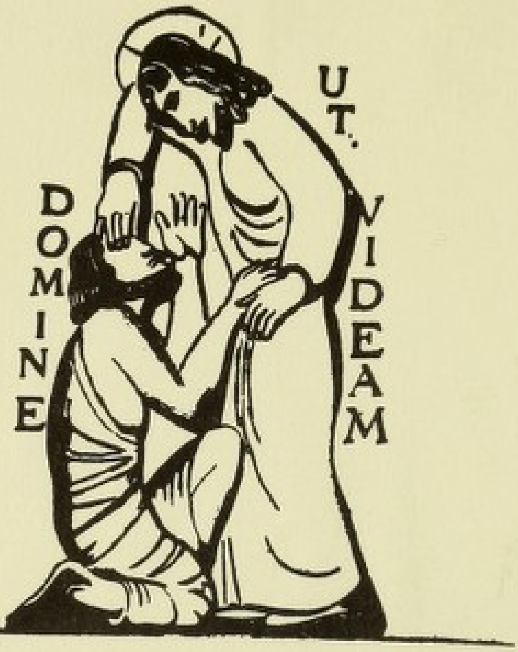

FRANS. CORN. DONDERS



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F. C. DONDERS

XXII International Congress of Physiological Sciences

Leiden 10 - IX - 1962

MCMLXII
DE ERVEN F. BOHN N.V. – HAARLEM

The Netherlands Physiological and Pharmacological Society takes pleasure in presenting to active members of the XXII International Congress of Physiological Sciences a complimentary copy of an abridged reprint of a physiological classic which was first published about a hundred years ago, *viz.* Donders' 'On the Anomalies of Accommodation and Refraction of the Eye'.

That the Society was able to do so is due to a combination of happy circumstances. The *Nederlands Tijdschrift voor Geneeskunde*—Netherlands Journal of Medicine—publishes, among other things, a series of reprints of classics, in the various fields of medicine in the broadest sense, written by Dutch authors. In this series, called 'Opuscula Selecta Neerlandicorum de Arte Medica', a reprint of Donders' book was planned to mark the centenary of its publication in 1864. The Editorial Board of the *Tijdschrift* immediately agreed to advance the time of publication of the new edition, and the Editor of the abridged version kindly changed his time schedule accordingly. In addition the *Tijdschrift* Board generously put the matter at the disposal of the Society which, thus, could afford to have the necessary extra copies printed. This complimentary copy differs from the regular copies in the 'Opuscula' series only in that it is printed on thinner paper, and lacks the tooled hard covers which are standard for the 'Opuscula'.

The Board of the Netherlands Physiological and Pharmacological Society wishes to express its deep appreciation to the Board of the *Nederlands Tijdschrift voor Geneeskunde*, in particular to its chairman, Professor J. R. Prakken, of Amsterdam, as well as to the Editor of the present volume, Professor M. C. Colenbrander, of Leiden.

J. W. Duyff

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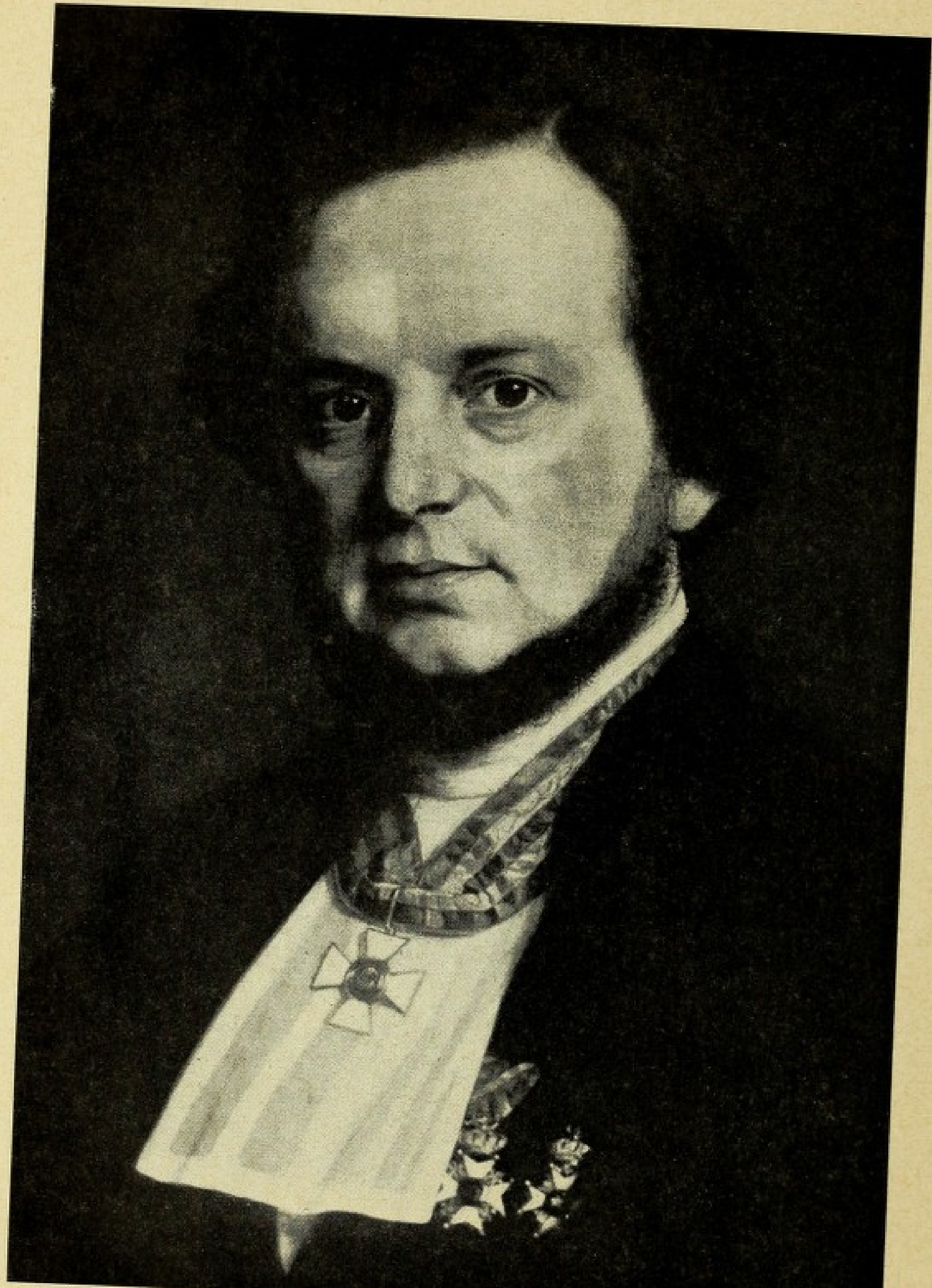


