi circle above is marked *orizonte* (horizon). The number 6 at the left hand side, outside the facsimile, is in the place of a figure which has become indistinct in the original.]

On the intensity of shadows as dependent on the distance from the light (150-152).

150

The smaller the light that falls upon an object the more shadow it will display. And the light will illuminate a smaller portion of the object in proportion as it is nearer to it; and conversely, a larger extent of it in proportion as it is farther off.

A light which is smaller than the object on which it falls will light up a smaller extent of it in proportion as it is nearer to it, and the converse, as it is farther from it. But when the light is larger than the object illuminated it will light a larger extent of the object in proportion as it is nearer and the converse when they are farther apart.

151

That portion of an illuminated object which is nearest to the source of light will be the most strongly illuminated.

152

That portion of the primary shadow will be least dark which is farthest from the edges.

The derived shadow will be darker than the primary shadow where it is contiguous with it.

On the proportion of light and shade (153-157).

153

That portion of an opaque body will be more in shade or more in light, which is nearer to the dark body, by which it is shaded, or to the light that illuminates it.

Objects seen in light and shade show in greater relief than those which are wholly in light or in shadow.

154

OF PERSPECTIVE.

The shaded and illuminated sides of opaque objects will display the same proportion of light and darkness as their objects [Footnote 6: The meaning of *obbietti* (objects) is explained in no 153, lines 1-4.—Between the title-line and the next there is, in the original, a small diagram representing a circle described round a square.].

155

OF PAINTING.

The outlines and form of any part of a body in light and shade are indistinct in the shadows and in the high lights; but in the portions between the light and the shadows they are highly conspicuous.

156

OF PAINTING.

Among objects in various degrees of shade, when the light proceeds from a single source, there will be the same proportion in their shadows as in the natural diminution of the light and the same must be understood of the degrees of light.

157

A single and distinct luminous body causes stronger relief in the object than a diffused light; as may be seen by comparing one side of a landscape illuminated by the sun, and one overshadowed by clouds, and so illuminated only by the diffused light of the atmosphere.

THIRD BOOK ON LIGHT AND SHADE

Definition of derived shadow (158. 159).

158

Derived shadow cannot exist without primary shadow. This is proved by the first of this which says: Darkness is the total absence of light, and shadow is an alleviation of darkness and of light, and it is more or less dark or light in proportion as the darkness is modified by the light.

159

Shadow is diminution of light.

Darkness is absence of light.

Shadow is divided into two kinds, of which the first is called primary shadow, the second is derived shadow. The primary shadow is always the basis of the derived shadow.

The edges of the derived shadow are straight lines.

[Footnote: The theory of the *ombra* dirivativa_—a technical expression for which there is no precise English equivalent is elaborately treated by Leonardo. But both text and diagrams (as Pl. IV, 1-3 and Pl. V) must at once convince the student that the distinction he makes between *ombra primitiva* and *ombra dirivativa* is not merely justifiable but scientific. *Ombra dirivativa* is by no means a mere abstract idea. This is easily proved by repeating the experiment made by Leonardo, and by filling with smoke the room in which the existence of the *ombra dirivativa* is investigated, when the shadow becomes visible. Nor is it difficult to perceive how much of Leonardo's teaching depended on this theory. The recognised, but extremely complicated science of cast shadows—*percussione dell' ombre dirivative* as Leonardo calls them—is thus rendered more intelligible if not actually simpler, and we must assume this theory as our chief guide through the investigations which follow.]

The darkness of the derived shadow diminishes in proportion as it is remote from the primary shadow.

Different sorts of derived shadows (160-162).

160

SHADOW AND LIGHT.

The forms of shadows are three: inasmuch as if the solid body which casts the shadow is equal (in size) to the light, the shadow resembles a column without any termination (in length). If the body is larger than the light the shadow resembles a truncated and inverted pyramid, and its length has also no defined termination. But if the body is smaller than the light, the shadow will resemble a pyramid and come to an end, as is seen in eclipses of the moon.

161

OF SIMPLE DERIVED SHADOWS.

The simple derived shadow is of two kinds: one kind which has its length defined, and two kinds which are undefined; and the defined shadow is pyramidal. Of the two undefined, one is a column and the other spreads out; and all three have rectilinear outlines. But the converging, that is the pyramidal, shadow proceeds from a body that is smaller than the light, and the columnar from a body equal in size to the light, and the spreading shadow from a body larger than the light; &c.

OF COMPOUND DERIVED SHADOWS.

Compound derived shadows are of two kinds; that is columnar and spreading.

162

OF SHADOW.

Derived shadows are of three kinds of which one is spreading, the second columnar, the third converging to the point where the two sides meet and intersect, and beyond this intersection the sides are infinitely prolonged or straight lines. And if you say, this shadow must terminate at the angle where the sides meet and extend no farther, I deny this, because above in the first on shadow I have proved: that a thing is completely terminated when no portion of it goes beyond its terminating lines. Now here, in this shadow, we see the converse of this, in as much as where this derived shadow originates we obviously have the figures of two pyramids of shadow which meet at their angles. Hence, if, as [my] opponent says, the first pyramid of shadow terminates the derivative shadow at the angle whence it starts, then the second pyramid of shadow—so says the adversary—must be caused by the angle and not from the body in shadow; and this is disproved with the help of the 2nd of this which says: Shadow is a condition produced by a body casting a shadow, and interposed between this shadow and the luminous body. By this it is made clear that the shadow is not produced by the angle of the derived shadow but only by the body casting the shadow; &c. If a spherical solid body is illuminated by a light of elongated form the shadow produced by the longest portion of this light will have less defined outlines than that which is produced by the breadth of the same light. And this is proved by what was said before, which is: That a shadow will have less defined outlines in proportion as the light which causes it is larger, and conversely, the outlines are clearer in proportion as it is smaller.

[Footnote: The two diagrams to this chapter are on Plate IV, No. 1.]

On the relation of derived and primary shadow (163-165).

163

The derived shadow can never resemble the body from which it proceeds unless the light is of the same form and size as the body causing the shadow.

The derived shadow cannot be of the same form as the primary shadow unless it is intercepted by a plane parallel to it.

164

HOW A CAST SHADOW CAN NEVER BE OF THE SAME SIZE AS THE BODY THAT CASTS IT.

If the rays of light proceed, as experience shows, from a single point and are diffused in a sphere round this point, radiating and dispersed through the air, the farther they spread the wider they must spread; and an object placed between the light and a wall is always imaged larger in its shadow, because the rays that strike it [Footnote: 7. The following lines are wanting to complete the logical connection.] would, by the time they have reached the wall, have become larger.

165

Any shadow cast by a body in light and shade is of the same nature and character as that which is inseparable from the body. The centre of the length of a shadow always corresponds to that of the luminous body [Footnote 6: This second statement of the same idea as in the former sentence, but in different words, does not, in the original, come next to the foregoing; sections 172 and 127 are placed between them.]. It is inevitable that every shadow must have its centre in a line with the centre of the light.

On the shape of derived shadows (166-174).

166

OF THE PYRAMIDAL SHADOW.

The pyramidal shadow produced by a columnar body will be narrower than the body itself in proportion as the simple derived shadow is intersected farther from the body which casts it.

[Footnote 166: Compare the first diagram to No. 161. If we here conceive of the outlines of the pyramid of shadow on the ground as prolonged beyond its apex this gives rise to a second pyramid; this is what is spoken of at the beginning of No. 166.]

167

The cast shadow will be longest when the light is lowest.
The cast shadow will be shortest when the light is highest.

168

Both the primary and derived shadow will be larger when caused by the light of a candle than by diffused light. The difference between the larger and smaller shadows will be in inverse proportion to the larger and smaller lights causing them.

[Footnote: In the diagrams *A* stands for *celo* (sky), *B* for *cadela* (candle).]

169

ALL BODIES, IN PROPORTION AS THEY ARE NEARER TO, OR FARTHER FROM THE SOURCE OF LIGHT, WILL PRODUCE LONGER OR SHORTER DERIVED SHADOWS.

Among bodies of equal size, that one which is illuminated by the largest light will have the shortest shadow. Experiment confirms this proposition. Thus the body *m n* is surrounded by a larger amount of light than the body *p q*, as is shown above. Let us say that *v c a b d x* is the sky, the source of light, and that *s t* is a window by which the luminous rays enter, and so *m n* and *p q* are bodies in light and shade as exposed to this light; *m n* will have a small derived shadow, because its original shadow will be small; and the derivative light will be large, again, because the original light *c d* will be large and *p q* will have more derived shadow because its original shadow will be larger, and its derived light will be smaller than that of the body *m n* because that portion of the hemisphere *a b* which illuminates it is smaller than the hemisphere *c d* which illuminates the body *m n*.

[Footnote: The diagram, given on Pl. IV, No. 2, stands in the original between lines 2 and 7, while the text of lines 3 to 6 is written on its left side. In the reproduction of this diagram the letter *v* at the outer right-hand end has been omitted.]

170

The shadow *m* bears the same proportion to the shadow *n* as the line *b c* to the line *f c*.

171

OF PAINTING.

Of different shadows of equal strength that which is nearest the eye will seem the least strong.

Why is the shadow *e a b* in the first grade of strength, *b c* in the second; *c d* in the third? The reason is that as from *e a b* the sky is nowhere visible, it gets no light whatever from the sky, and so has no direct [primary] light. *b c* faces the portion of the sky *f g* and is illuminated by it. *c d* faces the sky at *h k*. *c d*, being exposed to a larger extent of sky than *b c*, it is reasonable that it should be more lighted. And thus, up to a certain distance, the wall *a d* will grow lighter for the reasons here given, until the darkness of the room overpowers the light from the window.

172

When the light of the atmosphere is restricted [by an opening] and illuminates bodies which cast shadows, these bodies being equally distant from the centre of the window, that which is most obliquely placed will cast the largest shadow beyond it.

173

These bodies standing apart in a room lighted by a single window will have derivative shadows more or less short according as they are more or less opposite to the window. Among the shadows cast by bodies of equal mass but at unequal distances from the opening by which they are illuminated, that shadow will be the longest of the body which is least in the light. And in proportion as one body is better illuminated than another its shadow will be shorter than another. The proportion *n m* and *e v k* bear to *r t* and *v x* corresponds with that of the shadow *x* to 4 and *y*.

The reason why those bodies which are placed most in front of the middle of the window throw shorter shadows than those obliquely situated is:—That the window appears in its proper form and to the obliquely placed ones it appears foreshortened; to those in the middle, the window shows its full size, to the oblique ones it appears smaller; the one in the middle faces the whole hemisphere that is *e f* and those on the side have only a strip; that is *q r* faces *a b*; and *m n* faces *c d*; the body in the middle having a larger quantity of light than those at the sides is lighted from a point much below its centre, and thus the shadow is shorter. And the pyramid *g* 4 goes into *l y* exactly as often as *a b* goes into *e f*. The axis of every derivative shadow passes through 6 1/2 [Footnote 31: *passa per* 6 1/2 (passes through 6 1/2). The meaning of these words is probably this: Each of the three axes of the derived shadow intersects the centre (*mezzo*) of the primary shadow (*ombra originale*) and, by prolongation upwards crosses six lines.

This is self evident only in the middle diagram; but it is equally true of the side figures if we conceive of the lines 4 *f*, *x n v m*, *y l k v*, and 4 *e*, as prolonged beyond the semicircle of the horizon.] and is in a straight line with the centre of the primary shadow, with the centre of the body casting it and of the derivative light and with the centre of the window and, finally, with the centre of that portion of the source of light which is the celestial hemisphere, *y h* is the centre of the derived shade, *l h* of the primary shadow, *l* of the body throwing it, *l k* of the derived light, *v* is the centre of the window, *e* is the final centre of the original light afforded by that portion of the hemisphere of the sky which illuminates the solid body.

[Footnote: Compare the diagram on Pl. IV, No. 3. In the original this drawing is placed between lines 3 and 22; the rest, from line 4 to line 21, is written on the left hand margin.]

174

THE FARTHER THE DERIVED SHADOW IS PROLONGED THE LIGHTER IT BECOMES.

You will find that the proportion of the diameter of the derived shadow to that of the primary shadow will be the same as that between the darkness of the primary shadow and that of the derived shadow.

> [Footnote 6: Compare No. 177.] Let *a b* be the diameter of the primary shadow and *c d* that of the derived shadow, I say that *a b* going, as you see, three times into *d c*, the shadow *d c* will be three times as light as the shadow *a b*. [Footnote 8: Compare No. 177.]

If the size of the illuminating body is larger than that of the illuminated body an intersection of shadow will occur, beyond which the shadows will run off in two opposite directions as if they were caused by two separate lights.

On the relative intensity of derived shadows (175-179).

175

ON PAINTING.

The derived shadow is stronger in proportion as it is nearer to its place of origin.

176

HOW SHADOWS FADE AWAY AT LONG DISTANCES.

Shadows fade and are lost at long distances because the larger quantity of illuminated air which lies between the eye and the object seen tints the shadow with its own colour.

a b will be darker than *c d* in proportion as *c d* is broader than *a b*.

[Footnote: In the original MS. the word *lume* (light) is written at the apex of the pyramid.]

It can be proved why the shadow *o p c h* is darker in proportion as it is nearer to the line *p h* and is lighter in proportion as it is nearer to the line *o c*. Let the light *a b*, be a window, and let the dark wall in which this window is, be *b s*, that is, one of the sides of the wall.

Then we may say that the line *p h* is darker than any other part of the space *o p c h*, because this line faces the whole surface in shadow of [Footnote: In the original the diagram is placed between lines 27 and 28.] the wall *b s*. The line *o c* is lighter than the other part of this space *o p c h*, because this line faces the luminous space *a b*.

Where the shadow is larger, or smaller, or equal the body which casts it.

[First of the character of divided lights. [Footnote 14: *lumi divisi*. The text here breaks off abruptly.]

OF THE COMPOUND SHADOW *F, R, C, H* CAUSED BY A SINGLE LIGHT.

The shadow *f r c h* is under such conditions as that where it is farthest from its inner side it loses depth in proportion. To prove this:

Let *d a*, be the light and *f n* the solid body, and let *a e* be one of the side walls of the window that is *d a*. Then I say—according to the 2nd [proposition]: that the surface of any body is affected by the tone of the objects surrounding it,—that the side *r c*, which faces the dark wall *a e* must participate of its darkness and, in the same way that the outer surface which faces the light *d a* participates of the light; thus we get the outlines of the extremes on each side of the centre included between them.]

This is divided into four parts. The first the extremes, which include the compound shadow, secondly the compound shadow between these extremes.

179

THE ACTION OF THE LIGHT AS FROM ITS CENTRE.

If it were the whole of the light that caused the shadows beyond the bodies placed in front of it, it would follow that any body much smaller than the light would cast a pyramidal shadow; but experience not showing this, it must be the centre of the light that produces this effect.

> [Footnote: The diagram belonging to this passage is between lines 4 and 5 in the original. Comp. the reproduction Pl. IV, No. 4. The text and drawing of this chapter have already been published with tolerable accuracy. See M. JORDAN: "*Das Malerbuch des Leonardo da Vinci*". Leipzig 1873, P. 90.]

PROOF.

Let *a b* be the width of the light from a window, which falls on a stick set up at one foot from *a c* [Footnote 6: *bastone* (stick). The diagram has a sphere in place of a stick.]. And let *a d* be the space where all the light from the window is visible. At *c e* that part of the window which is between *l b* cannot be seen. In the same way *a m* cannot be seen from *d f* and therefore in these two portions the light begins to fail.

Shadow as produced by two lights of different size (180. 181).

180

A body in light and shade placed between two equal lights side by side will cast shadows in proportion to the [amount of] light. And the shadows will be one darker than the other in proportion as one light is nearer to the said body than the other on the opposite side.

A body placed at an equal distance between two lights will cast two shadows, one deeper than the other in proportion, as the light which causes it is brighter than the other.

[Footnote: In the MS. the larger diagram is placed above the first line; the smaller one between l. 4 & 5.]

181

A light which is smaller than the body it illuminates produces shadows of which the outlines end within [the surface of] the body, and not much compound shadow; and falls on less than half of it. A light which is larger than the body it illuminates, falls on more than half of it, and produces much compound shadow.

The effect of light at different distances.

182

OF THE SHADOW CAST BY A BODY PLACED BETWEEN 2 EQUAL LIGHTS.

A body placed between 2 equal lights will cast 2 shadows of itself in the direction of the lines of the 2 lights; and if you move this body placing it nearer to one of the lights the shadow cast towards the nearer light will be less deep than that which falls towards the more distant one.

Further complications in the derived shadows (183-187).

183

The greatest depth of shadow is in the simple derived shadow because it is not lighted by either of the two lights *a b, c d*.

The next less deep shadow is the derived shadow *e f n*; and in this the shadow is less by half, because it is illuminated by a single light, that is *c d*.

This is uniform in natural tone because it is lighted throughout by one only of the two luminous bodies [10]. But it varies with the conditions of shadow, inasmuch as the farther it is away from the light the less it is illuminated by it [13].

The third degree of depth is the middle shadow [Footnote 15: We gather from what follows that *q g r* here means *ombra media* (the middle shadow).]. But this is not uniform in natural tone; because the nearer it gets to the simple derived shadow the deeper it is [Footnote 18: Compare lines 10-13], and it is the uniformly gradual diminution by increase of distance which is what modifies it [Footnote 20: See Footnote 18]: that is to say the depth of a shadow increases in proportion to the distance from the two lights.

The fourth is the shadow *k r s* and this is all the darker in natural tone in proportion as it is nearer to *k s*, because it gets less of the light *a o*, but by the accident [of distance] it is rendered less deep, because it is nearer to the light *c d*, and thus is always exposed to both lights.

The fifth is less deep in shadow than either of the others because it is always entirely exposed to one of the lights and to the whole or part of the other; and it is less deep in proportion as it is nearer to the two lights, and in proportion as it is turned towards the outer side *x t*; because it is more exposed to the second light *a b*.

[Footnote: The diagram to this section is given on Pl. V. To the left is the facsimile of the beginning of the text belonging to it.]

184

OF SIMPLE SHADOWS.

Why, at the intersections *a*, *b* of the two compound shadows *e f* and *m e*, is a simple shadow pfoduced as at *e h* and *m g*, while no such simple shadow is produced at the other two intersections *c d* made by the very same compound shadows?

ANSWER.

Compound shadow are a mixture of light and shade and simple shadows are simply darkness. Hence, of the two lights *n* and *o*, one falls on the compound shadow from one side, and the other on the compound shadow from the other side, but where they intersect no light falls, as at *a b*; therefore it is a simple shadow. Where there is a compound shadow one light or the other falls; and here a difficulty arises for my adversary since he says that, where the compound shadows intersect, both the lights which produce the shadows must of necessity fall and therefore these shadows ought to be neutralised; inasmuch as the two lights do not fall there, we say that the shadow is a simple one and where only one of the two lights falls, we say the shadow is compound, and where both the lights fall the shadow is neutralised; for where both lights fall, no shadow of any kind is produced, but only a light background limiting the shadow. Here I shall say that what my adversary said was true: but he only mentions such truths as are in his favour; and if we go on to the rest he must conclude that my proposition is true. And that is: That if both lights fell on the point of intersection, the shadows would be neutralised. This I confess to be true if [neither of] the two shadows fell in the same spot; because, where a shadow and a light fall, a compound shadow is produced, and wherever two shadows or two equal lights fall, the shadow cannot vary in any part of it, the shadows and the lights both being equal. And this is proved in the eighth [proposition] on proportion where it is said that if a given quantity has a single unit of force and resistance, a double quantity will have double force and double resistance.

