the cathedral of Florence, and with similar round windows in its sides. In Pl. LXXXVII No. 2 it is circular like the model actually carried out by Michael Angelo at St. Peter's.

The cupola itself is either hidden under a pyramidal roof, as in the Baptistery of Florence, San Lorenzo of Milan and most of the Lombard churches (Pl. XCI No. 1 and Pl. XCII No. 1); but it more generally suggests the curve of Sta Maria del Fiore (Pl. LXXXVIII No. 5; Pl. XC No. 2; Pl. LXXXIX, M; Pl XC No. 4, Pl. XCVI No. 2). In other cases (Pl. LXXX No. 4; Pl. LXXXIX; Pl. XC No. 2) it shows the sides of the octagon crowned by semicircular pediments, as in Brunellesco's lantern of the Cathedral and in the model for the Cathedral of Pavia.

Finally, in some sketches the cupola is either semicircular, or as in Pl. LXXXVII No. 2, shows the beautiful line, adopted sixty years later by Michael Angelo for the existing dome of St. Peter's.

It is worth noticing that for all these domes Leonardo is not satisfied to decorate the exterior merely with ascending ribs or mouldings, but employs also a system of horizontal parallels to complete the architectural system. Not the least interesting are the designs for the tiburio (cupola) of the Milan Cathedral. They show some of the forms, just mentioned, adapted to the peculiar gothic style of that monument.

The few examples of interiors of churches recall the style employed in Lombardy by Bramante, for instance in S. Maria di Canepanuova at Pavia, or by Dolcebuono in the Monastero Maggiore at Milan (see Pl. CI No. 1 [C. A. 181b; 546b]; Pl. LXXXIV No. 10).

The few indications concerning palaces seem to prove that Leonardo followed Alberti's example of decorating the walls with pilasters and a flat rustica, either in stone or by graffitti (Pl. CII No. 1 and Pl. LXXXV No. 14).

By pointing out the analogies between Leonardo's architecture and that of other masters we in no way pretend to depreciate his individual and original inventive power. These are at all events beyond dispute. The project for the Mausoleum (Pl. XCVIII) would alone suffice to rank him among the greatest architects who ever lived. The peculiar shape of the tower (Pl. LXXX), of the churches for preaching (Pl. XCVII No. 1 and pages 56 and 57, Fig. 1-4), his curious plan for a city with high and low level streets (Pl. LXXVII and LXXVIII No. 2 and No. 3), his Loggia with fountains (Pl. LXXXII No. 4) reveal an originality, a power and facility of invention for almost any given problem, which are quite wonderful.

In addition to all these qualities he propably stood alone in his day in one department of architectural study,--his investigations, namely, as to the resistance of vaults, foundations, walls and arches.

As an application of these studies the plan of a semicircular vault (Pl. CIII No. 2) may be mentioned here, disposed so as to produce no thrust on the columns on which it rests: volta i botte e non ispignie ifori le colone. Above the geometrical patterns on the same sheet, close to a circle inscribed in a square is the note: la ragio d'una volta cioe il terzo del diamitro della sua ... del tedesco in domo.

There are few data by which to judge of Leonardo's style in the treatment of detail. On Pl. LXXXV No. 10 and Pl. CIII No. 3, we find some details of pillars; on Pl. CI No. 3 slender pillars designed for a fountain and on Pl. CIII No. 1 MS. B, is a pen and ink drawing of a vase which also seems intended for a fountain. Three handles seem to have been intended to connect the upper parts with the base. There can be no doubt that Leonardo, like Bramante, but unlike Michael Angelo, brought infinite delicacy of motive and execution to bear on the details of his work.

XIV.

Anatomy, Zoology and Physiology.

Leonardo's eminent place in the history of medicine, as a pioneer in the sciences of Anatomy and Physiology, will never be appreciated till it is possible to publish the mass of manuscripts in which he

largely treated of these two branches of learning. In the present work I must necessarily limit myself to giving the reader a general view of these labours, by publishing his introductory notes to the various books on anatomical subjects. I have added some extracts, and such observations as are scattered incidentally through these treatises, as serving to throw a light on Leonardo's scientific attitude, besides having an interest for a wider circle than that of specialists only.

VASARI expressly mentions Leonardo's anatomical studies, having had occasion to examine the manuscript books which refer to them. According to him Leonardo studied Anatomy in the companionship of Marc Antonio della Torre "aiutato e scambievolmente aiutando."--This learned Anatomist taught the science in the universities first of Padua and then of Pavia, and at Pavia he and Leonardo may have worked and studied together. We have no clue to any exact dates, but in the year 1506 Marc Antonio della Torre seems to have not yet left Padua. He was scarcely thirty years old when he died in 1512, and his writings on anatomy have not only never been published, but no manuscript copy of them is known to exist.

This is not the place to enlarge on the connection between Leonardo and Marc Antonio della Torre. I may however observe that I have not been able to discover in Leonardo's manuscripts on anatomy any mention of his younger contemporary. The few quotations which occur from writers on medicine--either of antiquity or of the middle ages

are printed in Section XXII. Here and there in the manuscripts mention is made of an anonymous "adversary" (avversario) whose views are opposed and refuted by Leonardo, but there is no ground for supposing that Marc Antonio della Torre should have been this "adversary".

Only a very small selection from the mass of anatomical drawings left by Leonardo have been published here in facsimile, but to form any adequate idea of their scientific merit they should be compared with the coarse and inadequate figures given in the published books of the early part of the XVI. century.