F. C. DONDERS

PREFACE

In the series 'Opuscula Selecta Neerlandicorum de Arte Medica', the Dutch medical journal *Nederlands Tijdschrift voor Geneeskunde*, has published a number of studies on the history of medicine in the Netherlands in book form.

In these Opuscula the original text is published together with an existing or new translation in English, French or German, in order to make the classical works of Dutch medicine accessible to students of medical history abroad.

The present volume, the 19th of the series, differs from preceding volumes in that its subject is not the life and work of a great physician, or a certain group or period; it is mainly an abridged reprint of a single work. On this occasion it was not necessary to have a Dutch researcher's text translated into English in order to bring it within the range of a wider circle of readers. F. C. Donders' masterpiece 'On the Anomalies of Accommodation and Refraction of the Eye' was published in English by the Sydenham Society nearly a century ago.

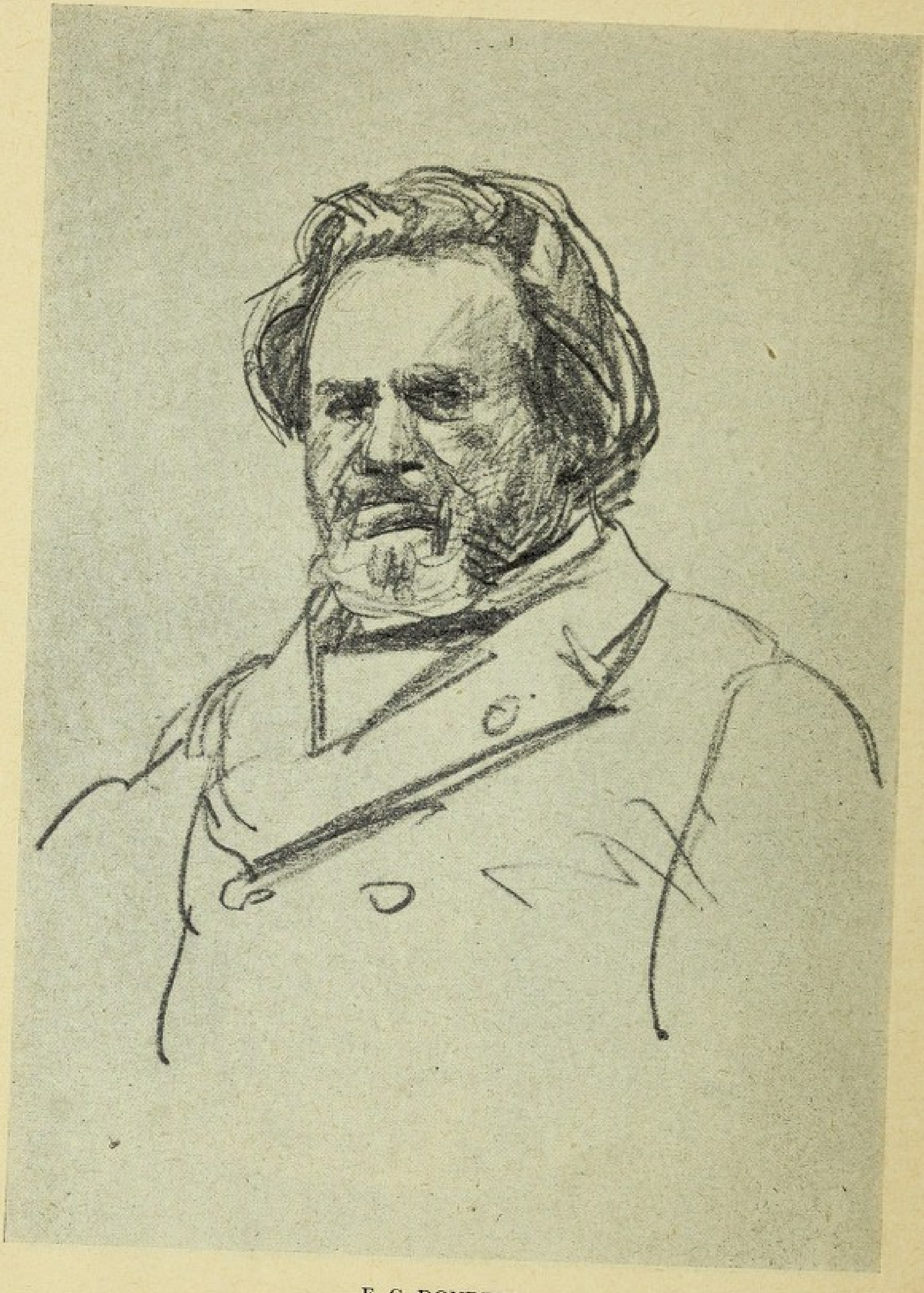
The great length of the original work made it desirable that it should be considerably reduced in volume. We greatly appreciate Professor Dr. M. C. Colenbrander's willingness to undertake this abridgment and add an introduction as well. To the present-day reader this considerable abridgement, which has left the continuity of the text intact, is a definite advantage.