DEFINITION.

The intersection *n* is produced by the shadows caused by the light *b*, because this light *b* produces the shadow *x b*, and the shadow *s b*, but the intersection *m* is produced by the light *a* which causes the shadow *s a*, and the shadow *x a*.

But if you uncover both the lights *a b*, then you get the two shadows *n m* both at once, and besides these, two other, simple shadows are produced at *r o* where neither of the two lights falls at all. The grades of depth in compound shadows are fewer in proportion as the lights falling on, and crossing them are less numerous.

186

Why the intersections at *n* being composed of two compound derived shadows, forms a compound shadow and not a simple one, as happens with other intersections of compound shadows. This occurs, according to the 2nd [diagram] of this [prop.] which says:—The intersection of derived shadows when produced by the intersection of columnar shadows caused by a single light does not produce a simple shadow. And this is the corollary of the 1st [prop.] which says:—The intersection of simple derived shadows never results in a deeper shadow, because the deepest shadows all added together cannot be darker than one by itself. Since, if many deepest shadows increased in depth by their duplication, they could not be called the *deepest* shadows, but only part-shadows. But if such intersections are illuminated by a second light placed between the eye and the intersecting bodies, then those shadows would become compound shadows and be uniformly dark just as much at the intersection as throughout the rest. In the 1st and 2nd above, the intersections *i k* will not be doubled in depth as it is doubled in quantity. But in this 3rd, at the intersections *g n* they will be double in depth and in quantity.

187

HOW AND WHEN THE SURROUNDINGS IN SHADOW MINGLE THEIR DERIVED SHADOW WITH THE LIGHT DERIVED FROM THE LUMINOUS BODY.

The derived shadow of the dark walls on each side of the bright light of the window are what mingle their various degrees of shade with the light derived from the window; and these various depths of shade modify every portion of the light, except where it is strongest, at *c*. To prove this let *d a* be the primary shadow which is turned towards the point *e*, and darkens it by its derived shadow; as may be seen by the triangle *a e d*, in which the angle *e* faces the darkened base *d a e*; the point *v* faces the dark shadow *a s* which is part of *a d*, and as the whole is greater than a part, *e* which faces the whole base [of the triangle], will be in deeper shadow than *v* which only faces part of it. In consequence of the conclusion [shown] in the above diagram, *t* will be less darkened than *v*, because the base of the *t* is part of the base of the *v*; and in the same way it follows that *p* is less in shadow than *t*, because the base of the *p* is part of the base of the *t*. And *c* is the terminal point of the derived shadow and the chief beginning of the highest light.

[Footnote: The diagram on Pl. IV, No. 5 belongs to this passage; but it must be noted that the text explains only the figure on the right-hand side.]

FOURTH BOOK ON LIGHT AND SHADE

On the shape of the cast shadows (188-191).

188

The form of the shadow cast by any body of uniform density can never be the same as that of the body producing it. [Footnote: Comp. the drawing on PI. XXVIII, No. 5.]

189

No cast shadow can produce the true image of the body which casts it on a vertical plane unless the centre of the light is equally distant from all the edges of that body.

190

If a window *a b* admits the sunlight into a room, the sunlight will magnify the size of the window and diminish the shadow of a man in such a way as that when the man makes that dim shadow of himself, approach to that which defines the real size of the window, he will see the shadows where they come into contact, dim and confused from the strength of the light, shutting off and not allowing the solar rays to pass; the effect of the shadow of the man cast by this contact will be exactly that figured above.

[Footnote: It is scarcely possible to render the meaning of this sentence with strict accuracy; mainly because the grammatical construction is defective in the most important part—line 4. In the very slight original sketch the shadow touches the upper arch of the window and the correction, here given is perhaps not justified.]

191

A shadow is never seen as of uniform depth on the surface which intercepts it unless every portion of that surface is equidistant from the luminous body. This is proved by the 7th which says:—The shadow will appear lighter or stronger as it is surrounded by a darker or a lighter background. And by the 8th of this:—The background will be in parts darker or lighter, in proportion as it is farther from or nearer to the luminous body. And:—Of various spots equally distant from the luminous body those will always be in the highest light on which the rays fall at the smallest angles: The outline of the shadow as it falls on inequalities in the surface will be seen with all the contours similar to those of the body that casts it, if the eye is placed just where the centre of the light was.

The shadow will look darkest where it is farthest from the body that casts it. The shadow *c d*, cast by the body in shadow *a b* which is equally distant in all parts, is not of equal depth because it is seen on a back ground of varying brightness. [Footnote: Compare the three diagrams on Pl. VI, no 1 which, in the original accompany this section.]

On the outlines of cast shadows (192-195).

192

The edges of a derived shadow will be most distinct where it is cast nearest to the primary shadow.

193

As the derived shadow gets more distant from the primary shadow, the more the cast shadow differs from the primary shadow.

194

OF SHADOWS WHICH NEVER COME TO AN END.

The greater the difference between a light and the body lighted by it, the light being the larger, the more vague will be the outlines of the shadow of that object.

The derived shadow will be most confused towards the edges of its interception by a plane, where it is remotest from the body casting it.

195

What is the cause which makes the outlines of the shadow vague and confused?

Whether it is possible to give clear and definite outlines to the edges of shadows.

On the relative size of shadows (196. 197).

196

THE BODY WHICH IS NEAREST TO THE LIGHT CASTS THE LARGEST SHADOW, AND WHY?

If an object placed in front of a single light is very close to it you will see that it casts a very large shadow on the opposite wall, and the farther you remove the object from the light the smaller will the image of the shadow become.

WHY A SHADOW LARGER THAN THE BODY THAT PRODUCES IT BECOMES OUT OF PROPORTION.

The disproportion of a shadow which is larger than the body producing it, results from the light being smaller than the body, so that it cannot be at an equal distance from the edges of the body [Footnote 11: H. LUDWIG in his edition of the old copies, in the Vatican library—in which this chapter is included under Nos. 612, 613 and 614 alters this passage as follows: *quella parte ch'e piu propinqua piu cresce che le distanti*, although the Vatican copy agrees with the original MS. in having *distante* in the former and *propinque* in the latter place. This supposed amendment seems to me to invert the facts. Supposing for instance, that on Pl. XXXI No. 3. *f* is the spot where the light is that illuminates the figure there represented, and that the line behind the figure represents a wall on which the shadow of the figure is thrown. It is evident, that in that case the nearest portion, in this case the under part of the thigh, is very little magnified in the shadow, and the remoter parts, for instance the head, are more magnified.]; and the portions which are most remote are made larger than the nearer portions for this reason [Footnote 12: See Footnote 11].

WHY A SHADOW WHICH IS LARGER THAN THE BODY CAUSING IT HAS ILL-DEFINED OUTLINES.

The atmosphere which surrounds a light is almost like light itself for brightness and colour; but the farther off it is the more it loses this resemblance. An object which casts a large shadow and is near to the light, is illuminated both by that light by the luminous atmosphere; hence this diffused light gives the shadow ill-defined edges.

197

A luminous body which is long and narrow in shape gives more confused outlines to the derived shadow than a spherical light, and this contradicts the proposition next following: A shadow will have its outlines more clearly defined in proportion as it is nearer to the primary shadow or, I should say, the body casting the shadow; [Footnote 14: The lettering refers to the lower diagram, Pl. XLI, No. 5.] the cause of this is the elongated form of the luminous body *a c*, &c. [Footnote 16: See Footnote 14].

Effects on cast shadows by the tone of the back ground.

198

OF MODIFIED SHADOWS.

Modified shadows are those which are cast on light walls or other illuminated objects.

A shadow looks darkest against a light background. The outlines of a derived shadow will be clearer as they are nearer to the primary shadow. A derived shadow will be most defined in shape where it is intercepted, where the plane intercepts it at the most equal angle.

Those parts of a shadow will appear darkest which have darker objects opposite to them. And they will appear less dark when they face lighter objects. And the larger the light object opposite, the more the shadow will be lightened.

And the larger the surface of the dark object the more it will darken the derived shadow where it is intercepted.

A disputed proposition.

199

OF THE OPINION OF SOME THAT A TRIANGLE CASTS NO SHADOW ON A PLANE SURFACE.

Certain mathematicians have maintained that a triangle, of which the base is turned to the light, casts no shadow on a plane; and this they prove by saying [5] that no spherical body smaller than the light can reach the middle with the shadow. The lines of radiant light are straight lines [6]; therefore, suppose the light to be *g h* and the triangle *l m n*, and let the plane be *i k*; they say the light *g* falls on the side of the triangle *l n*, and the portion of the plane *i q*. Thus again *h* like *g* falls on the side *l m*, and then on *m n* and the plane *p k*; and if the whole plane thus faces the lights *g h*, it is evident that the triangle has no shadow; and that which has no shadow can cast none. This, in this case appears credible. But if the triangle *n p g* were not illuminated by the two lights *g* and *h*, but by *i p* and *g* and *k* neither side is lighted by more than one single light: that is *i p* is invisible to *h g* and *k* will never be lighted by *g*; hence *p q* will be twice as light as the two visible portions that are in shadow.

[Footnote: 5—6. This passage is so obscure that it would be rash to offer an explanation. Several words seem to have been omitted.]

On the relative depth of cast shadows (200-202).

200

A spot is most in the shade when a large number of darkened rays fall upon it. The spot which receives the rays at the widest angle and by darkened rays will be most in the dark; a will be twice as dark as b, because it originates from twice as large a base at an equal distance. A spot is most illuminated when a large number of luminous rays fall upon it. d is the beginning of the shadow *d f*, and tinges *c* but *a* little; *d e* is half of the shadow *d f* and gives a deeper tone where it is cast at *b* than at *f*. And the whole shaded space *e* gives its tone to the spot *a*. [Footnote: The diagram here referred to is on Pl. XLI, No. 2.]

201

A n will be darker than *c r* in proportion to the number of times that *a b* goes into *c d*.

202

The shadow cast by an object on a plane will be smaller in proportion as that object is lighted by feebler rays. Let *d e* be the object and *d c* the plane surface; the number of times that *d e* will go into *f g* gives the proportion of light at *f h* to *d c*. The ray of light will be weaker in proportion to its distance from the hole through which it falls.

FIFTH BOOK ON LIGHT AND SHADE

Principles of reflection (203. 204).

203

OF THE WAY IN WHICH THE SHADOWS CAST BY OBJECTS OUGHT TO BE DEFINED.

If the object is the mountain here figured, and the light is at the point *a*, I say that from *b d* and also from *c f* there will be no light but from reflected rays. And this results from the fact that rays of light can only act in straight lines; and the same is the case with the secondary or reflected rays.

204

The edges of the derived shadow are defined by the hues of the illuminated objects surrounding the luminous body which produces the shadow.

On reverberation.

205

OF REVERBERATION.

Reverberation is caused by bodies of a bright nature with a flat and semi opaque surface which, when the light strikes upon them, throw it back again, like the rebound of a ball, to the former object.

WHERE THERE CAN BE NO REFLECTED LIGHTS.

All dense bodies have their surfaces occupied by various degrees of light and shade. The lights are of two kinds, one called original, the other borrowed. Original light is that which is inherent in the flame of fire or the light of the sun or of the atmosphere. Borrowed light will be reflected light; but to return to the promised definition: I say that this luminous reverberation is not produced by those portions of a body which are turned towards darkened objects, such as shaded spots, fields with grass of various height, woods whether green or bare; in which, though that side of each branch which is turned towards the original light has a share of that light, nevertheless the shadows cast by each branch separately are so numerous, as well as those cast by one branch on the others, that finally so much shadow is the result that the light counts for nothing. Hence objects of this kind cannot throw any reflected light on opposite objects.

Reflection on water (206. 207).

206

PERSPECTIVE.

The shadow or object mirrored in water in motion, that is to say in small wavelets, will always be larger than the external object producing it.

207

It is impossible that an object mirrored on water should correspond in form to the object mirrored, since the centre of the eye is above the surface of the water.

This is made plain in the figure here given, which demonstrates that the eye sees the surface *a b*, and cannot see it at *l f*, and at *r t*; it sees the surface of the image at *r t*, and does not see it in the real object *c d*. Hence it is impossible to see it, as has been said above unless the eye itself is situated on the surface of the water as is shown below [13].

[Footnote: *A* stands for *ochio* [eye], *B* for *aria* [air], *C* for *acqua* [water], *D* for *cateto* [cathetus].—In the original MS. the second diagram is placed below line 13.]

Experiments with the mirror (208-210).

208

THE MIRROR.

If the illuminated object is of the same size as the luminous body and as that in which the light is reflected, the amount of the reflected light will bear the same proportion to the intermediate light as this second light will bear to the first, if both bodies are smooth and white.

209

Describe how it is that no object has its limitation in the mirror but in the eye which sees it in the mirror. For if you look at your face in the mirror, the part resembles the whole in as much as the part is everywhere in the mirror, and the whole is in every part of the same mirror; and the same is true of the whole image of any object placed opposite to this mirror, &c.

210

No man can see the image of another man in a mirror in its proper place with regard to the objects; because every object falls on [the surface of] the mirror at equal angles. And if the one man, who sees the other in the mirror, is not in a direct line with the image he will not see it in the place where it really falls; and if he gets into the line, he covers the other man and puts himself in the place occupied by his image. Let *n o* be the mirror, *b* the eye of your friend and *d* your own eye. Your friend's eye will appear to you at *a*, and to him it will seem that yours is at *c*, and the intersection of the visual rays will occur at *m*, so that either of you touching *m* will touch the eye of the other man which shall be open. And if you touch the eye of the other man in the mirror it will seem to him that you are touching your own.

Appendix:—On shadows in movement (211. 212).

211

OF THE SHADOW AND ITS MOTION.

When two bodies casting shadows, and one in front of the other, are between a window and the wall with some space between them, the shadow of the body which is nearest to the plane of the wall will move if the body nearest to the window is put in transverse motion across the window. To prove this let *a* and *b* be two bodies placed between the window *n m* and the plane surface *o p* with sufficient space between them as shown by the space *a b*. I say that if the body *a* is moved towards *s* the shadow of the body *b* which is at *c* will move towards *d*.

212

OF THE MOTION OF SHADOWS.

The motion of a shadow is always more rapid than that of the body which produces it if the light is stationary. To prove this let *a* be the luminous body, and *b* the body casting the shadow, and *d* the shadow. Then I say that in the time while the solid body moves from *b* to *c*, the shadow *d* will move to *e*; and this proportion in the rapidity of the movements made in the same space of time, is equal to that in the length of the space moved over. Thus, given the proportion of the space moved over by the body *b* to *c*, to that moved over by the shadow *d* to *e*, the proportion in the rapidity of their movements will be the same.

But if the luminous body is also in movement with a velocity equal to that of the solid body, then the shadow and the body that casts it will move with equal speed. And if the luminous body moves more rapidly than the solid body, the motion of the shadow will be slower than that of the body casting it.

But if the luminous body moves more slowly than the solid body, then the shadow will move more rapidly than that body.

SIXTH BOOK ON LIGHT AND SHADE

The effect of rays passing through holes (213. 214).

213

PERSPECTIVE.

If you transmit the rays of the sun through a hole in the shape of a star you will see a beautiful effect of perspective in the spot where the sun's rays fall.

[Footnote: In this and the following chapters of MS. C the order of the original paging has been adhered to, and is shown in parenthesis. Leonardo himself has but rarely worked out the subject of these propositions. The space left for the purpose has occasionally been made use of for quite different matter. Even the numerous diagrams, most of them very delicately sketched, lettered and numbered, which occur on these pages, are hardly ever explained, with the exception of those few which are here given.]

214

No small hole can so modify the convergence of rays of light as to prevent, at a long distance, the transmission of the true form of the luminous body causing them. It is impossible that rays of light passing through a parallel [slit], should not display the form of the body causing them, since all the effects produced by a luminous body are [in fact] the reflection of that body: The moon, shaped like a boat, if transmitted through a hole is figured in the surface [it falls on] as a boatshaped object. [Footnote 8: In the MS. a blank space is left after this question.] Why the eye sees bodies at a distance, larger than they measure on the vertical plane?.

[Footnote: This chapter, taken from another MS. may, as an exception, be placed here, as it refers to the same subject as the preceding section.]

On gradation of shadows (215. 216).

215

Although the breadth and length of lights and shadow will be narrower and shorter in foreshortening, the quality and quantity of the light and shade is not increased nor diminished.

[3]The function of shade and light when diminished by foreshortening, will be to give shadow and to illuminate an object opposite, according to the quality and quantity in which they fall on the body.

[5]In proportion as a derived shadow is nearer to its penultimate extremities the deeper it will appear, *g z* beyond the intersection faces only the part of the shadow [marked] *y z*; this by intersection takes the shadow from *m n* but by direct line it takes the shadow *a m* hence it is twice as deep as *g z*. *Y x*, by intersection takes the shadow *n o*, but by direct line the shadow *n m a*, therefore *x y* is three times as dark as *z g*; *x f*, by intersection faces *o b* and by direct line *o n m a*, therefore we must say that the shadow between *f x* will be four times as dark as the shadow *z g*, because it faces four times as much shadow.

Let *a b* be the side where the primary shadow is, and *b c* the primary light, *d* will be the spot where it is intercepted,*f g* the derived shadow and *f e* the derived light.

And this must be at the beginning of the explanation.

[Footnote: In the original MS. the text of No. 252 precedes the one given here. In the text of No. 215 there is a blank space of about four lines between the lines 2 and 3. The diagram given on Pl. VI, No. 2 is placed between lines 4 and 5. Between lines 5 and 6 there is another space of about three lines and one line left blank between lines 8 and 9. The reader will find the meaning of the whole passage much clearer if he first reads the final lines 11—13. Compare also line 4 of No. 270.]

On relative proportion of light and shadows (216—221).

216

That part of the surface of a body on which the images [reflection] from other bodies placed opposite fall at the largest angle will assume their hue most strongly. In the diagram below, 8 is a larger angle than 4, since its base *a n* is larger than *e n* the base of 4. This diagram below should end at *a n* 4 8. [4]That portion of the illuminated surface on which a shadow is cast will be brightest which lies contiguous to the cast shadow. Just as an object which is lighted up by a greater quantity of luminous rays becomes brighter, so one on which a greater quantity of shadow falls, will be darker.

Let 4 be the side of an illuminated surface 4 8, surrounding the cast shadow *g e* 4. And this spot 4 will be lighter than 8, because less shadow falls on it than on 8. Since 4 faces only the shadow *i n*; and 8 faces and receives the shadow *a e* as well as *i n* which makes it twice as dark. And the same thing happens when you put the atmosphere and the sun in the place of shade and light.

[12] The distribution of shadow, originating in, and limited by, plane surfaces placed near to each other, equal in tone and directly opposite, will be darker at the ends than at the beginning, which will be determined by the incidence of the luminous rays. You will find the same proportion in the depth of the derived shadows *a n* as in the nearness of the luminous bodies *m b*, which cause them; and if the luminous bodies were of equal size you

would still farther find the same proportion in the light cast by the luminous circles and their shadows as in the distance of the said luminous bodies.

[Footnote: The diagram originally placed between lines 3 and 4 is on Pl. VI, No. 3. In the diagram given above line 14 of the original, and here printed in the text, the words *corpo luminoso* [luminous body] are written in the circle *m*, *luminoso* in the circle *b* and *ombroso* [body in shadow] in the circle *o*.]

217

THAT PART OF THE REFLECTION WILL BE BRIGHTEST WHERE THE REFLECTED RAYS ARE SHORTEST.

[2] The darkness occasioned by the casting of combined shadows will be in conformity with its cause, which will originate and terminate between two plane surfaces near together, alike in tone and directly opposite each other.