William Hunter, the great surgeon--a competent judge--who had an opportunity in the time of George III. of seeing the originals in the King's Library, has thus recorded his opinion: "I expected to see little more than such designs in Anatomy as might be useful to a painter in his own profession. But I saw, and indeed with astonishment, that Leonardo had been a general and deep student. When I consider what pains he has taken upon every part of the body, the superiority of his universal genius, his particular excellence in mechanics and hydraulics, and the attention with which such a man would examine and see objects which he has to draw, I am fully persuaded that Leonardo was the best Anatomist, at that time, in the world ... Leonardo was certainly the first man, we know of, who introduced the practice of making anatomical drawings" (Two introductory letters. London 1784, pages 37 and 39).

The illustrious German Naturalist Johan Friedrich Blumenback esteemed them no less highly; he was one of the privileged few who, after Hunter, had the chance of seeing these Manuscripts. He writes: Der Scharfblick dieses grossen Forschers und Darstellers der Natur hat schon auf Dinge geachtet, die noch Jahrhunderte nachher unbemerkt geblieben sind" (see Blumenbach's medicinische Bibliothek, Vol. 3, St. 4, 1795. page 728).

These opinions were founded on the drawings alone. Up to the present day hardly anything has been made known of the text, and, for the reasons I have given, it is my intention to reproduce here no more than a selection of extracts which I have made from the originals at Windsor Castle and elsewhere. In the Bibliography of the Manuscripts, at the end of this volume a short review is given of the valuable contents of these Anatomical note books which are at present almost all in the possession of her Majesty the Queen of England. It is, I believe, possible to assign the date with approximate accuracy to almost all the fragments, and I am thus led to conclude that the greater part of Leonardo's anatomical investigations were carried out after the death of della Torre.

Merely in reading the introductory notes to his various books on Anatomy which are here printed it is impossible to resist the impression that the Master's anatomical studies bear to a very great extent the stamp of originality and independent thought.

I.

ANATOMY.

796.

A general introduction

I wish to work miracles;--it may be that I shall possess less than other men of more peaceful lives, or than those who want to grow rich in a day. I may live for a long time in great poverty, as always happens, and to all eternity will happen, to alchemists, the would-be creators of gold and silver, and to engineers who would have dead water stir itself into life and perpetual motion, and to those supreme fools, the necromancer and the enchanter.

[Footnote 23: The following seems to be directed against students of painting and young artists rather than against medical men and anatomists.]

And you, who say that it would be better to watch an anatomist at work than to see these drawings, you would be right, if it were possible to observe all the things which are demonstrated in such drawings in a single figure, in which you, with all your cleverness, will not see nor obtain knowledge of more than some few veins, to

obtain a true and perfect knowledge of which I have dissected more than ten human bodies, destroying all the other members, and removing the very minutest particles of the flesh by which these veins are surrounded, without causing them to bleed, excepting the insensible bleeding of the capillary veins; and as one single body would not last so long, since it was necessary to proceed with several bodies by degrees, until I came to an end and had a complete knowledge; this I repeated twice, to learn the differences [59].

[Footnote: Lines 1-59 and 60-89 are written in two parallel columns. When we here find Leonardo putting himself in the same category as the Alchemists and Necromancers, whom he elsewhere mocks at so bitterly, it is evidently meant ironically. In the same way Leonardo, in the introduction to the Books on Perspective sets himself with transparent satire on a level with other writers on the subject.]

And if you should have a love for such things you might be prevented by loathing, and if that did not prevent you, you might be deterred by the fear of living in the night hours in the company of those corpses, quartered and flayed and horrible to see. And if this did not prevent you, perhaps you might not be able to draw so well as is necessary for such a demonstration; or, if you had the skill in drawing, it might not be combined with knowledge of perspective; and if it were so, you might not understand the methods of geometrical demonstration and the method of the calculation of forces and of the

strength of the muscles; patience also may be wanting, so that you lack perseverance. As to whether all these things were found in me or not [Footnote 84: Leonardo frequently, and perhaps habitually, wrote in note books of a very small size and only moderately thick; in most of those which have been preserved undivided, each contains less than fifty leaves. Thus a considerable number of such volumes must have gone to make up a volume of the bulk of the 'Codex Atlanticus' which now contains nearly 1200 detached leaves. In the passage under consideration, which was evidently written at a late period of his life, Leonardo speaks of his Manuscript note-books as numbering 12O; but we should hardly be justified in concluding from this passage that the greater part of his Manuscripts were now missing (see Prolegomena, Vol. I, pp. 5-7).], the hundred and twenty books composed by me will give verdict Yes or No. In these I have been hindered neither by avarice nor negligence, but simply by want of time. Farewell [89].

Plans and suggestions for the arrangement of materials (797-802).

797.

OF THE ORDER OF THE BOOK.

This work must begin with the conception of man, and describe the nature of the womb and how the foetus lives in it, up to what stage it resides there, and in what way it quickens into life and feeds.

Also its growth and what interval there is between one stage of growth and another. What it is that forces it out from the body of the mother, and for what reasons it sometimes comes out of the mother's womb before the due time.

Then I will describe which are the members, which, after the boy is born, grow more than the others, and determine the proportions of a boy of one year.

Then describe the fully grown man and woman, with their proportions, and the nature of their complexions, colour, and physiognomy.

Then how they are composed of veins, tendons, muscles and bones. This I shall do at the end of the book. Then, in four drawings, represent four universal conditions of men. That is, Mirth, with various acts of laughter, and describe the cause of laughter. Weeping in various aspects with its causes. Contention, with various acts of killing; flight, fear, ferocity, boldness, murder and every thing pertaining to such cases. Then represent Labour, with pulling, thrusting, carrying, stopping, supporting and such like things.

Further I would describe attitudes and movements. Then perspective, concerning the functions and effects of the eye; and of hearing--here I will speak of music--, and treat of the other senses.

And then describe the nature of the senses.