A very special circumstance has made it possible to bring this nineteenth Opusculum to the attention of a much wider circle of experts than its predecessors. It will be presented to all those attending the International Physiological Congress in Leiden in an edition which differs somewhat from the usual.

By a remarkable coincidence the *Nederlands Tijdschrift voor Geneeskunde* also had a connection with an earlier International Physiological Congress. At the Congress which met in Groningen in 1913 at the Hamburger Laboratory, then recently completed, all members were presented with the Donders Medal, which had been struck on the initiative of the Dutch medical journal.

The *Tijdschrift* considers it a privilege to make this modest contribution to scientific events of international importance.

J. R. PRAKKEN



F. C. DONDERS

FRANCISCUS CORNELIS DONDERS AND HIS TIME

The importance of Donders can only be fully understood if he is seen against the background of the period in which he lived. What he gave to suffering mankind by his scientific work is now so much taken for granted that we do not usually pause to consider the days without this knowledge, a time when such knowledge was brand-new and like a revelation.

Let me endeavour to sketch the period in which Donders lived.

Natural philosophy had flourished in the preceding century. The nineteenth century promised to be the age of natural history. Jordan[1] says on this subject:

'There was a time when biology saw its sole task in the classification of physical forms. Linnaeus (1707-1778) created a system which allows animals and plants to be classified as a good librarian will arrange all books: whatever the contents of a book may be, it has its natural place in the library. When it is in its proper place it can always be located.

To Linnaeus, zoölogists were only those men who occupied themselves with such classification. Those who occupied themselves with the organization itself were no more than zoophili. This view, which would be inconceivable nowadays, was by no means incorrect at the time. The system had to be created; for it is not possible to order the sum of our knowledge into a science if we have no scheme for classifying the various organisms. Linnaeus' concept of species in animals and plants was absolutely rigid. The species had been created and were preserved as such.

Similarly, Darwin's and Haeckel's evolution theories were from the first influenced by the systematization of animals and plants. The theory of evolution made an imaginary relationship into common descent. If we know the genetic relation between various organisms, i.e. their ancestry, then we know their natural order. Only in the second place did the theory of evolution attempt to give a scientific explanation of the causality of life.

Human effort will always outgrow its original intention. Darwin's theory assumes variability, which will produce hereditary modifications, and natural selection, i.e. survival of the fittest and extinction of individuals less suited to the struggle for existence. There is no question of any purpose here. The varieties themselves are not evolved in accordance with any plan, but causally, that is, as a result of causes which are totally unrelated to the usefulness of the variety. Only the struggle for life would turn this suitability of the new elements of the organization to the demands made by prevailing conditions into the characteristics of a new species'.

[1] H. J. Jordan, *De causale verklaring van het leven* (The causal explanation of life), Amsterdam, 1941.

It is not amazing that naturalists have never failed to be impressed again and again by the practical organization of living organisms. It seems as if the causal laws of physics and chemistry do not apply to the functions of the living organism. Here, it was thought, a different force prevailed, the vis vitalis or vital force, which, unlike the blind forces of nature, was capable of directing the vital functions along severely practical lines. An Aristotelean distinction was made between causae efficientes, or natural causes, and causae finales, causes directed to a certain practical end.

Naturalists were convinced, not only that everything in the organism was efficient, but also that everything could only be explained from the viewpoint of efficiency.

Donders has given a striking description of the qualities of this view and 'les défauts de ses qualités' in his notes from London and Paris, in which he reports on the work of the famous Claude Bernard. Donders writes:

'To every organ, as if it had been fitted into the body by a workman, Claude Bernard wants to attribute a strictly defined function. Such attribution is to him the object of physiology, and whenever we are unable to do this he suspects ignorance. Thus the stomach is supposed to serve exclusively for the digestion of proteins, the pancreas for the digestion of fats. Similarly, as we heard only recently, he wants to attribute specific functions to each of the salivary glands, etc.'.

For surely, if the functions of all three pairs of glands were identical, it would not, from the point of view of usefulness, be possible to account for the presence of more than one pair of salivary glands.

About the year 1840 there were great changes in the world of science. 'Bichat, the father of histology, clearly stated that the physiologist should reduce the phenomena of life to material properties. The tissues should be to the physiologist what the elements are to the chemist'[1].

'As chemistry knows simple elements which combine in different ways to form a variety of compounds, thus anatomy, says Bichat, has its simple tissues, which by combining 4 and 4, 6 and 6, 8 and 8, etc., form the organs'.

Here, then, it was clearly stated that the science of living structures should be analogous to the science of non-living matter.

Later this analogy was to become identity.

It is a remarkable fact that Bichat, who lived in the days when the microscope was coming into its own, was just as loth to use this instrument as his teacher, Stahl. The remarkable progress made by science was not in the first place the result of the greatly improved aids and appliances, but of the mental approach to scientific problems.