[4] In proportion as the source of light is larger, the luminous and shadow rays will be more mixed together. This result is produced because wherever there is a larger quantity of luminous rays, there is most light, but where there are fewer there is least light, consequently the shadow rays come in and mingle with them.

[Footnote: Diagrams are inserted before lines 2 and 4.]

218

In all the proportions I lay down it must be understood that the medium between the bodies is always the same. [2] The smaller the luminous body the more distinct will the transmission of the shadows be.

[3] When of two opposite shadows, produced by the same body, one is twice as dark as the other though similar in form, one of the two lights causing them must have twice the diameter that the other has and be at twice the distance from the opaque body. If the object is lowly moved across the luminous body, and the shadow is intercepted at some distance from the object, there will be the same relative proportion between the motion of the derived shadow and the motion of the primary shadow, as between the distance from the object to the light, and that from the object to the spot where the shadow is intercepted; so that though the object is moved slowly the shadow moves fast.

[Footnote: There are diagrams inserted before lines 2 and 3 but they are not reproduced here. The diagram above line 6 is written upon as follows: at *A lume* (light), at *B obbietto* (body), at *C ombra d'obbietto* (shadow of the object).]

219

A luminous body will appear less brilliant when surrounded by a bright background.

[2] I have found that the stars which are nearest to the horizon look larger than the others because light falls upon them from a larger proportion of the solar body than when they are above us; and having more light from the sun they give more light, and the bodies which are most luminous appear the largest. As may be seen by the sun through a mist, and overhead; it appears larger where there is no mist and diminished through mist. No portion of the luminous body is ever visible from any spot within the pyramid of pure derived shadow.

[Footnote: Between lines 1 and 2 there is in the original a large diagram which does not refer to this text.]

220

A body on which the solar rays fall between the thin branches of trees far apart will cast but a single shadow.

[2] If an opaque body and a luminous one are (both) spherical the base of the pyramid of rays will bear the same proportion to the luminous body as the base of the pyramid of shade to the opaque body.

[4] When the transmitted shadow is intercepted by a plane surface placed opposite to it and farther away from the luminous body than from the object [which casts it] it will appear proportionately darker and the edges more distinct.

[Footnote: The diagram which, in the original, is placed above line 2, is similar to the one, here given on page 73 (section 120).—The diagram here given in the margin stands, in the original, between lines 3 and 4.]

221

A body illuminated by the solar rays passing between the thick branches of trees will produce as many shadows as there are branches between the sun and itself.

Where the shadow-rays from an opaque pyramidal body are intercepted they will cast a shadow of bifurcate outline and various depth at the points. A light which is broader than the apex but narrower than the base of an opaque pyramidal body placed in front of it, will cause that pyramid to cast a shadow of bifurcate form and various degrees of depth.

If an opaque body, smaller than the light, casts two shadows and if it is the same size or larger, casts but one, it follows that a pyramidal body, of which part is smaller, part equal to, and part larger than, the luminous body, will cast a bifurcate shadow.

[Footnote: Between lines 2 and 3 there are in the original two large diagrams.]

IV.
Perspective of Disappearance

The theory of the "Prospettiva de' perdimenti" *would, in many important details, be quite unintelligible if it had not been led up by the principles of light and shade on which it is based. The word* "Prospettiva" *in the language of the time included the principles of optics; what Leonardo understood by* "Perdimenti" *will be clearly seen in the early chapters, Nos.* 222—224. *It is in the very nature of the case that the farther explanations given in the subsequent chapters must be limited to general rules. The sections given as* 227—231 *"On indistinctness at short distances" have, it is true, only an indirect bearing on the subject; but on the other hand, the following chapters,* 232—234, *"On indistinctness at great distances," go fully into the matter, and in chapters* 235—239, *which treat "Of the importance of light and shade in the Perspective of Disappearance", the practical issues are distinctly insisted on in their relation to the theory. This is naturally followed by the statements as to "the effect of light or dark backgrounds on the apparent size of bodies"* (*Nos.* 240—250). *At the end I have placed, in the order of the original, those sections from the MS.* C *which treat of the "Perspective of Disappearance" and serve to some extent to complete the treatment of the subject* (251—262).

Definition (222. 223).

222

OF THE DIMINISHED DISTINCTNESS OF THE OUTLINES OF OPAQUE BODIES.

If the real outlines of opaque bodies are indistinguishable at even a very short distance, they will be more so at long distances; and, since it is by its outlines that we are able to know the real form of any opaque body, when by its remoteness we fail to discern it as a whole, much more must we fail to discern its parts and outlines.

223

OF THE DIMINUTION IN PERSPECTIVE OF OPAQUE OBJECTS.

Among opaque objects of equal size the apparent diminution of size will be in proportion to their distance from the eye of the spectator; but it is an inverse proportion, since, where the distance is greater, the opaque body will appear smaller, and the less the distance the larger will the object appear. And this is the fundamental principle of linear perspective and it follows: —[11]every object as it becomes more remote loses first those parts which are smallest. Thus of a horse, we should lose the legs before the head, because the legs are thinner than the head; and the neck before the body for the same reason. Hence it follows that the last part of the horse which would be discernible by the eye would be the mass of the body in an oval form, or rather in a cylindrical form and this would lose its apparent thickness before its length—according to the 2nd rule given above, &c. [Footnote 23: Compare line 11.].

If the eye remains stationary the perspective terminates in the distance in a point. But if the eye moves in a straight [horizontal] line the perspective terminates in a line and the reason is that this line is generated by the motion of the point and our sight; therefore it follows that as we move our sight [eye], the point moves, and as we move the point, the line is generated, &c.

An illustration by experiment.

224

Every visible body, in so far as it affects the eye, includes three attributes; that is to say: mass, form and colour; and the mass is recognisable at a greater distance from the place of its actual existence than either colour or form. Again, colour is discernible at a greater distance than form, but this law does not apply to luminous bodies.

The above proposition is plainly shown and proved by experiment; because: if you see a man close to you, you discern the exact appearance of the mass and of the form and also of the colouring; if he goes to some distance you will not recognise who he is, because the character of the details will disappear, if he goes still farther you will not be able to distinguish his colouring, but he will appear as a dark object, and still farther he will appear as a very small dark rounded object. It appears rounded because distance so greatly diminishes the various details that nothing remains visible but the larger mass. And the reason is this: We know very well that all the images of objects reach the senses by a small aperture in the eye; hence, if the whole horizon *a d* is admitted through such an aperture, the object *b c* being but a very small fraction of this horizon what space can it fill in that minute image of so vast a hemisphere? And because luminous bodies have more power in darkness than any others, it is evident that, as the chamber of the eye is very dark, as is the nature of all colored cavities, the images of distant objects are confused and lost in the great light of the sky; and if they are visible at all, appear dark and black, as every small body must when seen in the diffused light of the atmosphere.

[Footnote: The diagram belonging to this passage is placed between lines 5 and 6; it is No. 4 on Pl. VI.]

A guiding rule.

225

OF THE ATMOSPHERE THAT INTERPOSES BETWEEN THE EYE AND VISIBLE OBJECTS.

An object will appear more or less distinct at the same distance, in proportion as the atmosphere existing between the eye and that object is more or less clear. Hence, as I know that the greater or less quantity of the air that lies between the eye and the object makes the outlines of that object more or less indistinct, you must diminish the definiteness of outline of those objects in proportion to their increasing distance from the eye of the spectator.

An experiment.

226

When I was once in a place on the sea, at an equal distance from the shore and the mountains, the distance from the shore looked much greater than that from the mountains.

On indistinctness at short distances (227-231).

227

If you place an opaque object in front of your eye at a distance of four fingers' breadth, if it is smaller than the space between the two eyes it will not interfere with your seeing any thing that may be beyond it. No object situated beyond another object seen by the eye can be concealed by this [nearer] object if it is smaller than the space from eye to eye.

228

The eye cannot take in a luminous angle which is too close to it.

229

That part of a surface will be better lighted on which the light falls at the greater angle. And that part, on which the shadow falls at the greatest angle, will receive from those rays least of the benefit of the light.

230

OF THE EYE.

The edges of an object placed in front of the pupil of the eye will be less distinct in proportion as they are closer to the eye. This is shown by the edge of the object *n* placed in front of the pupil *d*; in looking at this edge the pupil also sees all the space *a c* which is beyond the edge; and the images the eye receives from that space are mingled with the images of the edge, so that one image confuses the other, and this confusion hinders the pupil from distinguishing the edge.

231

The outlines of objects will be least clear when they are nearest to the eye, and therefore remoter outlines will be clearer. Among objects which are smaller than the pupil of the eye those will be less distinct which are nearer to the eye.

On indistinctness at great distances (232-234).

232

Objects near to the eye will appear larger than those at a distance.

Objects seen with two eyes will appear rounder than if they are seen with only one.

Objects seen between light and shadow will show the most relief.

233

OF PAINTING.

Our true perception of an object diminishes in proportion as its size is diminished by distance.

PERSPECTIVE.

Why objects seen at a distance appear large to the eye and in the image on the vertical plane they appear small.

PERSPECTIVE.

I ask how far away the eye can discern a non-luminous body, as, for instance, a mountain. It will be very plainly visible if the sun is behind it; and could be seen at a greater or less distance according to the sun's place in the sky.

[Footnote: The clue to the solution of this problem (lines 1-3) is given in lines 4-6, No. 232. Objects seen with both eyes appear solid since they are seen from two distinct points of sight separated by the distance between the eyes, but this solidity cannot be represented in a flat drawing. Compare No. 535.]

The importance of light and shade in the perspective of disappearance (235-239).

235

An opaque body seen in a line in which the light falls will reveal no prominences to the eye. For instance, let *a* be the solid body and *c* the light; *c m* and *c n* will be the lines of incidence of the light, that is to say the lines which transmit the light to the object *a*. The eye being at the point *b*, I say that since the light *c* falls on the whole part *m n* the portions in relief on that side will all be illuminated. Hence the eye placed at *c* cannot see any light and shade and, not seeing it, every portion will appear of the same tone, therefore the relief in the prominent or rounded parts will not be visible.

236

OF PAINTING.

When you represent in your work shadows which you can only discern with difficulty, and of which you cannot distinguish the edges so that you apprehend them confusedly, you must not make them sharp or definite lest your work should have a wooden effect.

237

OF PAINTING.

You will observe in drawing that among the shadows some are of undistinguishable gradation and form, as is shown in the 3rd [proposition] which says: Rounded surfaces display as many degrees of light and shade as there are varieties of brightness and darkness reflected from the surrounding objects.

238

OF LIGHT AND SHADE.

You who draw from nature, look (carefully) at the extent, the degree, and the form of the lights and shadows on each muscle; and in their position lengthwise observe towards which muscle the axis of the central line is directed.

239

An object which is [so brilliantly illuminated as to be] almost as bright as light will be visible at a greater distance, and of larger apparent size than is natural to objects so remote.

The effect of light or dark backgrounds on the apparent size of objects (240-250).

240

A shadow will appear dark in proportion to the brilliancy of the light surrounding it and conversely it will be less conspicuous where it is seen against a darker background.

241

OF ORDINARY PERSPECTIVE.

An object of equal breadth and colour throughout, seen against a background of various colours will appear unequal in breadth.

And if an object of equal breadth throughout, but of various colours, is seen against a background of uniform colour, that object will appear of various breadth. And the more the colours of the background or of the object seen against the ground vary, the greater will the apparent variations in the breadth be though the objects seen against the ground be of equal breadth [throughout].

242

A dark object seen against a bright background will appear smaller than it is.

A light object will look larger when it is seen against a background darker than itself.

243

OF LIGHT.

A luminous body when obscured by a dense atmosphere will appear smaller; as may be seen by the moon or sun veiled by mists.

OF LIGHT.

Of several luminous bodies of equal size and brilliancy and at an equal distance, that will look the largest which is surrounded by the darkest background.

OF LIGHT.

I find that any luminous body when seen through a dense and thick mist diminishes in proportion to its distance from the eye. Thus it is with the sun by day, as well as the moon and the other eternal lights by night. And when the air is clear, these luminaries appear larger in proportion as they are farther from the eye.

244

That portion of a body of uniform breadth which is against a lighter background will look narrower [than the rest].

[4] *e* is a given object, itself dark and of uniform breadth; *a b* and *c d* are two backgrounds one darker than the other; *b c* is a bright background, as it might be a spot lighted by the sun through an aperture in a dark room. Then I say that the object *e g* will appear larger at *e f* than at *g h*; because *e f* has a darker background than *g h*; and again at *f g* it will look narrower from being seen by the eye *o*, on the light background *b c*. [Footnote 12: The diagram to which the text, lines 1-11, refers, is placed in the original between lines 3 and 4, and is given on Pl. XLI, No. 3. Lines 12 to 14 are explained by the lower of the two diagrams on Pl. XLI, No. 4. In the original these are placed after line 14.] That part of a luminous body, of equal breadth and brilliancy throughout, will look largest which is seen against the darkest background; and the luminous body will seem on fire.

245

WHY BODIES IN LIGHT AND SHADE HAVE THEIR OUTLINES ALTERED BY THE COLOUR AND BRIGHTNESS OF THE OBJECTS SERVING AS A BACKGROUND TO THEM.

If you look at a body of which the illuminated portion lies and ends against a dark background, that part of the light which will look brightest will be that which lies against the dark [background] at *d*. But if this brighter part lies against a light background, the edge of the object, which is itself light, will be less distinct than before, and the highest light will appear to be between the limit of the background *m f* and the shadow. The same thing is seen with regard to the dark [side], inasmuch as that edge of the shaded portion of the object which lies against a light background, as at *l*, it looks much darker than the rest. But if this shadow lies against a dark background, the edge of the shaded part will appear lighter than before, and the deepest shade will appear between the edge and the light at the point *o*.

[Footnote: In the original diagram *o* is inside the shaded surface at the level of *d*.]

246

An opaque body will appear smaller when it is surrounded by a highly luminous background, and a light body will appear larger when it is seen against a darker background. This may be seen in the height of buildings at night, when lightning flashes behind them; it suddenly seems, when it lightens, as though the height of the building were diminished. For the same reason such buildings look larger in a mist, or by night than when the atmosphere is clear and light.

247

ON LIGHT BETWEEN SHADOWS

When you are drawing any object, remember, in comparing the grades of light in the illuminated portions, that the eye is often deceived by seeing things lighter than they are. And the reason lies in our comparing those parts with the contiguous parts. Since if two [separate] parts are in different grades of light and if the less bright is conterminous with a dark portion and the brighter is conterminous with a light background—as the sky or something equally bright—, then that which is less light, or I should say less radiant, will look the brighter and the brighter will seem the darker.

248

Of objects equally dark in themselves and situated at a considerable and equal distance, that will look the darkest which is farthest above the earth.

249

TO PROVE HOW IT IS THAT LUMINOUS BODIES APPEAR LARGER, AT A DISTANCE, THAN THEY ARE.

If you place two lighted candles side by side half a braccio apart, and go from them to a distance 200 braccia you will see that by the increased size of each they will appear as a single luminous body with the light of the two flames, one braccio wide.

TO PROVE HOW YOU MAY SEE THE REAL SIZE OF LUMINOUS BODIES.

If you wish to see the real size of these luminous bodies, take a very thin board and make in it a hole no bigger than the tag of a lace and place it as close to your eye as possible, so that when you look through this hole, at the said light, you can see a large space of air round it. Then by rapidly moving this board backwards and forwards before your eye you will see the light increase [and diminish].

Propositions on perspective of disappearance from MS. C. (250-262).

250

Of several bodies of equal size and equally distant from the eye, those will look the smallest which are against the lightest background.

Every visible object must be surrounded by light and shade. A perfectly spherical body surrounded by light and shade will appear to have one side larger than the other in proportion as one is more highly lighted than the other.

251

PERSPECTIVE.

No visible object can be well understood and comprehended by the human eye excepting from the difference of the background against which the edges of the object terminate and by which they are bounded, and no object will appear [to stand out] separate from that background so far as the outlines of its borders are concerned. The moon, though it is at a great distance from the sun, when, in an eclipse, it comes between our eyes and the sun, appears to the eyes of men to be close to the sun and affixed to it, because the sun is then the background to the moon.

252

A luminous body will appear more brilliant in proportion as it is surrounded by deeper shadow. [Footnote: The diagram which, in the original, is placed after this text, has no connection with it.]

253

The straight edges of a body will appear broken when they are conterminous with a dark space streaked with rays of light. [Footnote: Here again the diagrams in the original have no connection with the text.]

254

Of several bodies, all equally large and equally distant, that which is most brightly illuminated will appear to the eye nearest and largest. [Footnote: Here again the diagrams in the original have no connection with the text.]

255

If several luminous bodies are seen from a great distance although they are really separate they will appear united as one body.

256

If several objects in shadow, standing very close together, are seen against a bright background they will appear separated by wide intervals.

257

Of several bodies of equal size and tone, that which is farthest will appear the lightest and smallest.

258

Of several objects equal in size, brightness of background and length that which has the flattest surface will look the largest. A bar of iron equally thick throughout and of which half is red hot, affords an example, for the red hot part looks thicker than the rest.

259

Of several bodies of equal size and length, and alike in form and in depth of shade, that will appear smallest which is surrounded by the most luminous background.

260

DIFFERENT PORTIONS OF A WALL SURFACE WILL BE DARKER OR BRIGHTER IN PROPORTION AS THE LIGHT OR SHADOW FALLS ON THEM AT A LARGER ANGLE.

The foregoing proposition can be clearly proved in this way. Let us say that *m q* is the luminous body, then *f g* will be the opaque body; and let *a e* be the above-mentioned plane on which the said angles fall, showing [plainly] the nature and character of their bases. Then: *a* will be more luminous than *b*; the base of the angle *a* is larger than that of *b* and it therefore makes a greater angle which will be *a m q*; and the pyramid *b p m* will be narrower and *m o c* will be still finer, and so on by degrees, in proportion as they are nearer to *e*, the pyramids will become narrower and darker. That portion of the wall will be the darkest where the breadth of the pyramid of shadow is greater than the breadth of the pyramid of light.

At the point *a* the pyramid of light is equal in strength to the pyramid of shadow, because the base *f g* is equal to the base *r f*. At the point *d* the pyramid of light is narrower than the pyramid of shadow by so much as the base *s f* is less than the base *f g*.

Divide the foregoing proposition into two diagrams, one with the pyramids of light and shadow, the other with the pyramids of light [only].

261

Among shadows of equal depth those which are nearest to the eye will look least deep.

262

The more brilliant the light given by a luminous body, the deeper will the shadows be cast by the objects it illuminates.

V.
Theory of colours

Leonardo's theory of colours is even more intimately connected with his principles of light and shade than his Perspective of Disappearance and is in fact merely an appendix or supplement to those principles, as we gather from the titles to sections 264, 267_, and *276*, while others again_ (*Nos*. 281, 282_) are headed_ Prospettiva.

A very few of these chapters are to be found in the oldest copies and editions of the Treatise on Painting, and although the material they afford is but meager and the connection between them but slight, we must still attribute to them a special theoretical value as well as practical utility—all the more so because our knowledge of the theory and use of colours at the time of the Renaissance is still extremely limited.

The reciprocal effects of colours on objects placed opposite each other (263-272).

263

OF PAINTING.

The hue of an illuminated object is affected by that of the luminous body.

264

OF SHADOW.

The surface of any opaque body is affected by the colour of surrounding objects.

265

A shadow is always affected by the colour of the surface on which it is cast.

266

An image produced in a mirror is affected by the colour of the mirror.

267

OF LIGHT AND SHADE.