This mechanism of man we will demonstrate in ... figures; of which the three first will show the ramification of the bones; that is: first one to show their height and position and shape: the second will be seen in profile and will show the depth of the whole and of the parts, and their position. The third figure will be a demonstration of the bones of the backparts. Then I will make three other figures from the same point of view, with the bones sawn across, in which will be shown their thickness and hollowness. Three other figures of the bones complete, and of the nerves which rise from the nape of the neck, and in what limbs they ramify. And three others of the bones and veins, and where they ramify. Then three figures with the muscles and three with the skin, and their proper proportions; and three of woman, to illustrate the womb and the menstrual veins which go to the breasts.

[Footnote: The meaning of the word nervo varies in different passages, being sometimes used for muscolo (muscle).]

798.

THE ORDER OF THE BOOK.

This depicting of mine of the human body will be as clear to you as if you had the natural man before you; and the reason is that if you

wish thoroughly to know the parts of man, anatomically, you--or your eye--require to see it from different aspects, considering it from below and from above and from its sides, turning it about and seeking the origin of each member; and in this way the natural anatomy is sufficient for your comprehension. But you must understand that this amount of knowledge will not continue to satisfy you; seeing the very great confusion that must result from the combination of tissues, with veins, arteries, nerves, sinews, muscles, bones, and blood which, of itself, tinges every part the same colour. And the veins, which discharge this blood, are not discerned by reason of their smallness. Moreover integrity of the tissues, in the process of the investigating the parts within them, is inevitably destroyed, and their transparent substance being tinged with blood does not allow you to recognise the parts covered by them, from the similarity of their blood-stained hue; and you cannot know everything of the one without confusing and destroying the other. Hence, some further anatomy drawings become necessary. Of which you want three to give full knowledge of the veins and arteries, everything else being destroyed with the greatest care. And three others to display the tissues; and three for the sinews and muscles and ligaments; and three for the bones and cartilages; and three for the anatomy of the bones, which have to be sawn to show which are hollow and which are not, which have marrow and which are spongy, and which are thick from the outside inwards, and which are thin. And some are extremely thin in some parts and thick in others, and in some parts hollow or filled up with bone, or full of

marrow, or spongy. And all these conditions are sometimes found in one and the same bone, and in some bones none of them. And three you must have for the woman, in which there is much that is mysterious by reason of the womb and the foetus. Therefore by my drawings every part will be known to you, and all by means of demonstrations from three different points of view of each part; for when you have seen a limb from the front, with any muscles, sinews, or veins which take their rise from the opposite side, the same limb will be shown to you in a side view or from behind, exactly as if you had that same limb in your hand and were turning it from side to side until you had acquired a full comprehension of all you wished to know. In the same way there will be put before you three or four demonstrations of each limb, from various points of view, so that you will be left with a true and complete knowledge of all you wish to learn of the human figure[Footnote 35: Compare Pl. CVII. The original drawing at Windsor is 28 1/2 X 19 1/2 centimetres. The upper figures are slightly washed with Indian ink. On the back of this drawing is the text No. 1140.].

Thus, in twelve entire figures, you will have set before you the cosmography of this lesser world on the same plan as, before me, was adopted by Ptolemy in his cosmography; and so I will afterwards divide them into limbs as he divided the whole world into provinces; then I will speak of the function of each part in every direction, putting before your eyes a description of the whole form and substance of man, as regards his movements from place to place, by

means of his different parts. And thus, if it please our great Author, I may demonstrate the nature of men, and their customs in the way I describe his figure.

And remember that the anatomy of the nerves will not give the position of their ramifications, nor show you which muscles they branch into, by means of bodies dissected in running water or in lime water; though indeed their origin and starting point may be seen without such water as well as with it. But their ramifications, when under running water, cling and unite--just like flat or hemp carded for spinning--all into a skein, in a way which makes it impossible to trace in which muscles or by what ramification the nerves are distributed among those muscles.

799.

THE ARRANGEMENT OF ANATOMY

First draw the bones, let us say, of the arm, and put in the motor muscle from the shoulder to the elbow with all its lines. Then proceed in the same way from the elbow to the wrist. Then from the wrist to the hand and from the hand to the fingers.

And in the arm you will put the motors of the fingers which open, and these you will show separately in their demonstration. In the second demonstration you will clothe these muscles with the

secondary motors of the fingers and so proceed by degrees to avoid confusion. But first lay on the bones those muscles which lie close to the said bones, without confusion of other muscles; and with these you may put the nerves and veins which supply their nourishment, after having first drawn the tree of veins and nerves over the simple bones.

800.

Begin the anatomy at the head and finish at the sole of the foot.

801.

3 men complete, 3 with bones and nerves, 3 with the bones only. Here we have 12 demonstrations of entire figures.

802.

When you have finished building up the man, you will make the statue with all its superficial measurements.

[Footnote: Cresciere l'omo. The meaning of this expression appears to be different here and in the passage C.A. 157a, 468a (see No. 526, Note 1. 2). Here it can hardly mean anything else than modelling, since the sculptor forms the figure by degrees, by adding wet clay and the figure consequently increases or grows. Tu farai

la statua would then mean, you must work out the figure in marble. If this interpretation is the correct one, this passage would have no right to find a place in the series on anatomical studies. I may say that it was originally inserted in this connection under the impression that di cresciere should be read descrivere.]

Plans for the representation of muscles by drawings (803-809).

803.

You must show all the motions of the bones with their joints to follow the demonstration of the first three figures of the bones, and this should be done in the first book.

804.

Remember that to be certain of the point of origin of any muscle, you must pull the sinew from which the muscle springs in such a way as to see that muscle move, and where it is attached to the ligaments of the bones.

NOTE.