'But', says Donders[2], 'with the naked eye Bichat could not graduate

[1] *Nederlandsch Lancet*, 1851-1852.

[2] F. C. Donders, Grondvormen en weefsels (Basic forms and tissues), *Nederlandsch Lancet*, 1845-1846.

to that simplicity of tissues and basic forms, such as muscle fibres, connective tissue fibres, nerve fibres, elastic fibres and cells, which he had imagined'. This was made possible by Schleiden (1818) and Schwann (1839), who identified the cell as the basic form of life.

In 1844, Liebig pointed out the importance of chemical research for the physiology of plants and animals. 'Liebig's work', Donders says in the Preface to his translation of Liebig's '*Animal Chemistry*' (1842), 'abounded in bold ventures. Recklessly his hand reached into the innermost mysteries, and with great conviction he stated what could be found in those places where no human eye had ever penetrated'.

In 1845, Schleiden disputed the existence of the vis vitalis, maintaining that no transcendental forces could operate in animated nature.

Faraday pointed out the interaction between different forms of energy. Later, the law of conservation of energy was formulated, independently of each other, by Robert Mayer and Youle in 1845, by Colding in 1846 and by Von Helmholtz in 1847. The theory of the vis vitalis as a special form of energy had been exploded once for all. The period of scientific materialism had set in.

In '*Der Kreislauf des Lebens*' (The Cycle of Life, 1852), Jacob Moleschott made his well-known statement: 'Ohne Phosphorus kein Gedanken' (without phosphorus there can be no thinking). There is an indissoluble bond between matter and life, between life and thinking, between thinking and the will to make life better and happier. If only we can nourish our brains on the best food, our thinking and our volition will be developed to the very maximum degree, and all social questions will be solved.

Donders was dominated by a similar optimism as regards food: 'Whoever labours to develop this knowledge with all the strength of which he is possessed', he wrote, 'and strives persistently to find acceptance for the results of his studies, will be working for the advancement of mankind in the widest sense. If he has succeeded in making a single dietetic truth prevail, he can depart from this planet in the full consciousness of not having lived in vain'.

And elsewhere: 'Apparently not every physician knows the power which a thorough knowledge of dietetics will give him; many of them still labour under the delusion that the chief remedies for every disease, including a multitude of unsavoury and stinking substances, are collected in a certain place which they call a pharmacy, and are supplied by a certain person in elegant little phials, gallipots or boxes. The very experience that diseases arise without drugs would, I venture to think, suggest that most of them do not require drugs to cure them'.

Donders has given an excellent characterization of his time in his oration at the opening of the International Medical Congress of 1879, when he said: 'The art of medicine, which is not rooted in science, not even as regards its technique, is a divine gift, which cannot be improved by discussion. But that does not prevent discussion of the relationship between art and science. My teachers held the view that general therapy could be the basis for the treatment of the sick. Nature should be followed, guided perhaps, but never forced. That, then, was the secret: disguise ignorance, hide behind your faith in the vital force, and sleep peacefully in the arms of her all too willing daughter, the vis medicatrix naturae, the healing power of nature.

Then came Henle with his General Anatomy: *Allgemeine Anatomie* (Lehre von den Mischungs- und Formbestandteilen des menschlichen Körpers, 1841). The scales fell from our eyes. The quiet haven of teleology was destroyed with witty irony and biting sarcasm. The vital force succumbed under Gerrit Jan Mulder's picturesque style and Dubois Raymond's nervous phraseology, its loveliness faded into a phantom under the law of conservation of energy. But even if the sceptre has been wrenched away from teleology, it still remains to be demonstrated how exactly the object and effects of the co-operating organs and their relationships to the outside world are accomplished, how that harmony is born out of habit, training and heredity'.

Thus the time in which Donders lived. A new and fresh spirit was abroad in science. Great vistas were opening. Did not Haeckel think that once science would be able to produce living proteins, even new living creatures? For the chasm between organic and inorganic chemistry had been bridged since, in 1828, Wöhler had first synthetized an organic substance, urea.

There was optimism everywhere: 'They are happy days in which we live now,' said Donders[1]. 'Science is advancing in all directions, and nearly every day provides new food for our energy!'

Donders had a large share in all this.

Donders was born at Tilburg in 1818. His father died the year after he was born, leaving his mother with ten children and in poor circumstances.

Donders has described his life in a speech which he made in 1888, when he retired as a professor and head of the Netherlands Ophthalmic Hospital. Most of this speech has been translated and may be found elsewhere in this book. He died a year later.

The best biography of Donders was published in Dutch at the centenary of the Netherlands Ophthalmic Hospital, Utrecht, and written by Dr. G. ten Doesschate and Dr. F. P. Fischer.

This work has two pictures of Donders, of which in my opinion the first does most justice to the active mind we meet in his publications. This portrait is an excellent companion to that painted by Prof. Dr. G. Grijns' words[2].

[1] *De voedingsbeginselen. Grondslagen ener algemene voedingsleer* (The principles of nutrition, a basis for general dietetics). Tiel, 1852.

[2] *Driekwart eeuw Ned. Gasthuis voor Ooglijders* (The Netherlands Ophthalmic Hospital: Seventy-five Years). 1933

Prof. Grijns writes:

'What pleasure it was to watch him and to listen to him during his lectures, that handsome man with his lively eyes, his dignified gestures, his pleasant intonation, his cultured, clear and fascinating discourse. How he made them come alive, those scientists about whose discoveries he told us, by a racy anecdote or a personal reminiscence — for he knew nearly all contemporary physiologists personally. I can still see him, playing with his lorgnette, demonstrating the physiological experiments performed by his right-hand man, Kagenaar, who was his instrument maker. I can still recollect how one day Kagelaar was ill, and an experiment, which had been prepared by his assistant, failed. Donders watched his vain attempts for awhile, and then said: 'Gentlemen, I can see nothing except Kagenaar's absence'.