Every portion of the surface of a body is varied [in hue] by the [reflected] colour of the object that may be opposite to it.

EXAMPLE.

If you place a spherical body between various objects that is to say with [direct] sunlight on one side of it, and on the other a wall illuminated by the sun, which wall may be green or of any other colour, while the surface on which it is placed may be red, and the two lateral sides are in shadow, you will see that the natural colour of that body will assume something of the hue reflected from those objects. The strongest will be [given by] the luminous body; the second by the illuminated wall, the third by the shadows. There will still be a portion which will take a tint from the colour of the edges.

268

The surface of every opaque body is affected by the colour of the objects surrounding it. But this effect will be strong or weak in proportion as those objects are more or less remote and more or less strongly [coloured].

269

OF PAINTING.

The surface of every opaque body assumes the hues reflected from surrounding objects.

The surface of an opaque body assumes the hues of surrounding objects more strongly in proportion as the rays that form the images of those objects strike the surface at more equal angles.

And the surface of an opaque body assumes a stronger hue from the surrounding objects in proportion as that surface is whiter and the colour of the object brighter or more highly illuminated.

270

OF THE RAYS WHICH CONVEY THROUGH THE AIR THE IMAGES OF OBJECTS.

All the minutest parts of the image intersect each other without interfering with each other. To prove this let *r* be one of the sides of the hole, opposite to which let *s* be the eye which sees the lower end *o* of the line *n o*. The other extremity cannot transmit its image to the eye *s* as it has to strike the end *r* and it is the same with regard to *m* at the middle of the line. The case is the same with the upper extremity *n* and the eye *u*. And if the end *n* is red the eye *u* on that side of the holes will not see the green colour of *o*, but only the red of *n* according to the 7th of this where it is said: Every form projects images from itself by the shortest line, which necessarily is a straight line, &c.

[Footnote: 13. This probably refers to the diagram given under No. 66.]

271

OF PAINTING.

The surface of a body assumes in some degree the hue of those around it. The colours of illuminated objects are reflected from the surfaces of one to the other in various spots, according to the various positions of those objects. Let *o* be a blue object in full light, facing all by itself the space *b c* on the white sphere *a b e d e f*, and it will give it a blue tinge, *m* is a yellow body reflected onto the space *a b* at the same time as *o* the blue body, and they give it a green colour (by the 2nd [proposition] of this which shows that blue and yellow make a beautiful green &c.) And the rest will be set forth in the Book on Painting. In that Book it will be shown, that, by transmitting the images of objects and the colours of bodies illuminated by sunlight through a small round perforation and into a dark chamber onto a plane surface, which itself is quite white, &c.

But every thing will be upside down.

Combination of different colours in cast shadows.

272

That which casts the shadow does not face it, because the shadows are produced by the light which causes and surrounds the shadows. The shadow caused by the light *e*, which is yellow, has a blue tinge, because the shadow of the body *a* is cast upon the pavement at *b*, where the blue light falls; and the shadow produced by the light *d*, which is blue, will be yellow at *c*, because the yellow light falls there and the surrounding background to these shadows *b c* will, besides its natural colour, assume a hue compounded of yellow and blue, because it is lighted by the yellow light and by the blue light both at once.

Shadows of various colours, as affected by the lights falling on them. That light which causes the shadow does not face it.

[Footnote: In the original diagram we find in the circle *e* "*giallo*" (yellow) and the cirle *d* "*azurro"* (blue) and also under the circle of shadow to the left "*giallo*" is written and under that to the right "*azurro*".

In the second diagram where four circles are placed in a row we find written, beginning at the left hand, "*giallo*" (yellow), "*azurro*" (blue), "*verde*" (green), "*rosso*" (red).]

The effect of colours in the camera obscura (273-274).

273

The edges of a colour(ed object) transmitted through a small hole are more conspicuous than the central portions.

The edges of the images, of whatever colour, which are transmitted through a small aperture into a dark chamber will always be stronger than the middle portions.

OF THE INTERSECTIONS OF THE IMAGES IN THE PUPIL OF THE EYE.

The intersections of the images as they enter the pupil do not mingle in confusion in the space where that intersection unites them; as is evident, since, if the rays of the sun pass through two panes of glass in close contact, of which one is blue and the other yellow, the rays, in penetrating them, do not become blue or yellow but a beautiful green. And the same thing would happen in the eye, if the images which were yellow or green should mingle where they [meet and] intersect as they enter the pupil. As this does not happen such a mingling does not exist.

OF THE NATURE OF THE RAYS COMPOSED OF THE IMAGES OF OBJECTS, AND OF THEIR INTERSECTIONS.

The directness of the rays which transmit the forms and colours of the bodies whence they proceed does not tinge the air nor can they affect each other by contact where they intersect. They affect only the spot where they vanish and cease to exist, because that spot faces and is faced by the original source of these rays, and no other object, which surrounds that original source can be seen by the eye where these rays are cut off and destroyed, leaving there the spoil they have conveyed to it. And this is proved by the 4th [proposition], on the colour of bodies, which says: The surface of every opaque body is affected by the colour of surrounding objects; hence we may conclude that the spot which, by means of the rays which convey the image, faces —and is faced by the cause of the image, assumes the colour of that object.

On the colours of derived shadows (275. 276).

275

ANY SHADOW CAST BY AN OPAQUE BODY SMALLER THAN THE LIGHT CAUSING THE SHADOW WILL THROW A DERIVED SHADOW WHICH IS TINGED BY THE COLOUR OF THE LIGHT.

Let *n* be the source of the shadow *e f*; it will assume its hue. Let *o* be the source of *h e* which will in the same way be tinged by its hue and so also the colour of *v h* will be affected by *p* which causes it; and the shadow of the triangle *z k y* will be affected by the colour of *q*, because it is produced by it. [7] In proportion as *c d* goes into *a d*, will *n r s* be darker than *m*; and the rest of the space will be shadowless [11]. *f g* is the highest light, because here the whole light of the window *a d* falls; and thus on the opaque body *m e* is in equally high light; *z k y* is a triangle which includes the deepest shadow, because the light *a d* cannot reach any part of it. *x h* is the 2nd grade of shadow, because it receives only 1/3 of the light from the window, that is *c d*. The third grade of shadow is *h e*, where two thirds of the light from the window is visible. The last grade of shadow is *b d e f*, because the highest grade of light from the window falls at *f*.

[Footnote: The diagram Pl. III, No. 1 belongs to this chapter as well as the text given in No. 148. Lines 7-11 (compare lines 8-12 of No. 148) which are written within the diagram, evidently apply to both sections and have therefore been inserted in both.]

276

OF THE COLOURS OF SIMPLE DERIVED SHADOWS.

The colour of derived shadows is always affected by that of the body towards which they are cast. To prove this: let an opaque body be placed between the plane *s c t d* and the blue light *d e* and the red light *a b*, then I say that *d e*, the blue light, will fall on the whole surface *s c t d* excepting at *o p* which is covered by the shadow of the body *q r*, as is shown by the straight lines *d q o e r p*. And the same occurs with the light *a b* which falls on the whole surface *s c t d* excepting at the spot obscured by the shadow *q r*; as is shown by the lines *d q o*, and *e r p*. Hence we may conclude that the shadow *n m* is exposed to the blue light *d e*; but, as the red light *a b* cannot fall there, *n m* will appear as a blue shadow on a red background tinted with blue, because on the surface *s c t d* both lights can fall. But in the shadows only one single light falls; for this reason these shadows are of medium depth, since, if no light whatever mingled with the shadow, it would be of the first degree of darkness &c. But in the shadow at *o p* the blue light does not fall, because the body *q r* interposes and intercepts it there. Only the red light *a b* falls there and tinges the shadow of a red hue and so a ruddy shadow appears on the background of mingled red and blue.

The shadow of *q r* at *o p* is red, being caused by the blue light *d e*; and the shadow of *q r* at *o' p'* is blue being caused by the red light *a b*. Hence we say that the blue light in this instance causes a red derived shadow from the opaque body *q' r'*, while the red light causes the same body to cast a blue derived shadow; but the primary shadow [on the dark side of the body itself] is not of either of those hues, but a mixture of red and blue.

The derived shadows will be equal in depth if they are produced by lights of equal strength and at an equal distance; this is proved. [Footnote 53: The text is unfinished in the original.]

> [Footnote: In the original diagram Leonardo has written within the circle *q r corpo obroso* (body in shadow); at the spot marked *A, luminoso azzurro* (blue luminous body); at *B, luminoso rosso* (red luminous body). At *E* we read *ombra azzurra* (blue tinted shadow) and at *D ombra rossa* (red tinted shadow).]

On the nature of colours (277. 278).

277

No white or black is transparent.

278

OF PAINTING.

[Footnote 2: See Footnote 3] Since white is not a colour but the neutral recipient of every colour [Footnote 3: *il bianco non e colore ma e inpotentia ricettiva d'ogni colore* (white is not a colour, but the neutral recipient of every colour). LEON BATT. ALBERTI "*Della pittura*" libro I, asserts on the contrary: "*Il bianco e'l nero non sono veri colori, ma sono alteratione delli altri colori*" (ed. JANITSCHEK, p. 67; Vienna 1877).], when it is seen in the open air and high up, all its shadows are bluish; and this is caused, according to the 4th [prop.], which says: the surface of every opaque body assumes the hue of the surrounding objects. Now this white [body] being deprived of the light of the sun by the interposition of some body between the sun and itself, all that portion of it which is exposed to the sun and atmosphere assumes the colour of the sun and atmosphere; the side on which the sun does not fall remains in shadow and assumes the hue of the atmosphere. And if this white object did not reflect the green of the fields all the way to the horizon nor get the brightness of the horizon itself, it would certainly appear simply of the same hue as the atmosphere.

On gradations in the depth of colours (279. 280).

279

Since black, when painted next to white, looks no blacker than when next to black; and white when next to black looks no whiter than white, as is seen by the images transmitted through a small hole or by the edges of any opaque screen …

280

OF COLOURS.

Of several colours, all equally white, that will look whitest which is against the darkest background. And black will look intensest against the whitest background.

And red will look most vivid against the yellowest background; and the same is the case with all colours when surrounded by their strongest contrasts.

On the reflection of colours (281-283).

281

PERSPECTIVE.

Every object devoid of colour in itself is more or less tinged by the colour [of the object] placed opposite. This may be seen by experience, inasmuch as any object which mirrors another assumes the colour of the object mirrored in it. And if the surface thus partially coloured is white the portion which has a red reflection will appear red, or any other colour, whether bright or dark.

PERSPECTIVE.

Every opaque and colourless body assumes the hue of the colour reflected on it; as happens with a white wall.

282

PERSPECTIVE.

That side of an object in light and shade which is towards the light transmits the images of its details more distinctly and immediately to the eye than the side which is in shadow.

PERSPECTIVE.

The solar rays reflected on a square mirror will be thrown back to distant objects in a circular form.

PERSPECTIVE.

Any white and opaque surface will be partially coloured by reflections from surrounding objects.

[Footnote 281. 282: The title line of these chapters is in the original simply *"pro"*, which may be an abbreviation for either *Propositione* or *Prospettiva*—taking Prospettiva of course in its widest sense, as we often find it used in Leonardo's writings. The title *"pro"* has here been understood to mean *Prospettiva*, in accordance with the suggestion afforded by page 10b of this same MS., where the first section is headed *Prospettiva* in full (see No. 94), while the four following sections are headed merely *"pro"* (see No. 85).]

283

WHAT PORTION OF A COLOURED SURFACE OUGHT IN REASON TO BE THE MOST INTENSE.

If *a* is the light, and *b* illuminated by it in a direct line, *c*, on which the light cannot fall, is lighted only by reflection from *b* which, let us say, is red. Hence the light reflected from it, will be affected by the hue of the surface causing it and will tinge the surface *c* with red. And if *c* is also red you will see it much more intense than *b*; and if it were yellow you would see there a colour between yellow and red.

On the use of dark and light colours in painting (284—286).

284

WHY BEAUTIFUL COLOURS MUST BE IN THE [HIGHEST] LIGHT.

Since we see that the quality of colour is known [only] by means of light, it is to be supposed that where there is most light the true character of a colour in light will be best seen; and where there is most shadow the colour will be affected by the tone of that. Hence, O Painter! remember to show the true quality of colours in bright lights.

285

An object represented in white and black will display stronger relief than in any other way; hence I would remind you O Painter! to dress your figures in the lightest colours you can, since, if you put them in dark colours, they will be in too slight relief and inconspicuous from a distance. And the reason is that the shadows of all objects are dark. And if you make a dress dark there is little variety in the lights and shadows, while in light colours there are many grades.

286

OF PAINTING.

Colours seen in shadow will display more or less of their natural brilliancy in proportion as they are in fainter or deeper shadow.

But if these same colours are situated in a well-lighted place, they will appear brighter in proportion as the light is more brilliant.

THE ADVERSARY.

The variety of colours in shadow must be as great as that of the colours in the objects in that shadow.

THE ANSWER.

Colours seen in shadow will display less variety in proportion as the shadows in which they lie are deeper. And evidence of this is to be had by looking from an open space into the doorways of dark and shadowy churches, where the pictures which are painted in various colours all look of uniform darkness.

Hence at a considerable distance all the shadows of different colours will appear of the same darkness.

It is the light side of an object in light and shade which shows the true colour.

On the colours of the rainbow (287. 288).

287

Treat of the rainbow in the last book on Painting, but first write the book on colours produced by the mixture of other colours, so as to be able to prove by those painters' colours how the colours of the rainbow are produced.

WHETHER THE COLOURS OF THE RAINBOW ARE PRODUCED BY THE SUN.

The colours of the rainbow are not produced by the sun, for they occur in many ways without the sunshine; as may be seen by holding a glass of water up to the eye; when, in the glass—where there are those minute bubbles always seen in coarse glass—each bubble, even though the sun does not fall on it, will produce on one side all the colours of the rainbow; as you may see by placing the glass between the day light and your eye in such a way as that it is close to the eye, while on one side the glass admits the [diffused] light of the atmosphere, and on the other side the shadow of the wall on one side of the window; either left or right, it matters not which. Then, by turning the glass round you will see these colours all round the bubbles in the glass &c. And the rest shall be said in its place.

THAT THE EYE HAS NO PART IN PRODUCING THE COLOURS OF THE RAINBOW.

In the experiment just described, the eye would seem to have some share in the colours of the rainbow, since these bubbles in the glass do not display the colours except through the medium of the eye. But, if you place the glass full of water on the window sill, in such a position as that the outer side is exposed to the sun's rays, you will see the same colours produced in the spot of light thrown through the glass and upon the floor, in a dark place, below the window; and as the eye is not here concerned in it, we may evidently, and with certainty pronounce that the eye has no share in producing them.

OF THE COLOURS IN THE FEATHERS OF CERTAIN BIRDS.

There are many birds in various regions of the world on whose feathers we see the most splendid colours produced as they move, as we see in our own country in the feathers of peacocks or on the necks of ducks or pigeons, &c.

Again, on the surface of antique glass found underground and on the roots of turnips kept for some time at the bottom of wells or other stagnant waters [we see] that each root displays colours similar to those of the real rainbow. They may also be seen when oil has been placed on the top of water and in the solar rays reflected from the surface of a diamond or beryl; again, through the angular facet of a beryl every dark object against a background of the atmosphere or any thing else equally pale-coloured is surrounded by these rainbow colours between the atmosphere and the dark body; and in many other circumstances which I will not mention, as these suffice for my purpose.

VI.
'Prospettiva de' colri' (Perspective of Colour) and 'Prospettiva aerea' (Aerial Perspective)

Leonardo distinctly separates these branches of his subject, as may be seen in the beginning of No. 295. *Attempts have been made to cast doubts on the results which Leonardo arrived at by experiment on the perspective of colour, but not with justice, as may be seen from the original text of section* 294.

The question as to the composition of the atmosphere, which is inseparable from a discussion on Aerial Perspective, forms a separate theory which is treated at considerable length. Indeed the author enters into it so fully that we cannot escape the conviction that he must have dwelt with particular pleasure on this part of his subject, and that he attached great importance to giving it a character of general applicability.

General rules (289—291).

289

The variety of colour in objects cannot be discerned at a great distance, excepting in those parts which are directly lighted up by the solar rays.

290

As to the colours of objects: at long distances no difference is perceptible in the parts in shadow.

291

OF THE VISIBILITY OF COLOURS.

Which colour strikes most? An object at a distance is most conspicuous, when it is lightest, and the darkest is least visible.

An exceptional case.

292

Of the edges [outlines] of shadows. Some have misty and ill defined edges, others distinct ones.

No opaque body can be devoid of light and shade, except it is in a mist, on ground covered with snow, or when snow is falling on the open country which has no light on it and is surrounded with darkness.

And this occurs [only] in spherical bodies, because in other bodies which have limbs and parts, those sides of limbs which face each other reflect on each other the accidental [hue and tone] of their surface.

An experiment.

293

ALL COLOURS ARE AT A DISTANCE UNDISTINGUISHABLE AND UNDISCERNIBLE.

All colours at a distance are undistinguishable in shadow, because an object which is not in the highest light is incapable of transmitting its image to the eye through an atmosphere more luminous than itself; since the lesser brightness must be absorbed by the greater. For instance: We, in a house, can see that all the colours on the surface of the walls are clearly and instantly visible when the windows of the house are open; but if we were to go out of the house and look in at the windows from a little distance to see the paintings on those walls, instead of the paintings we should see an uniform deep and colourless shadow.

The practice of the prospettiva de colori.

HOW A PAINTER SHOULD CARRY OUT THE PERSPECTIVE OF COLOUR IN PRACTICE.

In order to put into practice this perspective of the variation and loss or diminution of the essential character of colours, observe at every hundred braccia some objects standing in the landscape, such as trees, houses, men and particular places. Then in front of the first tree have a very steady plate of glass and keep your eye very steady, and then, on this plate of glass, draw a tree, tracing it over the form of that tree. Then move it on one side so far as that the real tree is close by the side of the tree you have drawn; then colour your drawing in such a way as that in colour and form the two may be alike, and that both, if you close one eye, seem to be painted on the glass and at the same distance. Then, by the same method, represent a second tree, and a third, with a distance of a hundred braccia between each. And these will serve as a standard and guide whenever you work on your own pictures, wherever they may apply, and will enable you to give due distance in those works. [14] But I have found that as a rule the second is 4/5 of the first when it is 20 braccia beyond it.

[Footnote: This chapter is one of those copied in the Manuscript of the Vatican library Urbinas 1270, and the original text is rendered here with no other alterations, but in the orthography. H. LUDWIG, in his edition of this copy translates lines 14 and 15 thus: "*Ich finde aber als Regel, dass der zweite um vier Funftel des ersten abnimmt, wenn er namlich zwanzig Ellen vom ersten entfernt ist (?)".* He adds in his commentary: "*Das Ende der Nummer ist wohl jedenfalls verstummelt*". However the translation given above shows that it admits of a different rendering.]

The rules of aerial perspective (295—297).

OF AERIAL PERSPECTIVE.

There is another kind of perspective which I call Aerial Perspective, because by the atmosphere we are able to distinguish the variations in distance of different buildings, which appear placed on a single line; as, for instance, when we see several buildings beyond a wall, all of which, as they appear above the top of the wall, look of the same size, while you wish to represent them in a picture as more remote one than another and to give the effect of a somewhat dense atmosphere. You know that in an atmosphere of equal density the remotest objects seen through it, as mountains, in consequence of the great quantity of atmosphere between your eye and them—appear blue and almost of the same hue as the atmosphere itself [Footnote 10: *quado il sole e per leuante* (when the sun is in the East). Apparently the author refers here to morning light in general. H. LUDWIG however translates this passage from the Vatican copy "*wenn namlich die Sonne (dahinter) im Osten steht*".] when the sun is in the East [Footnote 11: See Footnote 10]. Hence you must make the nearest building above the wall of its real colour, but the more distant ones make less defined and bluer. Those you wish should look farthest away you must make proportionately bluer; thus, if one is to be five times as distant, make it five times bluer. And by this rule the buildings which above a [given] line appear of the same size, will plainly be distinguished as to which are the more remote and which larger than the others.