You will never get any thing but confusion in demonstrating the muscles and their positions, origin, and termination, unless you first make a demonstration of thin muscles after the manner of linen

threads; and thus you can represent them, one over another as nature has placed them; and thus, too, you can name them according to the limb they serve; for instance the motor of the point of the great toe, of its middle bone, of its first bone, &c. And when you have the knowledge you will draw, by the side of this, the true form and size and position of each muscle. But remember to give the threads which explain the situation of the muscles in the position which corresponds to the central line of each muscle; and so these threads will demonstrate the form of the leg and their distance in a plain and clear manner.

I have removed the skin from a man who was so shrunk by illness that the muscles were worn down and remained in a state like thin membrane, in such a way that the sinews instead of merging in muscles ended in wide membrane; and where the bones were covered by the skin they had very little over their natural size.

[Footnote: The photograph No. 41 of Grosvenor Gallery Publications: a drawing of the muscles of the foot, includes a complete facsimile of the text of this passage.]

805.

Which nerve causes the motion of the eye so that the motion of one eye moves the other?

Of frowning the brows, of raising the brows, of lowering the brows,--of closing the eyes, of opening the eyes,--of raising the nostrils, of opening the lips, with the teeth shut, of pouting with the lips, of smiling, of astonishment.--

Describe the beginning of man when it is caused in the womb and why an eight months child does not live. What sneezing is. What yawning is. Falling sickness, spasms, paralysis, shivering with cold, sweating, fatigue, hunger, sleepiness, thirst, lust.

Of the nerve which is the cause of movement from the shoulder to the elbow, of the movement from the elbow to the hand, from the joint of the hand to the springing of the fingers. From the springing of the fingers to the middle joints, and from the middle joints to the last.

Of the nerve which causes the movement of the thigh, and from the knee to the foot, and from the joint of the foot to the toes, and then to the middle of the toes and of the rotary motion of the leg.

806.

ANATOMY.

Which nerves or sinews of the hand are those which close and part the fingers and toes latteraly?

807.

Remove by degrees all the parts of the front of a man in making your dissection, till you come to the bones. Description of the parts of the bust and of their motions.

808.

Give the anatomy of the leg up to the hip, in all views and in every action and in every state; veins, arteries, nerves, sinews and muscles, skin and bones; then the bones in sections to show the thickness of the bones.

[Footnote: A straightened leg in profile is sketched by the side of this text.]

On corpulency and leanness (809-811).

809.

Make the rule and give the measurement of each muscle, and give the reasons of all their functions, and in which way they work and what makes them work &c.

[4] First draw the spine of the back; then clothe it by degrees, one

after the other, with each of its muscles and put in the nerves and arteries and veins to each muscle by itself; and besides these note the vertebrae to which they are attached; which of the intestines come in contact with them; and which bones and other organs &c.

The most prominent parts of lean people are most prominent in the muscular, and equally so in fat persons. But concerning the difference in the forms of the muscles in fat persons as compared with muscular persons, it shall be described below.

[Footnote: The two drawings given on Pl. CVIII no. 1 come between lines 3 and 4. A good and very early copy of this drawing without the written text exists in the collection of drawings belonging to Christ's College Oxford, where it is attributed to Leonardo.]

810.

Describe which muscles disappear in growing fat, and which become visible in growing lean.

And observe that that part which on the surface of a fat person is most concave, when he grows lean becomes more prominent.

Where the muscles separate one from another you must give profiles and where they coalesce ...

811.

OF THE HUMAN FIGURE.

Which is the part in man, which, as he grows fatter, never gains flesh?

Or what part which as a man grows lean never falls away with a too perceptible diminution? And among the parts which grow fat which is that which grows fattest?

Among those which grow lean which is that which grows leanest?

In very strong men which are the muscles which are thickest and most prominent?

In your anatomy you must represent all the stages of the limbs from man's creation to his death, and then till the death of the bone; and which part of him is first decayed and which is preserved the longest.

And in the same way of extreme leanness and extreme fatness.

The divisions of the head (812. 813).

812.

ANATOMY.

There are eleven elementary tissues:-- Cartilage, bones, nerves, veins, arteries, fascia, ligament and sinews, skin, muscle and fat.

OF THE HEAD.

The divisions of the head are 10, viz. 5 external and 5 internal, the external are the hair, skin, muscle, fascia and the skull; the internal are the dura mater, the pia mater, [which enclose] the brain. The pia mater and the dura mater come again underneath and enclose the brain; then the rete mirabile, and the occipital bone, which supports the brain from which the nerves spring.

813.

a. hair

n. skin

c. muscle

m. fascia

o. skull i.e. bone

b. dura mater

d. pia mater

f. brain

r. pia mater, below

t. dura mater

l. rete mirablile

s. the occipitul bone.

[Footnote: See Pl. CVIII, No. 3.]

Physiological problems (814. 815).

814.

Of the cause of breathing, of the cause of the motion of the heart, of the cause of vomiting, of the cause of the descent of food from the stomach, of the cause of emptying the intestines.

Of the cause of the movement of the superfluous matter through the

intestines.

Of the cause of swallowing, of the cause of coughing, of the cause of yawning, of the cause of sneezing, of the cause of limbs getting asleep.

Of the cause of losing sensibility in any limb.

Of the cause of tickling.

Of the cause of lust and other appetites of the body, of the cause of urine and also of all the natural excretions of the body.

[Footnote: By the side of this text stands the pen and ink drawing reproduced on Pl. CVIII, No. 4; a skull with indications of the veins in the fleshy covering.]

815.

The tears come from the heart and not from the brain.

Define all the parts, of which the body is composed, beginning with the skin with its outer cuticle which is often chapped by the influence of the sun.

II.

ZOOLOGY AND COMPARATIVE ANATOMY.

The divisions of the animal kingdom (816. 817).

816.