Was there no darker side to his character?

It has been said that a man's most pronounced qualities are often an overcompensation of his original defects. The second portrait of Donders is of later date. I regret to say that it has not impressed me as being that of an accommodating person. Perhaps this will be better understood when I quote Prof. Dr. C. Winkler (l.c.) on Donders:

'As a child of eight or thereabouts I once stayed with the Van Tienhovens in Amsterdam at a time when his (Donders') only daughter was staying there as well. She was already a grown-up woman then, and played all sorts of boys' games with me. I idolized her, that kind and lovely person, as boys will. Later she married Professor Engelmann, and when I was at the University she died when giving birth to her first child. Her death caused much sadness in Utrecht. Some time after her death, when I was working in the physiology laboratory, I received a message asking me to go to Prof. Donders' room. That was quite unusual. I went there and found him at his desk, which was covered with piles of letters. 'Winkler', he said, 'you met my daughter at the Van Tienhovens' when you were quite a young boy'. 'Yes, I remember her quite well'. 'Then I shall read to you what she wrote about you in those days. At the end of one of her letters she said: "Now I must stop, for Keesje Winkler is looking at me with a question in his eyes. I have promised to play marbles with him". The conversation which followed made a deep impression upon me. The loving father, heart-broken by the loss of his daughter, wanted to know how a child had admired her. Then I understood how great was his heart and how grievous to him the blow of this loss. Only much later did I understand the childlike naïvety with which he tried to hide that accidents of life could hurt him so deeply. Thus his ways remained strange to many who had not penetrated into his inner self. And they judged him to be a cold man, enigmatic, affected, and sometimes downright rude. In fact Donders' nature was simple as a child's'.

It was said that Donders would not bear being contradicted. How great must be our respect for the man who succeeded in guiding his difficult character by sheer self-control, and become so excellent a teacher; who managed to supplement his originally poor education by ceaseless energy, until he was a master of language. For this, too, was not due solely to talent, but also to discipline.

Winkler says: 'Donders' speeches were masterpieces. Form and content were highly polished, but do not ask how much time this took, for Donders left nothing to chance. No passage would please him until he was satisfied that no other words would express as briefly and accurately what had to be said. I first heard him state these requirements when I wished to know his opinion on an article which I had written. He suggested that we should go through the article together. He then formulated what he required — and nothing remained of my draft'.

Donders' work embraced nearly all physiological subjects, but most important of all has been his work *On the accommodation and refraction of the eye*. It was published in English in 1864. It summarized all that he had published on the subject in various journals in the Netherlands and elsewhere. The book was an overwhelming success, and was soon translated into French, German and Italian.

This book is an edition of Donders' main work, reduced to half the original size. No comment has been added[1].

When Donders wrote the first few chapters, it was not yet customary to have cylindrical lenses in the trial case. Donders managed by first determining the principal meridians with the figure of a star, and then determining the refraction with spherical lenses independently of each other in the two principal meridians by means of a slit diaphragm, the power of the lens being given in Parisian inches. The difference in refraction and the focal length of the cylinder required could then be calculated.

As long as, before Donders' time, only spherical correction of the eye was determined, it did not matter whether the power of a lens was given in its focal length or in its reciprocal value. But when astigmatism came to be determined, it was found much easier to use dioptres as the unit of measurement. As soon as Nagel introduced the one meter lens in Germany and Monoyer the dioptre in France, Donders became a warm advocate of this idea[2].

There were also numerous studies of colour vision, eye movements, intra-ocular pressure and general physiology.

But Donders' greatest merit has been that he created order in the field of refraction and accommodation. No doubt the times were ripe

[1]Nowadays everyone knows that lenses must be measured from the principal points, not from the nodal points.
Only a few particulars must be noted:
Calabar = physostigmine = eserine
Iridodenosis = iridodonesis
Iriddesis = iridodesis = iridencleisis.
With a few exceptions, no literature has been referred to.

[2]*Sitzungsbericht der Ophthalm. Verein*, Heidelberg, 1875.

for it. But this does not in any way detract from his merit. His own share of creative work in this field appears from numerous new concepts and terms which he introduced, and which are still the common property of ophthalmologists everywhere.

On every page of Donders' work we find wise moderation in evaluating divergent views and relating them to each other. Listen how he values the qualities of different nations (in his Notes on London and Paris): 'It is the ignorance of foreign literature which gives to British, and even more to French publications their characteristic qualities. It explains the bold assertions in which notably the latter abound, where the wings of genius are so seldom weighed down with the lead — nay, the gold — of knowledge. Yet we are perfectly serious when we maintain that such onesidedness has its particular advantages in science. In many people the imagination is curbed too much by the formal claim of unyielding facts, and causes them to trudge on in the direction they have once taken; but the very absence of such curbs has produced, among many abortive ideas, a number of fortunate ones as well, which, first launched in France, then submitted to Dutch and German criticism and experiments, have borne the finest fruits. Thus has French and British onesidedness become a bulwark against the onesidedness of German science'.

Donders was a truly brilliant link between the science of neighbouring nations. In all these countries he counted many intimate friends. I shall only mention two of them: Bowman in England, Von Graefe in Germany, who with Donders may be called the founders of modern ophthalmology.