296

The medium lying between the eye and the object seen, tinges that object with its colour, as the blueness of the atmosphere makes the distant mountains appear blue and red glass makes objects seen beyond it, look red. The light shed round them by the stars is obscured by the darkness of the night which lies between the eye and the radiant light of the stars.

297

Take care that the perspective of colour does not disagree with the size of your objects, hat is to say: that the colours diminish from their natural [vividness] in proportion as the objects at various distances dimmish from their natural size.

On the relative density of the atmosphere (298—290).

298

WHY THE ATMOSPHERE MUST BE REPRESENTED AS PALER TOWARDS THE LOWER PORTION.

Because the atmosphere is dense near the earth, and the higher it is the rarer it becomes. When the sun is in the East if you look towards the West and a little way to the South and North, you will see that this dense atmosphere receives more light from the sun than the rarer; because the rays meet with greater resistance. And if the sky, as you see it, ends on a low plain, that lowest portion of the sky will be seen through a denser and whiter atmosphere, which will weaken its true colour as seen through that medium, and there the sky will look whiter than it is above you, where the line of sight travels through a smaller space of air charged with heavy vapour. And if you turn to the East, the atmosphere will appear darker as you look lower down because the luminous rays pass less freely through the lower atmosphere.

299

OF THE MODE OF TREATING REMOTE OBJECTS IN PAINTING.

It is easy to perceive that the atmosphere which lies closest to the level ground is denser than the rest, and that where it is higher up, it is rarer and more transparent. The lower portions of large and lofty objects which are at a distance are not much seen, because you see them along a line which passes through a denser and thicker section of the atmosphere. The summits of such heights are seen along a line which, though it starts from your eye in a dense atmosphere, still, as it ends at the top of those lofty objects, ceases in a much rarer atmosphere than exists at their base; for this reason the farther this line extends from your eye, from point to point the atmosphere becomes more and more rare. Hence, O Painter! when you represent mountains, see that from hill to hill the bases are paler than the summits, and in proportion as they recede beyond each other make the bases paler than the summits; while, the higher they are the more you must show of their true form and colour.

On the colour of the atmosphere (300-307).

300

OF THE COLOUR OF THE ATMOSPHERE.

I say that the blueness we see in the atmosphere is not intrinsic colour, but is caused by warm vapour evaporated in minute and insensible atoms on which the solar rays fall, rendering them luminous against the infinite darkness of the fiery sphere which lies beyond and includes it. And this may be seen, as I saw it by any one going up [Footnote 5: With regard to the place spoken of as *M'oboso* (compare No. 301 line 20) its identity will be discussed under Leonardo's Topographical notes in Vol. II.] Monboso, a peak of the Alps which divide France from Italy. The base of this mountain gives birth to the four rivers which flow in four different directions through the whole of Europe. And no mountain has its base at so great a height as this, which lifts itself almost above the clouds; and snow seldom falls there, but only hail in the summer, when the clouds are highest. And this hail lies [unmelted] there, so that if it were not for the absorption of the rising and falling clouds, which does not happen twice in an age, an enormous mass of ice would be piled up there by the hail, and in the middle of July I found it very considerable. There I saw above me the dark sky, and the sun as it fell on the mountain was far brighter here than in the plains below, because a smaller extent of atmosphere lay between the summit of the mountain and the sun. Again as an illustration of the colour of the atmosphere I will mention the smoke of old and dry wood, which, as it comes out of a chimney, appears to turn very blue, when seen between the eye and the dark distance. But as it rises, and comes between the eye and the bright atmosphere, it at once shows of an ashy grey colour; and this happens because it no longer has darkness beyond it, but this bright and luminous space. If the smoke is from young, green wood, it will not appear blue, because, not being transparent and being full of superabundant moisture, it has the effect of condensed clouds which take distinct lights and shadows like a solid body. The same occurs with the atmosphere, which, when overcharged with moisture appears white, and the small amount of heated moisture makes it dark, of a dark blue colour; and this will suffice us so far as concerns the colour of the atmosphere; though it might be added that, if this transparent blue were the natural colour of the atmosphere, it would follow that wherever a larger mass air intervened between the eye and the element of fire, the azure colour would be more intense; as we see in blue glass and in sapphires, which are darker in proportion as they are larger. But the atmosphere in such circumstances behaves in an opposite manner, inasmuch as where a greater quantity of it lies between the eye and the sphere of fire, it is seen much whiter. This occurs towards the horizon. And the less the extent of atmosphere between the eye and the sphere of fire, the deeper is the blue colour, as may be seen even on low plains. Hence it follows, as I say, that the atmosphere assumes this azure hue by reason of the particles of moisture which catch the rays of the sun. Again, we may note the difference in particles of dust, or particles of smoke, in the sun beams admitted through holes into a dark chamber, when the former will look ash grey and the thin smoke will appear of a most beautiful blue; and it may be seen again in in the dark shadows of distant mountains when the air between the eye and those shadows will look very blue, though the brightest parts of those mountains will not differ much from their true colour. But if any one wishes for a final proof let him paint a board with various colours, among them an intense black; and over all let him lay a very thin and transparent [coating of] white. He will then see that this transparent white will nowhere show a more beautiful blue than over the black—but it must be very thin and finely ground.

[Footnote 7: *reta* here has the sense of *malanno*.]

301

Experience shows us that the air must have darkness beyond it and yet it appears blue. If you produce a small quantity of smoke from dry wood and the rays of the sun fall on this smoke, and if you then place behind the smoke a piece of black velvet on which the sun does not shine, you will see that all the smoke which is between the eye and the black stuff will appear of a beautiful blue colour. And if instead of the velvet you place a white cloth smoke, that is too thick smoke, hinders, and too thin smoke does not produce, the perfection of this blue colour. Hence a moderate amount of smoke produces the finest blue. Water violently ejected in a fine spray and in a dark chamber where the sun beams are admitted produces these blue rays and the more vividly if it is distilled water, and thin smoke looks blue. This I mention in order to show that the blueness of the atmosphere is caused by the darkness beyond it, and these instances are given for those who cannot confirm my experience on Monboso.

302

When the smoke from dry wood is seen between the eye of the spectator and some dark space [or object], it will look blue. Thus the sky looks blue by reason of the darkness beyond it. And if you look towards the horizon of the sky, you will see the atmosphere is not blue, and this is caused by its density. And thus at each degree, as you raise your eyes above the horizon up to the sky over your head, you will see the atmosphere look darker [blue] and this is because a smaller density of air lies between your eye and the [outer] darkness. And if you go to the top of a high mountain the sky will look proportionately darker above you as the atmosphere becomes rarer between you and the [outer] darkness; and this will be more visible at each degree of increasing height till at last we should find darkness.

That smoke will look bluest which rises from the driest wood and which is nearest to the fire and is seen against the darkest background, and with the sunlight upon it.

303

A dark object will appear bluest in proportion as it has a greater mass of luminous atmosphere between it and the eye. As may be seen in the colour of the sky.

304

The atmosphere is blue by reason of the darkness above it because black and white make blue.

305

In the morning the mist is denser above than below, because the sun draws it upwards; hence tall buildings, even if the summit is at the same distance as the base have the summit invisible. Therefore, also, the sky looks darkest [in colour] overhead, and towards the horizon it is not blue but rather between smoke and dust colour.

The atmosphere, when full of mist, is quite devoid of blueness, and only appears of the colour of clouds, which shine white when the weather is fine. And the more you turn to the west the darker it will be, and the brighter as you look to the east. And the verdure of the fields is bluish in a thin mist, but grows grey in a dense one.

The buildings in the west will only show their illuminated side, where the sun shines, and the mist hides the rest. When the sun rises and chases away the haze, the hills on the side where it lifts begin to grow clearer, and look blue, and seem to smoke with the vanishing mists; and the buildings reveal their lights and shadows; through the thinner vapour they show only their lights and through the thicker air nothing at all. This is when the movement of the mist makes it part horizontally, and then the edges of the mist will be indistinct against the blue of the sky, and towards the earth it will look almost like dust blown up. In proportion as the atmosphere is dense the buildings of a city and the trees in a landscape will look fewer, because only the tallest and largest will be seen.

Darkness affects every thing with its hue, and the more an object differs from darkness, the more we see its real and natural colour. The mountains will look few, because only those will be seen which are farthest apart; since, at such a distance, the density increases to such a degree that it causes a brightness by which the darkness of the hills becomes divided and vanishes indeed towards the top. There is less [mist] between lower and nearer hills and yet little is to be distinguished, and least towards the bottom.

306

The surface of an object partakes of the colour of the light which illuminates it; and of the colour of the atmosphere which lies between the eye and that object, that is of the colour of the transparent medium lying between the object and the eye; and among colours of a similar character the second will be of the same tone as the first, and this is caused by the increased thickness of the colour of the medium lying between the object and the eye.

307

OF PAINTING.

Of various colours which are none of them blue that which at a great distance will look bluest is the nearest to black; and so, conversely, the colour which is least like black will at a great distance best preserve its own colour.

Hence the green of fields will assume a bluer hue than yellow or white will, and conversely yellow or white will change less than green, and red still less.

VII.
On the Proportions and on the Movements of the Human Figure

Leonardo's researches on the proportions and movements of the human figure must have been for the most part completed and written before the year 1498; *for LUCA PACIOLO writes, in the dedication to Ludovico il Moro, of his book* Divina Proportione, *which was published in that year:* "Leonardo da venci … hauedo gia co tutta diligetia al degno libro de pictura e movimenti humani posto fine".

The selection of Leonardo's axioms contained in the Vatican copy attributes these words to the author: "e il resto si dira nella universale misura del huomo". (*MANZI, p. 147; LUDWIG, No. 264*). *LOMAZZO, again, in his* Idea del Tempio della Pittura Milano 1590, cap. IV, *says:* "Lionardo Vinci … dimostro anco in figura tutte le proporzioni dei membri del corpo umano".

The Vatican copy includes but very few sections of the "Universale misura del huomo" _and until now nothing has been made known of the original MSS. on the subject which have supplied the very extensive materials for this portion of the work. The collection at Windsor, belonging to her Majesty the Queen, includes by far the most important part of Leonardo's investigations on this subject, constituting about half of the whole of the materials here published; and the large number of original drawings adds greatly to the interest which the subject itself must command. Luca Paciolo would seem to have had these MSS. (which I have distinguished by the initials W. P.) in his mind when he wrote the passage quoted above. Still, certain notes of a later date—such as Nos. 360, 362 and 363, from MS. E, written in 1513—14, sufficiently prove that Leonardo did not consider his earlier studies on the Proportions and Movements of the Human Figure final and complete, as we might suppose from Luca Paciolo's statement. Or else he took the subject up again at a subsequent period, since his former researches had been carried on at Milan between 1490 and 1500. Indeed it is highly probable that the anatomical studies which he was pursuing zvith so much zeal between 1510—16 should have led him to reconsider the subject of Proportion.

Preliminary observations (308. 309).

308

Every man, at three years old is half the full height he will grow to at last.

309

If a man 2 braccia high is too small, one of four is too tall, the medium being what is admirable. Between 2 and 4 comes 3; therefore take a man of 3 braccia in height and measure him by the rule I will give you. If you tell me that I may be mistaken, and judge a man to be well proportioned who does not conform to this division, I answer that you must look at many men of 3 braccia, and out of the larger number who are alike in their limbs choose one of those who are most graceful and take your measurements. The length of the hand is 1/3 of a braccio [8 inches] and this is found 9 times in man. And the face [Footnote 7: The account here given of the *braccio* is of importance in understanding some of the succeeding chapters. *Testa* must here be understood to mean the face. The statements in this section are illustrated in part on Pl. XI.] is the same, and from the pit of the throat to the shoulder, and from the shoulder to the nipple, and from one nipple to the other, and from each nipple to the pit of the throat.

Proportions of the head and face (310-318).

310

The space between the parting of the lips [the mouth] and the base of the nose is one-seventh of the face.

The space from the mouth to the bottom of the chin *c d* is the fourth part of the face and equal to the width of the mouth.

The space from the chin to the base of the nose *e f* is the third part of the face and equal to the length of the nose and to the forehead.

The distance from the middle of the nose to the bottom of the chin *g h*, is half the length of the face.

The distance from the top of the nose, where the eyebrows begin, to the bottom of the chin, *i k*, is two thirds of the face.

The space from the parting of the lips to the top of the chin *l m*, that is where the chin ends and passes into the lower lip of the mouth, is the third of the distance from the parting of the lips to the bottom of the chin and is the twelfth part of the face. From the top to the bottom of the chin *m n* is the sixth part of the face and is the fifty fourth part of a man's height.

From the farthest projection of the chin to the throat *o p* is equal to the space between the mouth and the bottom of the chin, and a fourth of the face.

The distance from the top of the throat to the pit of the throat below *q r* is half the length of the face and the eighteenth part of a man's height.

From the chin to the back of the neck *s t*, is the same distance as between the mouth and the roots of the hair, that is three quarters of the head.

From the chin to the jaw bone *v x* is half the head and equal to the thickness of the neck in profile.

The thickness of the head from the brow to the nape is once and 3/4 that of the neck.

[Footnote: The drawings to this text, lines 1-10 are on Pl. VII, No. I. The two upper sketches of heads, Pl. VII, No. 2, belong to lines 11-14, and in the original are placed immediately below the sketches reproduced on Pl. VII, No. 1.]

311

The distance from the attachment of one ear to the other is equal to that from the meeting of the eyebrows to the chin, and in a fine face the width of the mouth is equal to the length from the parting of the lips to the bottom of the chin.

The cut or depression below the lower lip of the mouth is half way between the bottom of the nose and the bottom of the chin.

The face forms a square in itself; that is its width is from the outer corner of one eye to the other, and its height is from the very top of the nose to the bottom of the lower lip of the mouth; then what remains above and below this square amounts to the height of such another square, *a b* is equal to the space between *c d*; *d n* in the same way to *n c*, and likewise *s r*, *q p*, *h k* are equal to each other.

It is as far between *m* and *s* as from the bottom of the nose to the chin. The ear is exactly as long as the nose. It is as far from *x* to *j* as from the nose to the chin. The parting of the mouth seen in profile slopes to the angle of the jaw. The ear should be as high as from the bottom of the nose to the top of the eye-lid. The space between the eyes is equal to the width of an eye. The ear is over the middle of the neck, when seen in profile. The distance from 4 to 5 is equal to that from s_ to *r*.

[Footnote: See Pl. VIII, No. I, where the text of lines 3-13 is also given in facsimile.]

313

(a b) is equal to (c d).

[Footnote: See Pl. VII, No. 3. Reference may also be made here to two pen and ink drawings of heads in profile with figured measurements, of which there is no description in the MS. These are given on Pl. XVII, No. 2.—A head, to the left, with part of the torso [W. P. 5a], No. 1 on the same plate is from MS. A 2b and in the original occurs on a page with wholly irrelevant text on matters of natural history. M. RAVAISSON in his edition of the Paris MS. A has reproduced this head and discussed it fully [note on page 12]; he has however somewhat altered the original measurements. The complicated calculations which M. RAVAISSON has given appear to me in no way justified. The sketch, as we see it, can hardly have been intended for any thing more than an experimental attempt to ascertain relative proportions. We do not find that Leonardo made use of circular lines in any other study of the proportions of the human head. At the same time we see that the proportions of this sketch are not in accordance with the rules which he usually observed (see for instance No. 310).]

The head $a f$ 1/6 larger than $n f$.

315

From the eyebrow to the junction of the lip with the chin, and the angle of the jaw and the upper angle where the ear joins the temple will be a perfect square. And each side by itself is half the head.

The hollow of the cheek bone occurs half way between the tip of the nose and the top of the jaw bone, which is the lower angle of the setting on of the ear, in the frame here represented.

From the angle of the eye-socket to the ear is as far as the length of the ear, or the third of the face.

[Footnote: See Pl. IX. The text, in the original is written behind the head. The handwriting would seem to indicate a date earlier than 1480. On the same leaf there is a drawing in red chalk of two horsemen of which only a portion of the upper figure is here visible. The whole leaf measures 22 1/2 centimetres wide by 29 long, and is numbered 127 in the top right-hand corner.]

316

From *a* to *b*—that is to say from the roots of the hair in front to the top of the head—ought to be equal to *c d*;—that is from the bottom of the nose to the meeting of the lips in the middle of the mouth. From the inner corner of the eye *m* to the top of the head *a* is as far as from *m* down to the chin *s*. *s c f b* are all at equal distances from each other.

[Footnote: The drawing in silver-point on bluish tinted paper—Pl. X—which belongs to this chapter has been partly drawn over in ink by Leonardo himself.]

317

From the top of the head to the bottom of the chin is 1/9, and from the roots of the hair to the chin is 1/9 of the distance from the roots of the hair to the ground. The greatest width of the face is equal to the space between the mouth and the roots of the hair and is 1/12 of the whole height. From the top of the ear to the top of the head is equal to the distance from the bottom of the chin to the lachrymatory duct of the eye; and also equal to the distance from the angle of the chin to that of the jaw; that is the 1/16 of the whole. The small cartilage which projects over the opening of the ear towards the nose is half-way between the nape and the eyebrow; the thickness of the neck in profile is equal to the space between the chin and the eyes, and to the space between the chin and the jaw, and it is 1/18 of the height of the man.

318

a b, *c d*, *e f*, *g h*, *i k* are equal to each other in size excepting that *d f* is accidental.

[Footnote: See Pl. XI.]

Proportions of the head seen in front (319-321).

319

a n o f are equal to the mouth.

a c and *a f* are equal to the space between one eye and the other.

n m o f q r are equal to half the width of the eye lids, that is from the inner [lachrymatory] corner of the eye to its outer corner; and in like manner the division between the chin and the mouth; and in the same way the narrowest part of the nose between the eyes. And these spaces, each in itself, is the 19th part of the head, *n o* is equal to the length of the eye or of the space between the eyes.

m c is 1/3 of *n m* measuring from the outer corner of the eyelids to the letter *c*. *b s* will be equal to the width of the nostril.

[Footnote: See Pl. XII.]

320

The distance between the centres of the pupils of the eyes is 1/3 of the face. The space between the outer corners of the eyes, that is where the eye ends in the eye socket which contains it, thus the outer corners, is half the face.

The greatest width of the face at the line of the eyes is equal to the distance from the roots of the hair in front to the parting of the lips.

[Footnote: There are, with this section, two sketches of eyes, not reproduced here.]

321

The nose will make a double square; that is the width of the nose at the nostrils goes twice into the length from the tip of the nose to the eyebrows. And, in the same way, in profile the distance from the extreme side of the nostril where it joins the cheek to the tip of the nose is equal to the width of the nose in front from one nostril to the other. If you divide the whole length of the nose—that is from the tip to the insertion of the eyebrows, into 4 equal parts, you will find that one of these parts extends from the tip of the nostrils to the base of the nose, and the upper division lies between the inner corner of the eye and the insertion of the eyebrows; and the two middle parts [together] are equal to the length of the eye from the inner to the outer corner.

[Footnote: The two bottom sketches on Pl. VII, No. 4 face the six lines of this section,—With regard to the proportions of the head in profile see No. 312.]