Man. The description of man, which includes that of such creatures as are of almost the same species, as Apes, Monkeys and the like, which are many,

The Lion and its kindred, as Panthers. [Footnote 3: Leonza--wild cat? "Secondo alcuni, lo stesso che Leonessa; e secondo altri con piu certezza, lo stesso che Pantera" FANFANI, Vocabolario page 858.] Wildcats (?) Tigers, Leopards, Wolfs, Lynxes, Spanish cats, common cats and the like.

The Horse and its kindred, as Mule, Ass and the like, with incisor teeth above and below.

The Bull and its allies with horns and without upper incisors as the Buffalo, Stag Fallow Deer, Wild Goat, Swine, Goat, wild Goats Muskdeers, Chamois, Giraffe.

817.

Describe the various forms of the intestines of the human species, of apes and such like. Then, in what way the leonine species differ, and then the bovine, and finally birds; and arrange this description after the manner of a disquisition.

Miscellaneous notes on the study of Zoology (818-821).

818.

Procure the placenta of a calf when it is born and observe the form of the cotyledons, if their cotyledons are male or female.

819.

Describe the tongue of the woodpecker and the jaw of the crocodile.

820.

Of the flight of the 4th kind of butterflies that consume winged ants. Of the three principal positions of the wings of birds in downward flight.

[Footnote: A passing allusion is all I can here permit myself to Leonardo's elaborate researches into the flight of birds. Compare the observations on this subject in the Introduction to section XVIII and in the Bibliography of Manuscripts at the end of the

work.]

821.

Of the way in which the tail of a fish acts in propelling the fish; as in the eel, snake and leech.

[Footnote: A sketch of a fish, swimming upwards is in the original, inserted above this text.--Compare No. 1114.]

Comparative study of the structure of bones and of the action of muscles (822-826).

822.

OF THE PALM OF THE HAND.

Then I will discourse of the hands of each animal to show in what they vary; as in the bear, which has the ligatures of the sinews of the toes joined above the instep.

823.

A second demonstration inserted between anatomy and [the treatise on] the living being.

You will represent here for a comparison, the legs of a frog, which have a great resemblance to the legs of man, both in the bones and in the muscles. Then, in continuation, the hind legs of the hare, which are very muscular, with strong active muscles, because they are not encumbered with fat.

[Footnote: This text is written by the side of a drawing in black chalk of a nude male figure, but there is no connection between the sketch and the text.]

824.

Here I make a note to demonstrate the difference there is between man and the horse and in the same way with other animals. And first I will begin with the bones, and then will go on to all the muscles which spring from the bones without tendons and end in them in the same way, and then go on to those which start with a single tendon at one end.

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

825.

Note on the bendings of joints and in what way the flesh grows upon them in their flexions or extensions; and of this most important study write a separate treatise: in the description of the movements

of animals with four feet; among which is man, who likewise in his infancy crawls on all fours.

826.

OF THE WAY OF WALKING IN MAN.

The walking of man is always after the universal manner of walking in animals with 4 legs, inasmuch as just as they move their feet crosswise after the manner of a horse in trotting, so man moves his 4 limbs crosswise; that is, if he puts forward his right foot in walking he puts forward, with it, his left arm and vice versa, invariably.

III.

PHYSIOLOGY.

Comparative study of the organs of sense in men and animals.

827.

I have found that in the composition of the human body as compared with the bodies of animals the organs of sense are duller and coarser. Thus it is composed of less ingenious instruments, and of spaces less capacious for receiving the faculties of sense. I have

seen in the Lion tribe that the sense of smell is connected with part of the substance of the brain which comes down the nostrils, which form a spacious receptacle for the sense of smell, which enters by a great number of cartilaginous vesicles with several passages leading up to where the brain, as before said, comes down.

The eyes in the Lion tribe have a large part of the head for their sockets and the optic nerves communicate at once with the brain; but the contrary is to be seen in man, for the sockets of the eyes are but a small part of the head, and the optic nerves are very fine and long and weak, and by the weakness of their action we see by day but badly at night, while these animals can see as well at night as by day. The proof that they can see is that they prowl for prey at night and sleep by day, as nocturnal birds do also.

Advantages in the structure of the eye in certain animals (828-831).

828.

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.

In proportion as the eye or the pupil of the owl is larger in

proportion to the animal than that of man, so much the more light can it see at night than man can; hence at midday it can see nothing if its pupil does not diminish; and, in the same way, at night things look larger to it than by day.

829.

OF THE EYES IN ANIMALS.

The eyes of all animals have their pupils adapted to dilate and diminish of their own accord in proportion to the greater or less light of the sun or other luminary. But in birds the variation is much greater; and particularly in nocturnal birds, such as horned owls, and in the eyes of one species of owl; in these the pupil dilates in such away as to occupy nearly the whole eye, or diminishes to the size of a grain of millet, and always preserves the circular form. But in the Lion tribe, as panthers, pards, ounces, tigers, lynxes, Spanish cats and other similar animals the pupil diminishes from the perfect circle to the figure of a pointed oval such as is shown in the margin. But man having a weaker sight than any other animal is less hurt by a very strong light and his pupil increases but little in dark places; but in the eyes of these nocturnal animals, the horned owl--a bird which is the largest of all nocturnal birds--the power of vision increases so much that in the faintest nocturnal light (which we call darkness) it sees with much more distinctness than we do in the splendour of noon day, at

which time these birds remain hidden in dark holes; or if indeed they are compelled to come out into the open air lighted up by the sun, they contract their pupils so much that their power of sight diminishes together with the quantity of light admitted.

Study the anatomy of various eyes and see which are the muscles which open and close the said pupils of the eyes of animals.

[Footnote: Compare No. 24, lines 8 and fol.]

830.

a b n is the membrane which closes the eye from below, upwards, with an opaque film, c n b encloses the eye in front and behind with a transparent membrane.

It closes from below, upwards, because it [the eye] comes downwards.