LEIDEN, *January 1962* M. C. COLENBRANDER

On the Anomalies of

ACCOMMODATION
and
REFRACTION OF THE EYE

With a preliminary essay on

PHYSIOLOGICAL DIOPTRICS

by

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THE NEW SYDENHAM SOCIETY,
LONDON
MDCCCLXIV

To WILLIAM BOWMAN, F.R.S.

whose merits in the advancement of physiology
and ophthalmology are equally recognised and honoured
in every country, this work on the anomalies
of refraction and accommodation is, in testimony
of the warmest friendship and of the highest esteem, inscribed by

THE AUTHOR

PREFACE

My essay upon *Ametropie en hare gevolgen* ('Ametropia and its Results'), published in 1860, was confined to the anomalies of refraction, and treated of these exclusively from the dioptric point of view.

In the preface, however, I announced my intention of producing, subsequently to the appearance of that essay, a complete system of the anomalies of refraction and accommodation.

. . . .

When, later, I was honoured with a request, on the part of the New Sydenham Society, to prepare my essay for an English edition, I felt bound to endeavour to complete my work on the plan alluded to. This I have done to the best of my ability. The experience of many years, the examination of many thousands of eyes, in which I have been zealously assisted by several of my pupils, have been made available. I believe that my work has gained by its enlargement. I cannot, however, fail to regret that its bulk has increased beyond my expectation, and I feel bound to apologise to the Council both for the delay in its appearance, and for the inconsiderate manner in which I have used the liberty allowed me for its extension.

One object I have kept constantly in view, to make the book, notwithstanding its great size, useful and, in all its parts, easily accessible to the practical physician.

. . . .

The work forms, in a certain sense, a series of lesser monographs, united in a single volume, which is the emblem of their mutual connexion.

For the oculist it is perhaps an additional advantage that I am no mathematician. I freely admit that I am not competent to follow the investigations of Gauss and of Bessel in this department, and even the study of the physiological dioptrics of Helmholtz required an effort on my part. I have, therefore, sought a way of my own, and, as I believe, I have found it.

. . . .

To guard against the possibility of its leading on any point to error, I have requested my friend Hoek, our Professor of Astronomy, to look over it, and to his kindness I am indebted for many improvements in the form of the demonstration.

In the doctrine of the anomalies of refraction and accommodation, the connexion between science and practice is more closely drawn together than in any part of medicine.

. . . .

Practice, in connexion with science, here enjoys the rare, but splendid satisfaction, of not only being able to give infallible precepts based upon fixed rules, but also of being guided by a clear insight into the principles of her actions.

Is it then strange that the study and treatment of my subject have been to me a labour of love? the more so, as I felt proud in having been called upon to elaborate it for a country in which Young, Wells, Ware, Brewster, and Airy have pointed out to us the track which we had only to follow, and happy in being able to offer my work in this form to my highly esteemed friends and colleagues, whose proofs of kindness and affection have left with me the most agreeable recollection of my visits to England.

Among the privileges, which my task has procured me, dear friend Moore, is the agreeable relation into which it has brought me with you. If I have admired your talent, and highly appreciated your unwearied care, I have, above all, to thank you heartily for the interest and the love, with which the difficult task of the translation of my work has been accomplished by you. I feel that we have become friends, and friends we shall continue. You will, I am certain, gladly join me in thanking the Rev. Professor Haughton, for the solution of many doubtful points, and for his kind revision of certain portions of the work.

UTRECHT, *27th February, 1864.* F. C. DONDERS

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SIGNS AND ABBREVIATIONS USED IN THIS WORK

ρ, radius.
ρ°, radius of the cornea in the visual line.
n, coefficient of refraction.
k, nodal point.
h, principal point.
k' and k'', anterior and posterior nodal points of the same system.
h' and h'', „ „ principal „ „
φ' and φ'', „ „ focal „ „
k_1 and k_2, two nodal points of two different systems.
h_1 and h_2, „ principal „ „
φ_1 and φ_2, „ focal „ „
o, optical centre.
F' and F'', anterior and posterior principal focal distances.
F, principal focal distance where F′ and F″ are equal.
f' and f'', conjugate focal distances calculated from h' and h''.
B, an object; β, its image.
i, a point in the axis; j, its image.
i', a point outside the axis; j', its image.
p, (proximum) absolute nearest point of distinct vision.
p_1, („) relative „ „ „
p_2, („) binocular „ „ „
r, (remotissimum) absolute farthest point of distinct vision.
r_1, relative „ „ „
r_2, binocular „ „ „
$P_{,}$, P_1, and P_2, distances from $p_{,}$, p_1, and p_2 to k'.
R, R_1, and R_2, „ $r_{,}$, r_1, and r_2 „
P′ P″, and R′ R″, „ p, and from r to a lens or another given point.
1 : A, absolute range of accommodation.
1 : A_1, relative „ „
1 : A_2, binocular „ „

O, the eye; D or R, right; S or L, left.
C, the cornea.
L, crystalline lens.
l, a lens.
N, the retina.
V, the vitreous humour.
D, the thickness of a lens.
x, distance of a lens from a point.
α, angle between visual line and axis of the cornea.
S, acuteness of vision.

E, Emmetropia.