322

The great toe is the sixth part of the foot, taking the measure in profile, on the inside of the foot, from where this toe springs from the ball of the sole of the foot to its tip *a b*; and it is equal to the distance from the mouth to the bottom of the chin. If you draw the foot in profile from the outside, make the little toe begin at three quarters of the length of the foot, and you will find the same distance from the insertion of this toe as to the farthest prominence of the great toe.

323

For each man respectively the distance between *a b* is equal to *c d*.

324

Relative proportion of the hand and foot.

The foot is as much longer than the hand as the thickness of the arm at the wrist where it is thinnest seen facing.

Again, you will find that the foot is as much longer than the hand as the space between the inner angle of the little toe to the last projection of the big toe, if you measure along the length of the foot.

The palm of the hand without the fingers goes twice into the length of the foot without the toes.

If you hold your hand with the fingers straight out and close together you will find it to be of the same width as the widest part of the foot, that is where it is joined onto the toes.

And if you measure from the prominence of the inner ancle to the end of the great toe you will find this measure to be as long as the whole hand.

From the top angle of the foot to the insertion of the toes is equal to the hand from wrist joint to the tip of the thumb.

The smallest width of the hand is equal to the smallest width of the foot between its joint into the leg and the insertion of the toes.

The width of the heel at the lower part is equal to that of the arm where it joins the hand; and also to the leg where it is thinnest when viewed in front.

The length of the longest toe, from its first division from the great toe to its tip is the fourth of the foot from the centre of the ancle bone to the tip, and it is equal to the width of the mouth. The distance between the mouth and the chin is equal to that of the knuckles and of the three middle fingers and to the length of their first joints if the hand is spread, and equal to the distance from the joint of the thumb to the outset of the nails, that is the fourth part of the hand and of the face.

The space between the extreme poles inside and outside the foot called the ancle or ancle bone *a b* is equal to the space between the mouth and the inner corner of the eye.

325

The foot, from where it is attached to the leg, to the tip of the great toe is as long as the space between the upper part of the chin and the roots of the hair *a b*; and equal to five sixths of the face.

326

a d is a head's length, *c b* is a head's length. The four smaller toes are all equally thick from the nail at the top to the bottom, and are 1/13 of the foot.

[Footnote: See Pl. XIV, No. 1, a drawing of a foot with the text in three lines below it.]

327

The whole length of the foot will lie between the elbow and the wrist and between the elbow and the inner angle of the arm towards the breast when the arm is folded. The foot is as long as the whole head of a man, that is from under the chin to the topmost part of the head[Footnote 2: *nel modo che qui i figurato*. See Pl. VII, No. 4, the upper figure. The text breaks off at the end of line 2 and the text given under No. 321 follows below. It may be here remarked that the second sketch on W. P. 311 has in the original no explanatory text.] in the way here figured.

Proportions of the leg (328-331).

The greatest thickness of the calf of the leg is at a third of its height *a b*, and is a twentieth part thicker than the greatest thickness of the foot.

a c is half of the head, and equal to *d b* and to the insertion of the five toes *e f*. *d k* diminishes one sixth in the leg *g h*. *g h* is 1/3 of the head; *m n* increases one sixth from *a e* and is 7/12 of the head, *o p* is 1/10 less than *d k* and is 6/17 of the head. *a* is at half the distance between *b q*, and is 1/4 of the man. *r* is half way between *s* and *b*[Footnote 11: *b* is here and later on measured on the right side of the foot as seen by the spectator.]. The concavity of the knee outside *r* is higher than that inside *a*. The half of the whole height of the leg from the foot *r*, is half way between the prominence *s* and the ground *b*. *v* is half way between *t* and *b*. The thickness of the thigh seen in front is equal to the greatest width of the face, that is 2/3 of the length from the chin to the top of the head; *z r* is 5/6 of 7 to *v*; *m n* is equal to 7 *v* and is 1/4 of *r b*, *x y* goes 3 times into *r b*, and into *r s*.

[Footnote 22-35: The sketch illustrating these lines is on Pl. XIII, No. 2.]

[Footnote 22: a b *entra in* c f 6 *e* 6 *in* c n. Accurate measurement however obliges us to read 7 for 6.] *a b* goes six times into *c f* and six times into *c n* and is equal to *g h*;

i k l m goes 4 times into *d f*, and 4 times into *d n* and is 3/7 of the foot; *p q r s* goes 3 times into _d f, and 3 times into *b n*; [Footnote: 25. *y* is not to be found on the diagram and *x* occurs twice; this makes the passage very obscure.] *x y* is 1/8 of *x f* and is equal to *n q*. 3 7 is 1/9 of *n f*; 4 5 is 1/10 of *n f* [Footnote: 22-27. Compare with this lines 18-24 of No. 331, and the sketch of a leg in profile Pl. XV.].

I want to know how much a man increases in height by standing on tip-toe and how much *p g* diminishes by stooping; and how much it increases at *n q* likewise in bending the foot.

[Footnote 34: *e f* 4 *dal cazo*. By reading *i* for *e* the sense of this passage is made clear.] *e f* is four times in the distance between the genitals and the sole of the foot; [Footnote 35: 2 is not to be found in the sketch which renders the passage obscure. The two last lines are plainly legible in the facsimile.] 3 7 is six times from 3 to 2 and is equal to *g h* and *i k*.

[Footnote: The drawing of a leg seen in front Pl. XIII, No. 1 belongs to the text from lines 3-21. The measurements in this section should be compared with the text No. 331, lines 1-13, and the sketch of a leg seen in front on Pl. XV.]

329

The length of the foot from the end of the toes to the heel goes twice into that from the heel to the knee, that is where the leg bone [fibula] joins the thigh bone [femur].

330

a n b are equal; *c n d* are equal; *n c* makes two feet; *n d* makes 2 feet.

[Footnote: See the lower sketch, Pl. XIV, No. 1.]

m n o are equal. The narrowest width of the leg seen in front goes 8 times from the sole of the foot to the joint of the knee, and is the same width as the arm, seen in front at the wrist, and as the longest measure of the ear, and as the three chief divisions into which we divide the face; and this measurement goes 4 times from the wrist joint of the hand to the point of the elbow. [14] The foot is as long as the space from the knee between *a* and *b*; and the patella of the knee is as long as the leg between *r* and *s*.

[18] The least thickness of the leg in profile goes 6 times from the sole of the foot to the knee joint and is the same width as the space between the outer corner of the eye and the opening of the ear, and as the thickest part of the arm seen in profile and between the inner corner of the eye and the insertion of the hair.

a b c [*d*] are all relatively of equal length, *c d* goes twice from the sole of the foot to the centre of the knee and the same from the knee to the hip.

[28]*a b c* are equal; *a* to *b* is 2 feet—that is to say measuring from the heel to the tip of the great toe.

[Footnote: See Pl. XV. The text of lines 2-17 is to the left of the front view of the leg, to which it refers. Lines 18-27 are in the middle column and refer to the leg seen in profile and turned to the left, on the right hand side of the writing. Lines 20-30 are above, to the left and apply to the sketch below them.

Some farther remarks on the proportion of the leg will be found in No. 336, lines 6, 7.]

On the central point of the whole body.

332

In kneeling down a man will lose the fourth part of his height.

When a man kneels down with his hands folded on his breast the navel will mark half his height and likewise the points of the elbows.

Half the height of a man who sits—that is from the seat to the top of the head—will be where the arms fold below the breast, and below the shoulders. The seated portion—that is from the seat to the top of the head—will be more than half the man's [whole height] by the length of the scrotum.

[Footnote: See Pl. VIII, No. 2.]

The relative proportions of the torso and of the whole figure.

333

The cubit is one fourth of the height of a man and is equal to the greatest width of the shoulders. From the joint of one shoulder to the other is two faces and is equal to the distance from the top of the breast to the navel. [Footnote 9: *dalla detta somita*. It would seem more accurate to read here *dal detto ombilico*.] From this point to the genitals is a face's length.

[Footnote: Compare with this the sketches on the other page of the same leaf. Pl. VIII, No. 2.]

The relative proportions of the head and of the torso.

334

From the roots of the hair to the top of the breast *a b* is the sixth part of the height of a man and this measure is equal.

From the outside part of one shoulder to the other is the same distance as from the top of the breast to the navel and this measure goes four times from the sole of the foot to the lower end of the nose.

The [thickness of] the arm where it springs from the shoulder in front goes 6 times into the space between the two outside edges of the shoulders and 3 times into the face, and four times into the length of the foot and three into the hand, inside or outside.

[Footnote: The three sketches Pl. XIV, No. 2 belong to this text.]

The relative proportions of the torso and of the leg (335. 336).

335

a b c are equal to each other and to the space from the armpit of the shoulder to the genitals and to the distance from the tip of the fingers of the hand to the joint of the arm, and to the half of the breast; and you must know that *c b* is the third part of the height of a man from the shoulders to the ground; *d e f* are equal to each other and equal to the greatest width of the shoulders.

[Footnote: See Pl. XVI, No. 1.]

336

—Top of the chin—hip—the insertion of the middle finger. The end of the calf of the leg on the inside of the thigh.—The end of the swelling of the shin bone of the leg. [6] The smallest thickness of the leg goes 3 times into the thigh seen in front.

[Footnote: See Pl. XVII, No. 2, middle sketch.]

The relative proportions of the torso and of the foot.

337

The torso *a b* in its thinnest part measures a foot; and from *a* to *b* is 2 feet, which makes two squares to the seat—its thinnest part goes 3 times into the length, thus making 3 squares.

[Footnote: See Pl, VII, No. 2, the lower sketch.]

The proportions of the whole figure (338-341).

338

A man when he lies down is reduced to 1/9 of his height.

339

The opening of the ear, the joint of the shoulder, that of the hip and the ancle are in perpendicular lines; *a n* is equal to *m o*.

[Footnote: See Pl. XVI, No. 2, the upper sketch.]

340

From the chin to the roots of the hair is 1/10 of the whole figure. From the joint of the palm of the hand to the tip of the longest finger is 1/10. From the chin to the top of the head 1/8; and from the pit of the stomach to the top of the breast is 1/6, and from the pit below the breast bone to the top of the head 1/4. From the chin to the nostrils 1/3 Part of the face, the same from the nostrils to the brow and from the brow to the roots of the hair, and the foot is 1/6, the elbow 1/4, the width of the shoulders 1/4.

341

The width of the shoulders is 1/4 of the whole. From the joint of the shoulder to the hand is 1/3, from the parting of the lips to below the shoulder-blade is one foot.

The greatest thickness of a man from the breast to the spine is one 8th of his height and is equal to the space between the bottom of the chin and the top of the head.

The greatest width is at the shoulders and goes 4.

The torso from the front and back.

342

The width of a man under the arms is the same as at the hips.

A man's width across the hips is equal to the distance from the top of the hip to the bottom of the buttock, when a man stands equally balanced on both feet; and there is the same distance from the top of the hip to the armpit. The waist, or narrower part above the hips will be half way between the arm pits and the bottom of the buttock.

[Footnote: The lower sketch Pl. XVI, No. 2, is drawn by the side of line 1.]

Vitruvius' scheme of proportions.

343

Vitruvius, the architect, says in his work on architecture that the measurements of the human body are distributed by Nature as follows: that is that 4 fingers make 1 palm, and 4 palms make 1 foot, 6 palms make 1 cubit; 4 cubits make a man's height. And 4 cubits make one pace and 24 palms make a man; and these measures he used in his buildings. If you open your legs so much as to decrease your height 1/14 and spread and raise your arms till your middle fingers touch the level of the top of your head you must know that the centre of the outspread limbs will be in the navel and the space between the legs will be an equilateral triangle.

The length of a man's outspread arms is equal to his height.

From the roots of the hair to the bottom of the chin is the tenth of a man's height; from the bottom of the chin to the top of his head is one eighth of his height; from the top of the breast to the top of his head will be one sixth of a man. From the top of the breast to the roots of the hair will be the seventh part of the whole man. From the nipples to the top of the head will be the fourth part of a man. The greatest width of the shoulders contains in itself the fourth part of the man. From the elbow to the tip of the hand will be the fifth part of a man; and from the elbow to the angle of the armpit will be the eighth part of the man. The whole hand will be the tenth part of the man; the beginning of the genitals marks the middle of the man. The foot is the seventh part of the man. From the sole of the foot to below the knee will be the fourth part of the man. From below the knee to the beginning of the genitals will be the fourth part of the man. The distance from the bottom of the chin to the nose and from the roots of the hair to the eyebrows is, in each case the same, and like the ear, a third of the face.

[Footnote: See Pl. XVIII. The original leaf is 21 centimetres wide and 33 1/2 long. At the ends of the scale below the figure are written the words *diti* (fingers) and *palmi* (palms). The passage quoted from Vitruvius is Book III, Cap. 1, and Leonardo's drawing is given in the editions of Vitruvius by FRA GIOCONDO (Venezia 1511, fol., Firenze 1513, 8vo.) and by CESARIANO (Como 1521).]

The arm and head.

344

From *b* to *a* is one head, as well as from *c* to *a* and this happens when the elbow forms a right angle.

[Footnote: See Pl. XLI, No. 1.]

Proportions of the arm (345-349).

345

From the tip of the longest finger of the hand to the shoulder joint is four hands or, if you will, four faces.

a b c are equal and each interval is 2 heads.

[Footnote: Lines 1-3 are given on Pl. XV below the front view of the leg; lines 4 and 5 are below again, on the left side. The lettering refers to the bent arm near the text.]

346

The hand from the longest finger to the wrist joint goes 4 times from the tip of the longest finger to the shoulder joint.

347

a b c are equal to each other and to the foot and to the space between the nipple and the navel *d e* will be the third part of the whole man.

f g is the fourth part of a man and is equal to *g h* and measures a cubit.

[Footnote: See Pl. XIX, No. 1. 1. *mamolino* (=*bambino*, little child) may mean here the navel.]

a b goes 4 times into *a c* and 9 into *a m*. The greatest thickness of the arm between the elbow and the hand goes 6 times into *a m* and is equal to *r f*. The greatest thickness of the arm between the shoulder and the elbow goes 4 times into *c m*, and is equal to *h n g*. The smallest thickness of the arm above the elbow *x y* is not the base of a square, but is equal to half the space *h* 3 which is found between the inner joint of the arm and the wrist joint.

[11]The width of the wrist goes 12 times into the whole arm; that is from the tip of the fingers to the shoulder joint; that is 3 times into the hand and 9 into the arm.

The arm when bent is 4 heads.

The arm from the shoulder to the elbow in bending increases in length, that is in the length from the shoulder to the elbow, and this increase is equal to the thickness of the arm at the wrist when seen in profile. And the space between the bottom of the chin and the parting of the lips, is equal to the thickness of the 2 middle fingers, and to the width of the mouth and to the space between the roots of the hair on the forehead and the top of the head [Footnote: *Queste cose*. This passage seems to have been written on purpose to rectify the foregoing lines. The error is explained by the accompanying sketch of the bones of the arm.]. All these distances are equal to each other, but they are not equal to the above-mentioned increase in the arm.

The arm between the elbow and wrist never increases by being bent or extended.

The arm, from the shoulder to the inner joint when extended.

When the arm is extended, *p n* is equal to *n a*. And when it is bent *n a* diminishes 1/6 of its length and *p n* does the same. The outer elbow joint increases 1/7 when bent; and thus by being bent it increases to the length of 2 heads. And on the inner side, by bending, it is found that whereas the arm from where it joins the side to the wrist, was 2 heads and a half, in bending it loses the half head and measures only two: one from the [shoulder] joint to the end [by the elbow], and the other to the hand.

The arm when folded will measure 2 faces up to the shoulder from the elbow and 2 from the elbow to the insertion of the four fingers on the palm of the hand. The length from the base of the fingers to the elbow never alters in any position of the arm.

If the arm is extended it decreases by 1/3 of the length between *b* and *h*; and if—being extended—it is bent, it will increase the half of *o e*. [Footnote 59-61: The figure sketched in the margin is however drawn to different proportions.] The length from the shoulder to the elbow is the same as from the base of the thumb, inside, to the elbow *a b c*.

> [Footnote 62-64: The arm sketch on the margin of the MS. is identically the same as that given below on Pl. XX which may therefore be referred to in this place. In line 62 we read therefore *z c* for *m n*.] The smallest thickness of the arm in profile *z c* goes 6 times between the knuckles of

the hand and the dimple of the elbow when extended and 14 times in the whole arm and 42 in the whole man [64]. The greatest thickness of the arm in profile is equal to the greatest thickness of the arm in front; but the first is placed at a third of the arm from the shoulder joint to the elbow and the other at a third from the elbow towards the hand.

[Footnote: Compare Pl. XVII. Lines 1-10 and 11-15 are written in two columns below the extended arm, and at the tips of the fingers we find the words: *fine d'unghie* (ends of the nails). Part of the text—lines 22 to 25—is visible by the side of the sketches on Pl. XXXV, No. 1.]

349

From the top of the shoulder to the point of the elbow is as far as from that point to the joints of the four fingers with the palm of the hand, and each is 2 faces.

[5]*a e* is equal to the palm of the hand, *r f* and *o g* are equal to half a head and each goes 4 times into *a b* and *b c*. From *c* to *m* is 1/2 a head; *m n* is 1/3 of a head and goes 6 times into *c b* and into *b a*; *a b* loses 1/7 of its length when the arm is extended; *c b* never alters; *o* will always be the middle point between *a* and *s*.

y l is the fleshy part of the arm and measures one head; and when the arm is bent this shrinks 2/5 of its length; *o a* in bending loses 1/6 and so does *o r*.

a b is 1/7 of *r c*. *f s* will be 1/8 of *r c*, and each of those 2 measurements is the largest of the arm; *k h* is the thinnest part between the shoulder and the elbow and it is 1/8 of the whole arm *r c*; *o p* is 1/5 of *r l*; *c z* goes 13 times into *r c*.

[Footnote: See Pl. XX where the text is also seen from lines 5-23.]

The movement of the arm (350-354).

350

In the innermost bend of the joints of every limb the reliefs are converted into a hollow, and likewise every hollow of the innermost bends becomes a convexity when the limb is straightened to the utmost. And in this very great mistakes are often made by those who have insufficient knowledge and trust to their own invention and do not have recourse to the imitation of nature; and these variations occur more in the middle of the sides than in front, and more at the back than at the sides.

351

When the arm is bent at an angle at the elbow, it will produce some angle; the more acute the angle is, the more will the muscles within the bend be shortened; while the muscles outside will become of greater length than before. As is shown in the example; *d c e* will shrink considerably; and *b n* will be much extended.

[Footnote: See Pl. XIX, No. 2.]

352

OF PAINTING.

The arm, as it turns, thrusts back its shoulder towards the middle of the back.

353

The principal movements of the hand are 10; that is forwards, backwards, to right and to left, in a circular motion, up or down, to close and to open, and to spread the fingers or to press them together.

354

OF THE MOTIONS OF THE FINGERS.

The movements of the fingers principally consist in extending and bending them. This extension and bending vary in manner; that is, sometimes they bend altogether at the first joint; sometimes they bend, or extend, half way, at the 2nd joint; and sometimes they bend in their whole length and in all the three joints at once. If the 2 first joints are hindered from bending, then the 3rd joint can be bent with greater ease than before; it can never bend of itself, if the other joints are free, unless all three joints are bent. Besides all these movements there are 4 other principal motions of which 2 are up and down, the two others from side to side; and each of these is effected by a single tendon. From these there follow an infinite number of other movements always effected by two tendons; one tendon ceasing to act, the other takes up the movement. The tendons are made thick inside the fingers and thin outside; and the tendons inside are attached to every joint but outside they are not.