When the eye of a bird closes with its two lids, the first to close is the nictitating membrane which closes from the lacrymal duct over to the outer corner of the eye; and the outer lid closes from below upwards, and these two intersecting motions begin first from the lacrymatory duct, because we have already seen that in front and below birds are protected and use only the upper portion of the eye from fear of birds of prey which come down from above and behind; and they uncover first the membrane from the outer corner, because

if the enemy comes from behind, they have the power of escaping to the front; and again the muscle called the nictitating membrane is transparent, because, if the eye had not such a screen, they could not keep it open against the wind which strikes against the eye in the rush of their rapid flight. And the pupil of the eye dilates and contracts as it sees a less or greater light, that is to say intense brilliancy.

831.

If at night your eye is placed between the light and the eye of a cat, it will see the eye look like fire.

Remarks on the organs of speech

(832. 833).

832.

a e i o u
ba be bi bo bu
ca ce ci co cu
da de di do du
fa fe fi fo fu
ga ge gi go gu
la le li lo lu

ma me mi mo mu

na ne ni no nu

pa pe pi po pu

qa qe qi qo qu

ra re ri ro ru

sa se si so su

ta te ti to tu

The tongue is found to have 24 muscles which correspond to the six muscles which compose the portion of the tongue which moves in the mouth.

And when a o u are spoken with a clear and rapid pronunciation, it is necessary, in order to pronounce continuously, without any pause between, that the opening of the lips should close by degrees; that is, they are wide apart in saying a, closer in saying o, and much closer still to pronounce u.

It may be shown how all the vowels are pronounced with the farthest portion of the false palate which is above the epiglottis.

833.

If you draw in breath by the nose and send it out by the mouth you will hear the sound made by the division that is the membrane in [Footnote 5: The text here breaks off.]...

On the conditions of sight (834. 835).

834.

OF THE NATURE OF SIGHT.

I say that sight is exercised by all animals, by the medium of light; and if any one adduces, as against this, the sight of nocturnal animals, I must say that this in the same way is subject to the very same natural laws. For it will easily be understood that the senses which receive the images of things do not project from themselves any visual virtue [Footnote 4: Compare No. 68.]. On the contrary the atmospheric medium which exists between the object and the sense incorporates in itself the figure of things, and by its contact with the sense transmits the object to it. If the object--whether by sound or by odour--presents its spiritual force to the ear or the nose, then light is not required and does not act. The forms of objects do not send their images into the air if they are not illuminated [8]; and the eye being thus constituted cannot receive that from the air, which the air does not possess, although it touches its surface. If you choose to say that there are many animals that prey at night, I answer that when the little light which suffices the nature of their eyes is wanting, they direct themselves by their strong sense of hearing and of smell, which are not impeded by the darkness, and in which they are very far superior

to man. If you make a cat leap, by daylight, among a quantity of jars and crocks you will see them remain unbroken, but if you do the same at night, many will be broken. Night birds do not fly about unless the moon shines full or in part; rather do they feed between sun-down and the total darkness of the night.

[Footnote 8: See No. 58-67.]

No body can be apprehended without light and shade, and light and shade are caused by light.

835.

WHY MEN ADVANCED IN AGE SEE BETTER AT A DISTANCE.

Sight is better from a distance than near in those men who are advancing in age, because the same object transmits a smaller impression of itself to the eye when it is distant than when it is near.

The seat of the common sense.

836.

The Common Sense, is that which judges of things offered to it by the other senses. The ancient speculators have concluded that that

part of man which constitutes his judgment is caused by a central organ to which the other five senses refer everything by means of impressibility; and to this centre they have given the name Common Sense. And they say that this Sense is situated in the centre of the head between Sensation and Memory. And this name of Common Sense is given to it solely because it is the common judge of all the other five senses i.e. Seeing, Hearing, Touch, Taste and Smell. This Common Sense is acted upon by means of Sensation which is placed as a medium between it and the senses. Sensation is acted upon by means of the images of things presented to it by the external instruments, that is to say the senses which are the medium between external things and Sensation. In the same way the senses are acted upon by objects. Surrounding things transmit their images to the senses and the senses transfer them to the Sensation. Sensation sends them to the Common Sense, and by it they are stamped upon the memory and are there more or less retained according to the importance or force of the impression. That sense is most rapid in its function which is nearest to the sensitive medium and the eye, being the highest is the chief of the others. Of this then only we will speak, and the others we will leave in order not to make our matter too long. Experience tells us that the eye apprehends ten different natures of things, that is: Light and Darkness, one being the cause of the perception of the nine others, and the other its absence:-- Colour and substance, form and place, distance and nearness, motion and stillness [Footnote 15: Compare No. 23.].

On the origin of the soul.

837.

Though human ingenuity may make various inventions which, by the help of various machines answering the same end, it will never devise any inventions more beautiful, nor more simple, nor more to the purpose than Nature does; because in her inventions nothing is wanting, and nothing is superfluous, and she needs no counterpoise when she makes limbs proper for motion in the bodies of animals. But she puts into them the soul of the body, which forms them that is the soul of the mother which first constructs in the womb the form of the man and in due time awakens the soul that is to inhabit it. And this at first lies dormant and under the tutelage of the soul of the mother, who nourishes and vivifies it by the umbilical vein, with all its spiritual parts, and this happens because this umbilicus is joined to the placenta and the cotyledons, by which the child is attached to the mother. And these are the reason why a wish, a strong craving or a fright or any other mental suffering in the mother, has more influence on the child than on the mother; for there are many cases when the child loses its life from them, &c.

This discourse is not in its place here, but will be wanted for the one on the composition of animated bodies--and the rest of the definition of the soul I leave to the imaginations of friars, those fathers of the people who know all secrets by inspiration.