H, Hypermetropia.
Hm, manifest H.
Hl, latent H.
Ht, total H.
M, Myopia.
Pr, Presbyopia.
As, Astigmatism.
Ah, Hypermetropic astigmatism.
Am, Myopic ,,
Amh and Ahm, mixed ,,
In H, in the horizontal principal meridian.
In V, in the vertical ,, ,,
M_o, principal meridian of maximum of curvature of the eye.
M_c, ,, ,, ,, ,, ,, cornea.
M_l, ,, ,, ,, ,, ,, crystallinelens.
A_s, Astigmatism of the whole eye.
A_{sc}, ,, ,, cornea.
A_{sl}, ,, ,, crystalline lens.
%, per cent.
′ (after a numeral) foot or feet, as 2′, 2 feet.
″ (,, ,,) inch or inches, as 2″, 2 inches.
‴ (,, ,,) line or lines, as 2‴, 2 lines.

GENERAL PART

INTRODUCTION

§ 1. *On the Conditions of Accurate Vision. Function of the Retina*

In order to see an object distinctly and accurately, two conditions must be fulfilled. In the first place, an inverted, but well-defined, image of the object must be formed on the surface of the membrana Jacobi or layer of rods and bulbs of the retina. In the second place, the local change here excited must be conveyed to the fibres of the optic nerve, communicated to the brain, and again, in an inverted direction, projected outwards.

Through this double inversion the projected image corresponds to the object, and we therefore say that we see the object, although, properly speaking, only the projected retinal image stands, as it were, before our eyes.

Every disturbance of vision depends on a disturbance in one of these two conditions, or in both together. If the projection outwards be disturbed, by anomalies in the retina, in the optic nerve, or in the brain, the affection belongs to the domain of amblyopia or amaurosis. If no image be formed, or if the image be clouded through diffusion of light in the eye, obscurities in the way of the radiation of light through the organ are the foundation of the mischief. Lastly, if the image of objects placed at the ordinary distances of distinct vision, be not formed on the layer of rods and bulbs, or even if, through abnormity in the curving of the surfaces, no defined image is on the whole produced, anomalies of refraction or of accommodation are developed.

The lesions of vision, for each eye separately, may therefore all be referred to *three* principal classes: amblyopia, obscurities, anomalies of refraction and of accommodation. If the power of vision of an eye be impaired, one of these three species of disturbance must necessarily exist.

A glance with the ophthalmoscope into such an eye will show whether obscurity of the light-refracting media be present or not. If such be not found, we may infer the existence of either amblyopia or of disturbance of refraction or of accommodation. If now, even with the aid of convex glasses, perfectly-defined vision can at no distance be obtained, the case is one of amblyopia. If, on the contrary, the power of vision be, at one distance or other, accurately defined; or if, at least, by the employment of a convex glass, a perfect definition be attainable, we have to deal with an anomaly of refraction or accommodation, opacity and amblyopia are excluded.

The difference between lesions of refraction and of accommodation is deducible from the words themselves. The lesions of refraction are to be sought in the structure of the eye, in the condition of rest, without attendant action of accommodation. The disturbances of accommodation, on the other hand, have their foundation in abnormal action of the internal muscular system of the eye. This will be more fully explained in Chapter II.

Note on § 1

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Purkinje's experiment proves that the perceptive layer is situated tolerably far behind the fibrous layer. This experiment consists in making the vessels of the retina visible to ourselves. In it, properly speaking, we perceive the shadows of these vessels. The characteristic ramifications are made to appear, by moving a candle to and fro beside the eye, opened and directed towards an uniformly dark chamber; and still more easily are they rendered visible to any one, by turning the cornea as much as possible towards the nose, and moving the dioptric image of a flame, formed by a convex lens of one or two Parisian inches' focus, to and fro, or up and down on the exposed sclerotic. In either case an image of light is formed on a circumscribed part of the membranes of the eye, which sends out light through the whole eye, but must necessarily in the deeper layers cast shadows of the great vessels of the fibrous layer. The shadows now change their place with the movements of the image of light, and the object (in this case the bloodvessels), which produces the shadows, can therefore not be situated in the layer which perceives the shadows. From the amount of this displacement H. Mueller has inferred, that the perceptive curtain actually lies about where the surface of the layer of bulbs and rods is to be found.

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CHAPTER I

§ 2. *Proofs of the Existence of Accommodation in the Eye*

The media of the eye form a compound dioptric system, wherein we can accurately and easily trace the course of the rays of light only by being acquainted with its cardinal points. But, to clear up a number of questions, it is satisfactory to consider the whole system as a single lens, with a definite focus, and the action of such a lens is then sufficient to give an idea of the accommodation.

It is well known that when *parallel* rays of light fall upon a convex lens, these, at a certain distance behind the lens, unite nearly into a point, called the *principal focus*.

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Parallel rays of light proceed from infinitely distant objects. From each point of an object, placed at a finite distance, proceed rays, which have a *diverging* direction. When such rays fall on the lens, they unite likewise almost into a point, but this point lies further behind the lens than the principal focus.

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In the normal eye, the retina is placed precisely at the focal distance of the dioptric system. Parallel rays, derived from infinitely distant objects, are therefore brought into union exactly in the retina. The objects are accurately perceived. From near objects, as we have observed, the rays proceed in a diverging direction, and their point of union in the normal eye, consequently, lies behind the retina, and yet the organ is capable of perceiving near objects also accurately. It therefore has the further power of bringing divergent rays into union on the retina. Now, this power of bringing at will rays of different directions into union on the retina is the *power of accommodation of the eye*.

We can easily convince ourselves that the normal eye possesses such a power. That we are able clearly and accurately to distinguish objects at different distances, everyone knows by experience. We need, therefore, only assure ourselves that we *cannot at the same time* plainly distinguish remote and proximate objects, to obtain a proof that an acommodating power exists.