[Footnote 26: This head line has, in the original, no text to follow.] Of the strength [and effect] of the 3 tendons inside the fingers at the 3 joints.

The movement of the torso (355-361).

355

Observe the altered position of the shoulder in all the movements of the arm, going up and down, inwards and outwards, to the back and to the front, and also in circular movements and any others.

And do the same with reference to the neck, hands and feet and the breast above the lips &c.

356

Three are the principal muscles of the shoulder, that is *b c d*, and two are the lateral muscles which move it forward and backward, that is *a o*; *a* moves it forward, and *o* pulls it back; and bed raises it; *a b c* moves it upwards and forwards, and *c d o* upwards and backwards. Its own weight almost suffices to move it downwards.

The muscle *d* acts with the muscle *c* when the arm moves forward; and in moving backward the muscle *b* acts with the muscle *c*.

[Footnote: See Pl. XXI. In the original the lettering has been written in ink upon the red chalk drawing and the outlines of the figures have in most places been inked over.]

357

OF THE LOINS, WHEN BENT.

The loins or backbone being bent. The breasts are are always lower than the shoulderblades of the back.

If the breast bone is arched the breasts are higher than the shoulderblades.

If the loins are upright the breast will always be found at the same level as the shoulderblades.

[Footnote: See Pl. XXII, No. 1.]

358

a b the tendon and ankle in raising the heel approach each other by a finger's breadth; in lowering it they separate by a finger's breadth.

[Footnote: See Pl. XXII, No. 2. Compare this facsimile and text with Pl. III, No. 2, and p. 152 of MANZI'S edition. Also with No. 274 of LUDWIG'S edition of the Vatican Copy.]

359

Just so much as the part *d a* of the nude figure decreases in this position so much does the opposite part increase; that is: in proportion as the length of the part *d a* diminishes the normal size so does the opposite upper part increase beyond its [normal] size. The navel does not change its position to the male organ; and this shrinking arises because when a figure stands on one foot, that foot becomes the centre [of gravity] of the superimposed weight. This being so, the middle between the shoulders is thrust above it out of it perpendicular line, and this line, which forms the central line of the external parts of the body, becomes bent at its upper extremity [so as to be] above the foot which supports the body; and the transverse lines are forced into such angles that their ends are lower on the side which is supported. As is shown at *a b c*.

[Footnote: See Pl. XXII, No. 3.]

360

OF PAINTING.

Note in the motions and attitudes of figures how the limbs vary, and their feeling, for the shoulderblades in the motions of the arms and shoulders vary the [line of the] back bone very much. And you will find all the causes of this in my book of Anatomy.

361

OF [CHANGE OF] ATTITUDE.

The pit of the throat is over the feet, and by throwing one arm forward the pit of the throat is thrown off that foot. And if the leg is thrown forward the pit of the throat is thrown forward; and. so it varies in every attitude.

362

OF PAINTING.

Indicate which are the muscles, and which the tendons, which become prominent or retreat in the different movements of each limb; or which do neither [but are passive]. And remember that these indications of action are of the first importance and necessity in any painter or sculptor who professes to be a master &c.

And indicate the same in a child, and from birth to decrepitude at every stage of its life; as infancy, childhood, boyhood, youth &c.

And in each express the alterations in the limbs and joints, which swell and which grow thinner.

363

O Anatomical Painter! beware lest the too strong indication of the bones, sinews and muscles, be the cause of your becoming wooden in your painting by your wish to make your nude figures display all their feeling. Therefore, in endeavouring to remedy this, look in what manner the muscles clothe or cover their bones in old or lean persons; and besides this, observe the rule as to how these same muscles fill up the spaces of the surface that extend between them, which are the muscles which never lose their prominence in any amount of fatness; and which too are the muscles of which the attachments are lost to sight in the very least plumpness. And in many cases several muscles look like one single muscle in the increase of fat; and in many cases, in growing lean or old, one single muscle divides into several muscles. And in this treatise, each in its place, all their peculiarities will be explained—and particularly as to the spaces between the joints of each limb &c. Again, do not fail [to observe] the variations in the forms of the above mentioned muscles, round and about the joints of the limbs of any animal, as caused by the diversity of the motions of each limb; for on some side of those joints the prominence of these muscles is wholly lost in the increase or diminution of the flesh of which these muscles are composed, &c.

[Footnote: DE ROSSI remarks on this chapter, in the Roman edition of the Trattato, p. 504: "*Non in questo luogo solo, ma in altri ancora osserverŕ il lettore, che Lionardo va fungendo quelli che fanno abuso della loro dottrina anatomica, e sicuramente con ciň ha in mira il suo rivale Bonarroti, che di anatomia facea tanta pompa*." Note, that Leonardo wrote this passage in Rome, probably under the immediate impression of MICHAELANGELO'S paintings in the Sistine Chapel and of RAPHAEL'S Isaiah in Sant' Agostino.]

364

OF THE DIFFERENT MEASUREMENTS OF BOYS AND MEN.

There is a great difference in the length between the joints in men and boys for, in man, from the top of the shoulder [by the neck] to the elbow, and from the elbow to the tip of the thumb and from one shoulder to the other, is in each instance two heads, while in a boy it is but one because Nature constructs in us the mass which is the home of the intellect, before forming that which contains the vital elements.

365

OF PAINTING.

Which are the muscles which subdivide in old age or in youth, when becoming lean? Which are the parts of the limbs of the human frame where no amount of fat makes the flesh thicker, nor any degree of leanness ever diminishes it?

The thing sought for in this question will be found in all the external joints of the bones, as the shoulder, elbow, wrists, finger-joints, hips, knees, ankle-bone and toes and the like; all of which shall be told in its place. The greatest thickness acquired by any limb is at the part of the muscles which is farthest from its attachments.

Flesh never increases on those portions of the limb where the bones are near to the surface.

At *b r d a c e f* the increase or diminution of the flesh never makes any considerable difference. Nature has placed in front of man all those parts which feel most pain under a blow; and these are the shin of the leg, the forehead, and the nose. And this was done for the preservation of man, since, if such pain were not felt in these parts, the number of blows to which they would be exposed must be the cause of their destruction.

Describe why the bones of the arm and leg are double near the hand and foot [respectively].

And where the flesh is thicker or thinner in the bending of the limbs.

366

OF PAINTING.

Every part of the whole must be in proportion to the whole. Thus, if a man is of a stout short figure he will be the same in all his parts: that is with short and thick arms, wide thick hands, with short fingers with their joints of the same character, and so on with the rest. I would have the same thing understood as applying to all animals and plants; in diminishing, [the various parts] do so in due proportion to the size, as also in enlarging.

367

OF THE AGREEMENT OF THE PROPORTION OF THE LIMBS.

And again, remember to be very careful in giving your figures limbs, that they must appear to agree with the size of the body and likewise to the age. Thus a youth has limbs that are not very muscular not strongly veined, and the surface is delicate and round, and tender in colour. In man the limbs are sinewy and muscular, while in old men the surface is wrinkled, rugged and knotty, and the sinews very prominent.

HOW YOUNG BOYS HAVE THEIR JOINTS JUST THE REVERSE OF THOSE OF MEN, AS TO SIZE.

Little children have all the joints slender and the portions between them are thick; and this happens because nothing but the skin covers the joints without any other flesh and has the character of sinew, connecting the bones like a ligature. And the fat fleshiness is laid on between one joint and the next, and between the skin and the bones. But, since the bones are thicker at the joints than between them, as a mass grows up the flesh ceases to have that superfluity which it had, between the skin and the bones; whence the skin clings more closely to the bone and the limbs grow more slender. But since there is nothing over the joints but the cartilaginous and sinewy skin this cannot dry up, and, not drying up, cannot shrink. Thus, and for this reason, children are slender at the joints and fat between the joints; as may be seen in the joints of the fingers, arms, and shoulders, which are slender and dimpled, while in man on the contrary all the joints of the fingers, arms, and legs are thick; and wherever children have hollows men have prominences.

The movement of the human figure (368-375).

368

Of the manner of representing the 18 actions of man. Repose, movement, running, standing, supported, sitting, leaning, kneeling, lying down, suspended. Carrying or being carried, thrusting, pulling, striking, being struck, pressing down and lifting up.

[As to how a figure should stand with a weight in its hand [Footnote 8: The original text ends here.] Remember].

369

A sitting man cannot raise himself if that part of his body which is front of his axis [centre of gravity] does not weigh more than that which is behind that axis [or centre] without using his arms.

A man who is mounting any slope finds that he must involuntarily throw the most weight forward, on the higher foot, rather than behind—that is in front of the axis and not behind it. Hence a man will always, involuntarily, throw the greater weight towards the point whither he desires to move than in any other direction.

The faster a man runs, the more he leans forward towards the point he runs to and throws more weight in front of his axis than behind. A man who runs down hill throws the axis onto his heels, and one who runs up hill throws it into the points of his feet; and a man running on level ground throws it first on his heels and then on the points of his feet.

This man cannot carry his own weight unless, by drawing his body back he balances the weight in front, in such a way as that the foot on which he stands is the centre of gravity.

[Footnote: See Pl. XXII, No. 4.]

370

How a man proceeds to raise himself to his feet, when he is sitting on level ground.

371

A man when walking has his head in advance of his feet.

A man when walking across a long level plain first leans [rather] backwards and then as much forwards.

[Footnote 3-6: He strides forward with the air of a man going down hill; when weary, on the contrary he walks like a man going up hill.]

372

A man when running throws less weight on his legs than when standing still. And in the same way a horse which is running feels less the weight of the man he carries. Hence many persons think it wonderful that, in running, the horse can rest on one single foot. From this it may be stated that when a weight is in progressive motion the more rapid it is the less is the perpendicular weight towards the centre.

373

If a man, in taking a jump from firm ground, can leap 3 braccia, and when he was taking his leap it were to recede 1/3 of a braccio, that would be taken off his former leap; and so if it were thrust forward 1/3 of a braccio, by how much would his leap be increased?

374

OF DRAWING.

When a man who is running wants to neutralise the impetus that carries him on he prepares a contrary impetus which is generated by his hanging backwards. This can be proved, since, if the impetus carries a moving body with a momentum equal to 4 and the moving body wants to turn and fall back with a momentum of 4, then one momentum neutralises the other contrary one, and the impetus is neutralised.

Of walking up and down (375-379)

375

When a man wants to stop running and check the impetus he is forced to hang back and take short quick steps. [Footnote: Lines 5-31 refer to the two upper figures, and the lower figure to the right is explained by the last part of the chapter.] The centre of gravity of a man who lifts one of his feet from the ground always rests on the centre of the sole of the foot [he stands on].

A man, in going up stairs involuntarily throws so much weight forward and on the side of the upper foot as to be a counterpoise to the lower leg, so that the labour of this lower leg is limited to moving itself.

The first thing a man does in mounting steps is to relieve the leg he is about to lift of the weight of the body which was resting on that leg; and besides this, he gives to the opposite leg all the rest of the bulk of the whole man, including [the weight of] the other leg; he then raises the other leg and sets the foot upon the step to which he wishes to raise himself. Having done this he restores to the upper foot all the weight of the body and of the leg itself, and places his hand on his thigh and throws his head forward and repeats the movement towards the point of the upper foot, quickly lifting the heel of the lower one; and with this impetus he lifts himself up and at the same time extends the arm which rested on his knee; and this extension of the arm carries up the body and the head, and so straightens the spine which was curved.

[32] The higher the step is which a man has to mount, the farther forward will he place his head in advance of his upper foot, so as to weigh more on *a* than on *b*; this man will not be on the step *m*. As is shown by the line *g f*.

[Footnote: See Pl. XXIII, No. 1. The lower sketch to the left belongs to the four first lines.]

376

I ask the weight [pressure] of this man at every degree of motion on these steps, what weight he gives to *b* and to *c*.

[Footnote 8: These lines are, in the original, written in ink] Observe the perpendicular line below the centre of gravity of the man.

[Footnote: See Pl. XXIII, No. 2.]

377

In going up stairs if you place your hands on your knees all the labour taken by the arms is removed from the sinews at the back of the knees.

[Footnote: See Pl. XXIII, No. 3.]

378

The sinew which guides the leg, and which is connected with the patella of the knee, feels it a greater labour to carry the man upwards, in proportion as the leg is more bent; and the muscle which acts upon the angle made by the thigh where it joins the body has less difficulty and has a less weight to lift, because it has not the [additional] weight of the thigh itself. And besides this it has stronger muscles, being those which form the buttock.

379

A man coming down hill takes little steps, because the weight rests upon the hinder foot, while a man mounting takes wide steps, because his weight rests on the foremost foot.

[Footnote: See Pl. XXIII, No. 4.]

On the human body in action (380-388).

380

OF THE HUMAN BODY IN ACTION.

When you want to represent a man as moving some weight consider what the movements are that are to be represented by different lines; that is to say either from below upwards, with a simple movement, as a man does who stoops forward to take up a weight which he will lift as he straightens himself. Or as a man does who wants to squash something backwards, or to force it forwards or to pull it downwards with ropes passed through pullies [Footnote 10: Compare the sketch on page 198 and on 201 (S. K. M. II.1 86b).]. And here remember that the weight of a man pulls in proportion as his centre of gravity is distant from his fulcrum, and to this is added the force given by his legs and bent back as he raises himself.

381

Again, a man has even a greater store of strength in his legs than he needs for his own weight; and to see if this is true, make a man stand on the shore-sand and then put another man on his back, and you will see how much he will sink in. Then take the man from off his back and make him jump straight up as high as he can, and you will find that the print of his feet will be made deeper by the jump than from having the man on his back. Hence, here, by 2 methods it is proved that a man has double the strength he requires to support his own body.

382

OF PAINTING.

If you have to draw a man who is in motion, or lifting or pulling, or carrying a weight equal to his own, in what way must you set on his legs below his body?

[Footnote: In the MS. this question remains unanswered.]

383

OF THE STRENGTH OF MAN.

A man pulling a [dead] weight balanced against himself cannot pull more than his own weight. And if he has to raise it he will [be able to] raise as much more than his weight as his strength may be more than that of other men. [Footnote 7: The stroke at the end of this line finishes in the original in a sort of loop or flourish, and a similar flourish occurs at the end of the previous passage written on the same page. M. RAVAISSON regards these as numbers (compare the photograph of page 30b in his edition of MS. A). He remarks: "*Ce chiffre* 8 *et, a la fin de l'alinea precedent, le chiffre* 7 *sont, dans le manuscrit, des renvois*."] The greatest force a man can apply, with equal velocity and impetus, will be when he sets his feet on one end of the balance [or lever] and then presses his shoulders against some stable body. This will raise a weight at the other end of the balance [lever], equal to his own weight and [added to that] as much weight as he can carry on his shoulders.

384

No animal can simply move [by its dead weight] a greater weight than the sum of its own weight outside the centre of his fulcrum.

385

A man who wants to send an arrow very far from the bow must be standing entirely on one foot and raising the other so far from the foot he stands on as to afford the requisite counterpoise to his body which is thrown on the front foot. And he must not hold his arm fully extended, and in order that he may be more able to bear the strain he must hold a piece of wood which there is in all crossbows, extending from the hand to the breast, and when he wishes to shoot he suddenly leaps forward at the same instant and extends his arm with the bow and releases the string. And if he dexterously does every thing at once it will go a very long way.

386

When two men are at the opposite ends of a plank that is balanced, and if they are of equal weight, and if one of them wants to make a leap into the air, then his leap will be made down from his end of the plank and the man will never go up again but must remain in his place till the man at the other end dashes up the board.

[Footnote: See Pl. XXIV, No. 3.]

387

Of delivering a blow to the right or left.

[Footnote: Four sketches on Pl. XXIV, No. 1 belong to this passage. The rest of the sketches and notes on that page are of a miscellaneous nature.]

388

Why an impetus is not spent at once [but diminishes] gradually in some one direction? [Footnote 1: The paper has been damaged at the end of line 1.] The impetus acquired in the line *a b c d* is spent in the line *d e* but not so completely but that some of its force remains in it and to this force is added the momentum in the line *d e* with the force of the motive power, and it must follow than the impetus multiplied by the blow is greater that the simple impetus produced by the momentum *d e*.

> [Footnote 8: The sketch No. 2 on Pl. XXIV stands, in the original, between lines 7 and 8. Compare also the sketches on Pl. LIV.] A man who has to deal a great blow with his weapon prepares himself with all his force on the opposite side to that where the spot is which he is to hit; and this is because a body as it gains in velocity gains in force against the object which impedes its motion.

On hair falling down in curls.

389

Observe the motion of the surface of the water which resembles that of hair, and has two motions, of which one goes on with the flow of the surface, the other forms the lines of the eddies; thus the water forms eddying whirlpools one part of which are due to the impetus of the principal current and the other to the incidental motion and return flow.

[Footnote: See Pl. XXV. Where also the text of this passage is given in facsimile.]

On draperies (390—392).

OF THE NATURE OF THE FOLDS IN DRAPERY.

That part of a fold which is farthest from the ends where it is confined will fall most nearly in its natural form.

Every thing by nature tends to remain at rest. Drapery, being of equal density and thickness on its wrong side and on its right, has a tendency to lie flat; therefore when you give it a fold or plait forcing it out of its flatness note well the result of the constraint in the part where it is most confined; and the part which is farthest from this constraint you will see relapses most into the natural state; that is to say lies free and flowing.

EXAMPLE.

[Footnote 13: *a c sia*. In the original text *b* is written instead of *c*—an evident slip of the pen.] Let *a b c* be the fold of the drapery spoken of above, *a c* will be the places where this folded drapery is held fast. I maintain that the part of the drapery which is farthest from the plaited ends will revert most to its natural form.

Therefore, *b* being farthest from *a* and *c* in the fold *a b c* it will be wider there than anywhere else.

[Footnote: See Pl. XXVIII, No. 6, and compare the drawing from Windsor Pl. XXX for farther illustration of what is here stated.]

391

OF SMALL FOLDS IN DRAPERIES.

How figures dressed in a cloak should not show the shape so much as that the cloak looks as if it were next the flesh; since you surely cannot wish the cloak to be next the flesh, for you must suppose that between the flesh and the cloak there are other garments which prevent the forms of the limbs appearing distinctly through the cloak. And those limbs which you allow to be seen you must make thicker so that the other garments may appear to be under the cloak. But only give something of the true thickness of the limbs to a nymph [Footnote 9: *Una nifa*. Compare the beautiful drawing of a Nymph, in black chalk from the Windsor collection, Pl. XXVI.] or an angel, which are represented in thin draperies, pressed and clinging to the limbs of the figures by the action of the wind.

392

You ought not to give to drapery a great confusion of many folds, but rather only introduce them where they are held by the hands or the arms; the rest you may let fall simply where it is its nature to flow; and do not let the nude forms be broken by too many details and interrupted folds. How draperies should be drawn from nature: that is to say if youwant to represent woollen cloth draw the folds from that; and if it is to be silk, or fine cloth or coarse, or of linen or of crape, vary the folds in each and do not represent dresses, as many do, from models covered with paper or thin leather which will deceive you greatly.

[Footnote: The little pen and ink drawing from Windsor (W. 102), given on Pl. XXVIII, No. 7, clearly illustrates the statement made at the beginning of this passage; the writing of the cipher 19 on the same page is in Leonardo's hand; the cipher 21 is certainly not.]

VIII.
Botany for Painters and Elements of Landscape Painting

The chapters composing this portion of the work consist of observations on Form, Light and Shade in Plants, and particularly in Trees summed up in certain general rules by which the author intends to guide the artist in the pictorial representation of landscape.