[Footnote 57: lettere incoronate. By this term Leonardo probably understands not the Bible only, but the works of the early Fathers, and all the books recognised as sacred by the Roman Church.] I leave alone the sacred books; for they are supreme truth.

On the relations of the soul to the organs of sense.

838.

HOW THE FIVE SENSES ARE THE MINISTERS OF THE SOUL.

The soul seems to reside in the judgment, and the judgment would seem to be seated in that part where all the senses meet; and this is called the Common Sense and is not all-pervading throughout the body, as many have thought. Rather is it entirely in one part. Because, if it were all-pervading and the same in every part, there would have been no need to make the instruments of the senses meet in one centre and in one single spot; on the contrary it would have sufficed that the eye should fulfil the function of its sensation on its surface only, and not transmit the image of the things seen, to the sense, by means of the optic nerves, so that the soul--for the reason given above-- may perceive it in the surface of the eye. In the same way as to the sense of hearing, it would have sufficed if the voice had merely sounded in the porous cavity of the indurated portion of the temporal bone which lies within the ear, without

making any farther transit from this bone to the common sense, where the voice confers with and discourses to the common judgment. The sense of smell, again, is compelled by necessity to refer itself to that same judgment. Feeling passes through the perforated cords and is conveyed to this common sense. These cords diverge with infinite ramifications into the skin which encloses the members of the body and the viscera. The perforated cords convey volition and sensation to the subordinate limbs. These cords and the nerves direct the motions of the muscles and sinews, between which they are placed; these obey, and this obedience takes effect by reducing their thickness; for in swelling, their length is reduced, and the nerves shrink which are interwoven among the particles of the limbs; being extended to the tips of the fingers, they transmit to the sense the object which they touch.

The nerves with their muscles obey the tendons as soldiers obey the officers, and the tendons obey the Common [central] Sense as the officers obey the general. [27] Thus the joint of the bones obeys the nerve, and the nerve the muscle, and the muscle the tendon and the tendon the Common Sense. And the Common Sense is the seat of the soul [28], and memory is its ammunition, and the impressibility is its referendary since the sense waits on the soul and not the soul on the sense. And where the sense that ministers to the soul is not at the service of the soul, all the functions of that sense are also wanting in that man's life, as is seen in those born mute and blind.

[Footnote: The peculiar use of the words nervo, muscolo, corda, senso comune, which are here literally rendered by nerve, muscle cord or tendon and Common Sense may be understood from lines 27 and 28.]

On involuntary muscular action.

839.

HOW THE NERVES SOMETIMES ACT OF THEMSELVES WITHOUT ANY COMMANDS FROM

THE OTHER FUNCTIONS OF THE SOUL.

This is most plainly seen; for you will see palsied and shivering persons move, and their trembling limbs, as their head and hands, quake without leave from their soul and their soul with all its power cannot prevent their members from trembling. The same thing happens in falling sickness, or in parts that have been cut off, as in the tails of lizards. The idea or imagination is the helm and guiding-rein of the senses, because the thing conceived of moves the sense. Pre-imagining, is imagining the things that are to be. Post-imagining, is imagining the things that are past.

Miscellaneous physiological observations (840-842).

840.

There are four Powers: memory and intellect, desire and covetousness. The two first are mental and the others sensual. The three senses: sight, hearing and smell cannot well be prevented; touch and taste not at all. Smell is connected with taste in dogs and other gluttonous animals.

841.

I reveal to men the origin of the first, or perhaps second cause of their existence.

842.

Lust is the cause of generation.

Appetite is the support of life. Fear or timidity is the prolongation of life and preservation of its instruments.

The laws of nutrition and the support of life (843-848).

843.

HOW THE BODY OF ANIMALS IS CONSTANTLY DYING AND BEING RENEWED.

The body of any thing whatever that takes nourishment constantly

dies and is constantly renewed; because nourishment can only enter into places where the former nourishment has expired, and if it has expired it no longer has life. And if you do not supply nourishment equal to the nourishment which is gone, life will fail in vigour, and if you take away this nourishment, the life is entirely destroyed. But if you restore as much is destroyed day by day, then as much of the life is renewed as is consumed, just as the flame of the candle is fed by the nourishment afforded by the liquid of this candle, which flame continually with a rapid supply restores to it from below as much as is consumed in dying above: and from a brilliant light is converted in dying into murky smoke; and this death is continuous, as the smoke is continuous; and the continuance of the smoke is equal to the continuance of the nourishment, and in the same instant all the flame is dead and all regenerated, simultaneously with the movement of its own nourishment.

844.

King of the animals--as thou hast described him--I should rather say king of the beasts, thou being the greatest--because thou hast spared slaying them, in order that they may give thee their children for the benefit of the gullet, of which thou hast attempted to make a sepulchre for all animals; and I would say still more, if it were allowed me to speak the entire truth [5]. But we do not go outside human matters in telling of one supreme wickedness, which does not happen among the animals of the earth, inasmuch as among them are

found none who eat their own kind, unless through want of sense (few indeed among them, and those being mothers, as with men, albeit they be not many in number); and this happens only among the rapacious animals, as with the leonine species, and leopards, panthers lynxes, cats and the like, who sometimes eat their children; but thou, besides thy children devourest father, mother, brothers and friends; nor is this enough for thee, but thou goest to the chase on the islands of others, taking other men and these half-naked, the ... and the ... thou fattenest, and chasest them down thy own throat[18]; now does not nature produce enough simples, for thee to satisfy thyself? and if thou art not content with simples, canst thou not by the mixture of them make infinite compounds, as Platina wrote[Footnote 21: Come scrisse il Platina (Bartolomeo Sacchi, a famous humanist). The Italian edition of his treatise De arte coquinaria, was published under the title De la honestra voluptate, e valetudine, Venezia 1487.], and other authors on feeding?

[Footnote: We are led to believe that Leonardo himself was a vegetarian from the following interesting passage in the first of Andrea Corsali's letters to Giuliano de'Medici: Alcuni gentili chiamati Guzzarati non si cibano di cosa, alcuna che tenga sangue, ne fra essi loro consentono che si noccia ad alcuna cosa animata, come il nostro Leonardo da Vinci.

5-18. Amerigo Vespucci, with whom Leonardo was personally

acquainted, writes in his second letter to Pietro Soderini, about the inhabitants of the Canary Islands after having stayed there in 1503: "Hanno una scelerata liberta di viuere; ... si cibano di carne humana, di maniera che il padre magia il figliuolo, et all'incontro il figliuolo il padre secondo che a caso e per sorte auiene. Io viddi un certo huomo sceleratissimo che si vantaua, et si teneua a non piccola gloria di hauer mangiato piu di trecento huomini. Viddi anche vna certa citta, nella quale io dimorai forse ventisette giorni, doue le carni humane, hauendole salate, eran appicate alli traui, si come noi alli traui di cucina appicchiamo le carni di cinghali secche al sole o al fumo, et massimamente salsiccie, et altre simil cose: anzi si marauigliauano gradem ete che noi non magiaissimo della carne de nemici, le quali dicono muouere appetito, et essere di marauiglioso sapore, et le lodano come cibi soaui et delicati (Lettere due di Amerigo Vespucci Fiorentino drizzate al magnifico Pietro Soderini, Gonfaloniere della eccelsa Republica di Firenze; various editions).]

845.

Our life is made by the death of others.

In dead matter insensible life remains, which, reunited to the stomachs of living beings, resumes life, both sensual and intellectual.

846.

Here nature appears with many animals to have been rather a cruel stepmother than a mother, and with others not a stepmother, but a most tender mother.

847.

Man and animals are really the passage and the conduit of food, the sepulchre of animals and resting place of the dead, one causing the death of the other, making themselves the covering for the corruption of other dead [bodies].

On the circulation of the blood (848-850).

848.

Death in old men, when not from fever, is caused by the veins which go from the spleen to the valve of the liver, and which thicken so much in the walls that they become closed up and leave no passage for the blood that nourishes it.

[6]The incessant current of the blood through the veins makes these veins thicken and become callous, so that at last they close up and prevent the passage of the blood.

849.

The waters return with constant motion from the lowest depths of the sea to the utmost height of the mountains, not obeying the nature of heavier bodies; and in this they resemble the blood of animated beings which always moves from the sea of the heart and flows towards the top of the head; and here it may burst a vein, as may be seen when a vein bursts in the nose; all the blood rises from below to the level of the burst vein. When the water rushes out from the burst vein in the earth, it obeys the law of other bodies that are heavier than the air since it always seeks low places.

[Footnote: From this passage it is quite plain that Leonardo had not merely a general suspicion of the circulation of the blood but a very clear conception of it. Leonardo's studies on the muscles of the heart are to be found in the MS. W. An. III. but no information about them has hitherto been made public. The limits of my plan in this work exclude all purely anatomical writings, therefore only a very brief excerpt from this note book can be given here. WILLIAM HARVEY (born 1578 and Professor of Anatomy at Cambridge from 1615) is always considered to have been the discoverer of the circulation of the blood. He studied medicine at Padua in 1598, and in 1628 brought out his memorable and important work: De motu cordis et sanguinis.]

850.

That the blood which returns when the heart opens again is not the same as that which closes the valves of the heart.

Some notes on medicine (851-855).

851.

Make them give you the definition and remedies for the case ... and you will see that men are selected to be doctors for diseases they do not know.

852.

A remedy for scratches taught me by the Herald to the King of France. 4 ounces of virgin wax, 4 ounces of colophony, 2 ounces of incense. Keep each thing separate; and melt the wax, and then put in the incense and then the colophony, make a mixture of it and put it on the sore place.

853.

Medicine is the restoration of discordant elements; sickness is the discord of the elements infused into the living body.

854.

Those who are annoyed by sickness at sea should drink extract of wormwood.

855.

To keep in health, this rule is wise: Eat only when you want and relish food. Chew thoroughly that it may do you good. Have it well cooked, unspiced and undisguised. He who takes medicine is ill advised.

[Footnote: This appears to be a sketch for a poem.]

856.

I teach you to preserve your health; and in this you will succed better in proportion as you shun physicians, because their medicines are the work of alchemists.

[Footnote: This passage is written on the back of the drawing Pl. CVIII. Compare also No. 1184.]

XV.

Astronomy.

Ever since the publication by Venturi in 1797 and Libri in 1840 of some few passages of Leonardo's astronomical notes, scientific astronomers have frequently expressed the opinion, that they must have been based on very important discoveries, and that the great painter also deserved a conspicuous place in the history of this science. In the passages here printed, a connected view is given of his astronomical studies as they lie scattered through the manuscripts, which have come down to us. Unlike his other purely scientific labours, Leonardo devotes here a good deal of attention to the opinions of the ancients, though he does not follow the practice universal in his day of relying on them as authorities; he only quotes them, as we shall see, in order to refute their arguments. His researches throughout have the stamp of independent thought. There is nothing in these writings to lead us to suppose that they were merely an epitome of the general learning common to the astronomers of the period. As early as in the XIVth century there were chairs of astronomy in the universities of Padua and Bologna, but so late as during the entire XVIth century Astronomy and Astrology were still closely allied.

It is impossible now to decide whether Leonardo, when living in Florence, became acquainted in his youth with the doctrines of Paolo Toscanelli the great astronomer and mathematician (died 1482), of whose influence and teaching but little is now known, beyond the fact that he advised and encouraged Columbus to carry out his project of sailing round the world. His name is nowhere mentioned by