With these the first principles of a Theory of Landscape painting *are laid down—a theory as profoundly thought out in its main lines as it is lucidly worked out in its details. In reading these chapters the conviction is irresistible that such a* Botany for painters *is or ought to be of similar importance in the practice of painting as the principles of the Proportions and Movements of the human figure* i. e. Anatomy for painters.

There can be no doubt that Leonardo, in laying down these rules, did not intend to write on Botany in the proper scientific sense—his own researches on that subject have no place here; it need only be observed that they are easily distinguished by their character and contents from those which are here collected and arranged under the title 'Botany for painters'. In some cases where this division might appear doubtful,—as for instance in No. 402 *—the Painter is directly addressed and enjoined to take the rule to* *heart as of special importance in his art.*

The original materials are principally derived from MS. G, *in which we often find this subject treated on several pages in succession without any of that intermixture of other matters, which is so frequent in Leonardo's writings. This MS., too, is one of the latest; when it was written, the great painter was already more than sixty years of age, so we can scarcely doubt that he regarded all he wrote as his final views on the subject. And the same remark applies to the chapters from MSS.* E *and* M *which were also written between* 1513—15.

For the sake of clearness, however, it has been desirable to sacrifice—with few exceptions—the original order of the passages as written, though it was with much reluctance and only after long hesitation that I resigned myself to this necessity. Nor do I mean to impugn the logical connection of the author's ideas in his MS.; but it will be easily understood that the sequence of disconnected notes, as they occurred to Leonardo and were written down from time to time, might be hardly satisfactory as a systematic arrangement of his principles. The reader will find in the Appendix an exact account of the order of the chapters in the original MS. and from the data there given can restore them at will. As the materials are here arranged, the structure of the tree as regards the growth of the branches comes first (394-411) *and then the insertion of the leaves on the stems* (412-419). *Then follow the laws of Light and Shade as applied, first, to the leaves (420-434), and, secondly, to the whole tree and to groups of* *trees* (435-457). *After the remarks on the Light and Shade in landscapes generally* (458-464), *we find special observations on that of views of towns and buildings* (465-469). *To the theory of Landscape Painting belong also the passages on the effect of Wind on Trees* (470-473) *and on the Light and Shade of Clouds* (474-477), *since we find in these certain comparisons with the effect of Light and Shade on Trees* (e. g.: *in No.* 476, 4. 5; *and No.* 477, 9. 12). *The chapters given in the Appendix Nos.* 478 *and* 481 *have hardly any connection with the subjects previously treated.*

Classification of trees.

393

TREES.

Small, lofty, straggling, thick, that is as to foliage, dark, light, russet, branched at the top; some directed towards the eye, some downwards; with white stems; this transparent in the air, that not; some standing close together, some scattered.

The relative thickness of the branches to the trunk (393—396).

394

All the branches of a tree at every stage of its height when put together are equal in thickness to the trunk [below them].

All the branches of a water [course] at every stage of its course, if they are of equal rapidity, are equal to the body of the main stream.

395

Every year when the boughs of a plant [or tree] have made an end of maturing their growth, they will have made, when put together, a thickness equal to that of the main stem; and at every stage of its ramification you will find the thickness of the said main stem; as: *i k*, *g h*, *e f*, *c d*, *a b*, will always be equal to each other; unless the tree is pollard—if so the rule does not hold good.

All the branches have a direction which tends to the centre of the tree *m*.

[Footnote: The two sketches of leafless trees one above another on the left hand side of Pl. XXVII, No. 1, belong to this passage.]

396

If the plant n grows to the thickness shown at m, its branches will correspond [in thickness] to the junction a b in consequence of the growth inside as well as outside.

The branches of trees or plants have a twist wherever a minor branch is given off; and this giving off the branch forms a fork; this said fork occurs between two angles of which the largest will be that which is on the side of the larger branch, and in proportion, unless accident has spoilt it.

[Footnote: The sketches illustrating this are on the right hand side of PI. XXVII, No. I, and the text is also given there in facsimile.]

397

There is no boss on branches which has not been produced by some branch which has failed.

The lower shoots on the branches of trees grow more than the upper ones and this occurs only because the sap that nourishes them, being heavy, tends downwards more than upwards; and again, because those [branches] which grow downwards turn away from the shade which exists towards the centre of the plant. The older the branches are, the greater is the difference between their upper and their lower shoots and in those dating from the same year or epoch.

[Footnote: The sketch accompanying this in the MS. is so effaced that an exact reproduction was impossible.]

398

OF THE SCARS ON TREES.

The scars on trees grow to a greater thickness than is required by the sap of the limb which nourishes them.

399

The plant which gives out the smallest ramifications will preserve the straightest line in the course of its growth.

[Footnote: This passage is illustrated by two partly effaced sketches. One of these closely resembles the lower one given under No. 408, the other also represents short closely set boughs on an upright trunk.]

400

OF THE RAMIFICATION.

The beginning of the ramification [the shoot] always has the central line [axis] of its thickness directed to the central line [axis] of the plant itself.

401

In starting from the main stem the branches always form a base with a prominence as is shown at *a b c d*.

402

WHY, VERY FREQUENTLY, TIMBER HAS VEINS THAT ARE NOT STRAIGHT.

When the branches which grow the second year above the branch of the preceding year, are not of equal thickness above the antecedent branches, but are on one side, then the vigour of the lower branch is diverted to nourish the one above it, although it may be somewhat on one side.

But if the ramifications are equal in their growth, the veins of the main stem will be straight [parallel] and equidistant at every degree of the height of the plant.

Wherefore, O Painter! you, who do not know these laws! in order to escape the blame of those who understand them, it will be well that you should represent every thing from nature, and not despise such study as those do who work [only] for money.

The direction of growth (403-407).

403

OF THE RAMIFICATIONS OF PLANTS.

The plants which spread very much have the angles of the spaces which divide their branches more obtuse in proportion as their point of origin is lower down; that is nearer to the thickest and oldest portion of the tree. Therefore in the youngest portions of the tree the angles of ramification are more acute. [Footnote: Compare the sketches on the lower portion of Pl. XXVII, No. 2.]

404

The tips of the boughs of plants [and trees], unless they are borne down by the weight of their fruits, turn towards the sky as much as possible.

The upper side of their leaves is turned towards the sky that it may receive the nourishment of the dew which falls at night.

The sun gives spirit and life to plants and the earth nourishes them with moisture. [9] With regard to this I made the experiment of leaving only one small root on a gourd and this I kept nourished with water, and the gourd brought to perfection all the fruits it could produce, which were about 60 gourds of the long kind, andi set my mind diligently [to consider] this vitality and perceived that the dews of night were what supplied it abundantly with moisture through the insertion of its large leaves and gave nourishment to the plant and its offspring—or the seeds which its offspring had to produce—[21].

The rule of the leaves produced on the last shoot of the year will be that they will grow in a contrary direction on the twin branches; that is, that the insertion of the leaves turns round each branch in such a way, as that the sixth leaf above is produced over the sixth leaf below, and the way they turn is that if one turns towards its companion to the right, the other turns to the left, the leaf serving as the nourishing breast for the shoot or fruit which grows the following year.

[Footnote: A French translation of lines 9-12 was given by M. RAVAISSON in the *Gazette des Beaux Arts*, Oct. 1877; his paper also contains some valuable information as to botanical science in the ancient classical writers and at the time of the Renaissance.]

405

The lowest branches of those trees which have large leaves and heavy fruits, such as nut-trees, fig-trees and the like, always droop towards the ground.

The branches always originate above [in the axis of] the leaves.

406

The upper shoots of the lateral branches of plants lie closer to the parent branch than the lower ones.

407

The lowest branches, after they have formed the angle of their separation from the parent stem, always bend downwards so as not to crowd against the other branches which follow them on the same stem and to be better able to take the air which nourishes them. As is shown by the angle *b a c*; the branch *a c* after it has made the corner of the angle *a c* bends downwards to *c d* and the lesser shoot *c* dries up, being too thin.

The main branch always goes below, as is shown by the branch *f n m*, which does not go to *f n o*.

The forms of trees (408—411).

408

The elm always gives a greater length to the last branches of the year's growth than to the lower ones; and Nature does this because the highest branches are those which have to add to the size of the tree; and those at the bottom must get dry because they grow in the shade and their growth would be an impediment to the entrance of the solar rays and the air among the main branches of the tree.

The main branches of the lower part bend down more than those above, so as to be more oblique than those upper ones, and also because they are larger and older.

409

In general almost all the upright portions of trees curve somewhat turning the convexity towards the South; and their branches are longer and thicker and more abundant towards the South than towards the North. And this occurs because the sun draws the sap towards that surface of the tree which is nearest to it.

And this may be observed if the sun is not screened off by other plants.

410

The cherry-tree is of the character of the fir tree as regards its ramification placed in stages round its main stem; and its branches spring, 4 or five or 6 [together] opposite each other; and the tips of the topmost shoots form a pyramid from the middle upwards; and the walnut and oak form a hemisphere from the middle upwards.

411

The bough of the walnut which is only hit and beaten when it has brought to perfection…

[Footnote: The end of the text and the sketch in red chalk belonging to it, are entirely effaced.]

The insertion of the leaves (412—419).

412

OF THE INSERTION OF THE BRANCHES ON PLANTS.

Such as the growth of the ramification of plants is on their principal branches, so is that of the leaves on the shoots of the same plant. These leaves have [Footnote 6: *Quattro modi* (four modes). Only three are described in the text, the fourth is only suggested by a sketch.

This passage occurs in MANZI'S edition of the Trattato, p. 399, but without the sketches and the text is mutilated in an important part. The whole passage has been commented on, from MANZI'S version, in Part I of the *Nuovo Giornale Botanico Italiano*, by Prof. G. UZIELLI (Florence 1869, Vol. I). He remarks as to the 'four modes': "*Leonardo, come si vede nelle linie sententi da solo tre esempli. Questa ed altre inessattezze fanno desiderare, sia esaminato di nuovo il manoscritto Vaticano*". This has since been done by D. KNAPP of Tubingen, and his accurate copy has been published by H. LUDWIG, the painter. The passage in question occurs in his edition as No. 833; and there also the drawings are wanting. The space for them has been left vacant, but in the Vatican copy '*niente*' has been written on the margin; and in it, as well as in LUDWIG'S and MANZI'S edition, the text is mutilated.] four modes of growing one above another. The first, which is the most general, is that the sixth always originates over the sixth below [Footnote 8: *la sesta di sotto. "Disposizione 2/5 o 1/5. Leonardo osservo probabilmente soltanto la prima"* (UZIELLl).]; the second is that two third ones above are over the two third ones below [Footnote 10: *terze di sotto: "Intende qui senza dubbio parlare di foglie decussate, in cui il terzo verticello e nel piano del primo"* (UZIELLI).]; and the third way is that the third above is over the third below [Footnote 11: 3a *di sotto: "Disposizione 1/2"* (UZIELLI).].

[Footnote: See the four sketches on the upper portion of the page reproduced as fig. 2 on P1. XXVII.]

413

A DESCRIPTION OF THE ELM.

The ramification of the elm has the largest branch at the top. The first and the last but one are smaller, when the main trunk is straight.

The space between the insertion of one leaf to the rest is half the extreme length of the leaf or somewhat less, for the leaves are at an interval which is about the 3rd of the width of the leaf.

The elm has more leaves near the top of the boughs than at the base; and the broad [surface] of the leaves varies little as to [angle and] aspect.

[Footnote: See Pl. XXVII, No. 3. Above the sketch and close under the number of the page is the word '*olmo*' (elm).]

414

In the walnut tree the leaves which are distributed on the shoots of this year are further apart from each other and more numerous in proportion as the branch from which this shoot springs is a young one. And they are inserted more closely and less in number when the shoot that bears them springs from an old branch. Its fruits are borne at the ends of the shoots. And its largest boughs are the lowest on the boughs they spring from. And this arises from the weight of its sap which is more apt to descend than to rise, and consequently the branches which spring from them and rise towards the sky are small and slender [20]; and when the shoot turns towards the sky its leaves spread out from it [at an angle] with an equal distribution of their tips; and if the shoot turns to the horizon the leaves lie flat; and this arises from the fact that leaves without exception, turn their underside to the earth [29].

The shoots are smaller in proportion as they spring nearer to the base of the bough they spring from.

[Footnote: See the two sketches on Pl XXVII, No. 4. The second refers to the passage lines 20-30.]

415

OF THE INSERTION OF THE LEAVES ON THE BRANCHES.

The thickness of a branch never diminishes within the space between one leaf and the next excepting by so much as the thickness of the bud which is above the leaf and this thickness is taken off from the branch above [the node] as far as the next leaf.

Nature has so placed the leaves of the latest shoots of many plants that the sixth leaf is always above the first, and so on in succession, if the rule is not [accidentally] interfered with; and this occurs for two useful ends in the plant: First that as the shoot and the fruit of the following year spring from the bud or eye which lies above and in close contact with the insertion of the leaf [in the axil], the water which falls upon the shoot can run down to nourish the bud, by the drop being caught in the hollow [axil] at the insertion of the leaf. And the second advantage is, that as these shoots develop in the following year one will not cover the next below, since the 5 come forth on five different sides; and the sixth which is above the first is at some distance.

416

OF THE RAMIFICATIONS OF TREES AND THEIR FOLIAGE.

The ramifications of any tree, such as the elm, are wide and slender after the manner of a hand with spread fingers, foreshortened. And these are seen in the distribution [thus]: the lower portions are seen from above; and those that are above are seen from below; and those in the middle, some from below and some from above. The upper part is the extreme [top] of this ramification and the middle portion is more foreshortened than any other of those which are turned with their tips towards you. And of those parts of the middle of the height of the tree, the longest will be towards the top of the tree and will produce a ramification like the foliage of the common willow, which grows on the banks of rivers.

Other ramifications are spherical, as those of such trees as put forth their shoots and leaves in the order of the sixth being placed above the first. Others are thin and light like the willow and others.

417

You will see in the lower branches of the elder, which puts forth leaves two and two placed crosswise [at right angles] one above another, that if the stem rises straight up towards the sky this order never fails; and its largest leaves are on the thickest part of the stem and the smallest on the slenderest part, that is towards the top. But, to return to the lower branches, I say that the leaves on these are placed on them crosswise like [those on] the upper branches; and as, by the law of all leaves, they are compelled to turn their upper surface towards the sky to catch the dew at night, it is necessary that those so placed should twist round and no longer form a cross.

[Footnote: See Pl. XXVII, No. 5.]

418

A leaf always turns its upper side towards the sky so that it may the better receive, on all its surface, the dew which drops gently from the atmosphere. And these leaves are so distributed on the plant as that one shall cover the other as little as possible, but shall lie alternately one above another as may be seen in the ivy which covers the walls. And this alternation serves two ends; that is, to leave intervals by which the air and sun may penetrate between them. The 2nd reason is that the drops which fall from the first leaf may fall onto the fourth or—in other trees—onto the sixth.

419

Every shoot and every fruit is produced above the insertion [in the axil] of its leaf which serves it as a mother, giving it water from the rain and moisture from the dew which falls at night from above, and often it protects them against the too great heat of the rays of the sun.

LIGHT ON BRANCHES AND LEAVES (420—422).

420

That part of the body will be most illuminated which is hit by the luminous ray coming between right angles.

[Footnote: See Pl. XXVIII, No. 1.]

421

Young plants have more transparent leaves and a more lustrous bark than old ones; and particularly the walnut is lighter coloured in May than in September.

422

OF THE ACCIDENTS OF COLOURING IN TREES.

The accidents of colour in the foliage of trees are 4. That is: shadow, light, lustre [reflected light] and transparency.

OF THE VISIBILITY OF THESE ACCIDENTS.

These accidents of colour in the foliage of trees become confused at a great distance and that which has most breadth [whether light or shade, &c.] will be most conspicuous.

The proportions of light and shade in a leaf (423-426).

423

OF THE SHADOWS OF A LEAF.

Sometimes a leaf has three accidents [of light] that is: shade, lustre [reflected light] and transparency [transmitted light]. Thus, if the light were at *n* as regards the leaf *s*, and the eye at *m*, it would see *a* in full light, *b* in shadow and *c* transparent.

424

A leaf with a concave surface seen from the under side and up-side-down will sometimes show itself as half in shade, and half transparent. Thus, if *o p* is the leaf and the light *m* and the eye *n*, this will see *o* in shadow because the light does not fall upon it between equal angles, neither on the upper nor the under side, and *p* is lighted on the upper side and the light is transmitted to its under side. [Footnote: See Pl. XXVIII, No. 2, the upper sketch on the page. In the original they are drawn in red chalk.]

425

Although those leaves which have a polished surface are to a great extent of the same colour on the right side and on the reverse, it may happen that the side which is turned towards the atmosphere will have something of the colour of the atmosphere; and it will seem to have more of this colour of the atmosphere in proportion as the eye is nearer to it and sees it more foreshortened. And, without exception the shadows show as darker on the upper side than on the lower, from the contrast offered by the high lights which limit the shadows.

The under side of the leaf, although its colour may be in itself the same as that of the upper side, shows a still finer colour—a colour that is green verging on yellow—and this happens when the leaf is placed between

426

the eye and the light which falls upon it from the opposite side.

And its shadows are in the same positions as those were of the opposite side. Therefore, O Painter! when you do trees close at hand, remember that if the eye is almost under the tree you will see its leaves [some] on the upper and [some] on the under side, and the upper side will be bluer in proportion as they are seen more foreshortened, and the same leaf sometimes shows part of the right side and part of the under side, whence you must make it of two colours.

Of the transparency of leaves (427-429).

427

The shadows in transparent leaves seen from the under side are the same shadows as there are on the right side of this leaf, they will show through to the underside together with lights, but the lustre [reflected light] can never show through.

428

When one green has another [green] behind it, the lustre on the leaves and their transparent [lights] show more strongly than in those which are [seen] against the brightness of the atmosphere.

And if the sun illuminates the leaves without their coming between it and the eye and without the eye facing the sun, then the reflected lights and the transparent lights are very strong.

It is very effective to show some branches which are low down and dark and so set off the illuminated greens which are at some distance from the dark greens seen below. That part is darkest which is nearest to the eye or which is farthest from the luminous atmosphere.

429

Never paint leaves transparent to the sun, because they are confused; and this is because on the transparency of one leaf will be seen the shadow of another leaf which is above it. This shadow has a distinct outline and a certain depth of shade and sometimes is [as much as] half or a third of the leaf which is shaded; and consequently such an arrangement is very confused and the imitation of it should be avoided.

The light shines least through a leaf when it falls upon it at an acute angle.

The gradations of shade and colour in leaves (430-434).

430

The shadows of plants are never black, for where the atmosphere penetrates there can never be utter darkness.

431

If the light comes from *m* and the eye is at *n* the eye will see the colour of the leaves *a b* all affected by the colour of *m* —that is of the atmosphere; and *b c* will be seen from the under side as transparent, with a beautiful green colour verging on yellow.

If *m* is the luminous body lighting up the leaf *s* all the eyes that see the under side of this leaf will see it of a beautiful light green, being transparent.

In very many cases the positions of the leaves will be without shadow [or in full light], and their under side will be transparent and the right side lustrous [reflecting light].

432

The willow and other similar trees, which have their boughs lopped every 3 or 4 years, put forth very straight branches, and their shadow is about the middle where these boughs spring; and towards the extreme ends they cast but little shade from having small leaves and few and slender branches. Hence the boughs which rise towards the sky will have but little shade and little relief; and the branches which are at an angle from the horizon, downwards, spring from the dark part of the shadow and grow thinner by degrees up to their ends, and these will be in strong relief, being in gradations of light against a background of shadow.

Конец ознакомительного фрагмента.