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Ordinary observation will abundantly demonstrate it. It is well illustrated by holding a veil at some inches from the eye, and a book at a greater distance; we can then at will see accurately either the texture of the veil, or the letters of the book, but never both together.

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The circle of diffusion in imperfect accommodation can be most distinctly seen at an illuminated point, or at a darker spot on a piece of ordinary window-glass. The latter is held close to one eye (while the other eye is shut), but so that the point can still be accurately perceived—the objects situated at a certain distance on the other side of the glass are then observed without defined contours. We can now, however, at will, immediately see, in the direction of the point, the objects at the remote side of the glass distinctly, whereupon the point appears as a larger, diffused spot. A change has consequently taken place in the eye.

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In uniting, whether before or behind the retina, the rays proceeding from each separate point formed a *round* spot on the retina, instead of a point. The section of these rays has, in fact, nearly the *form of the pupil.*

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All the little spots, which represent the several points of the object in the retinal picture, are now like so many blotted points of an accurate image covering one another, and it is evident, that the former must, therefore, lose its sharp contour and be diffused on the surface. But as the retinal, so is the projected picture, and we therefore say, that we see the object diffused. In such a state do all objects appear, for which the eye is not accommodated.

§ 3. *Change of the Dioptric System of the Eye in Accommodation*

That in the eye, in accommodation, a change is produced, has in the preceding section been placed beyond a doubt. The question now is, in what that change consists? Since Kepler first attempted to answer it, the inquiry has been the constant source of much difference of opinion among natural philosophers and physiologists. All imaginable hypotheses have been advanced. Alteration of situation of the lens, elongation of the axis of vision, contraction of the pupil, change of form of the lens, have all in turns been made use of in the explanation, and those who were satisfied with none of these theories, were sometimes bold enough altogether to deny the existence of an accommodation power.

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It is not my intention to subject anew to criticism the long series of incorrect views upon the subject. I am not writing a history of errors. We now know what change the dioptric system undergoes in accommodation, and the source of this knowledge alone can here be sketched in its leading features. *The change consists in an alteration of form of the lens: above all, its anterior surface becomes more convex and approaches to the cornea.*

It is now nearly sixty years since Thomas Young (1801) had satisfied himself that the power of accommodation depends upon a change of form in the lens. Nor was he led to this conviction merely by the exclusion of other hypotheses; he adduced reasons which, properly understood, should be taken as positive proofs. As an hypothesis the idea had already existed; but previously to the time of Young it could be considered as little more than a loose assertion, to which no value was to be attached. The force of Young's experiments was, however, not understood, and his doctrine scarcely found a place in the long list of incorrect opinions and hazardous suggestions, which were constantly anew brought forward. Perhaps the necessary attention was not paid to Young's demonstration, because physiologists, not being acquainted with any muscular elements in the eye, could scarcely imagine by what mechanism the crystalline lens should change its form, and they were little inclined to believe with Young in the contractility of the fibres of the lens. It was not until after direct proofs (within the reach of every one's observation and comprehension) of the change of form of the lens had been brought forward by others, that Helmholtz placed the able investigation of Thomas Young in its proper light. The direct proofs were given a few years ago, and to our fellow-countryman Cramer, too early snatched from science, belongs the highest honour in the matter.

For many years the reflected images of the anterior and posterior surfaces of the lens were generally known. Purkinje had discovered them in 1823, and Sanson had made them available in the diagnosis of cataract (1837).

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For the recognition of cataract they lost their value, when more decisive means of attaining it were discovered. But it was they which could give an infallible answer to the question, whether the lens in the accommodation of the eye undergoes a change, either in form or in situation.

Maximilian Langenbeck (1849) was the first to whom it occurred to investigate the reflected images of the lens with reference to this important question. He examined them, however, only with the naked eye, moreover at a very unfavourable angle, almost solely with respect to the depth of their situation in the eye, and we can, therefore, scarcely assume that this investigation was sufficiently decisive to produce conviction. Nevertheless, he announced the most important fact: namely, that *in accommodation for near objects the anterior surface of the lens becomes more convex*. This statement lay hidden in a work, whose title was little adapted to attract the attention of physiologists. Accidentally the book fell into my hands. Struck with Langenbeck's fortunate idea, I immediately endeavoured to satisfy myself of the correctness of his assertion; but owing to defects in the means I employed, no satisfactory result was obtained. That on examination with a magnifier the reflected images should show with certainty, whether in accommodation a change of the crystalline lens arises, I did not hesitate to predict. I soon heard that Cramer, led by this prediction, had taken up the question. He comprehended its full importance, solved it in the manner pointed out by me, and so put forward his result, that its correctness was in a very short time universally admitted.

I have above observed, that from the reflected images of the lens we may learn both the *curvature* and the *situation* of its surfaces. Cramer had already deduced both from his investigations.

In the first place, as relates to the curvature, we know that convex mirrors produce a diminished image behind, concave mirrors before the reflecting surface, and that the images are smallei in proportion as the radius of curvature is less.

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Now, the anterior surface of the crystalline lens is a convex mirror; the posterior surface, or rather the anterior surface of the vitreous humour corresponding thereto, represents a concave mirror. The reflected images are feebly illuminated, because the difference in refraction between the fluids of the eye and the lens being small, the reflexion is not considerable. They are, however, clearly discernible, when we hold a bright flame at one side of the eye, and look into the organ at the other side. If a line, drawn from the flame to the eye, forms an angle of about 30° with the axis of vision, and if we look at the other side, likewise at an angle of about 30° with the axis of vision, into the eye, the three little images appear flat, close to one another, in the pupil (fig. 1).

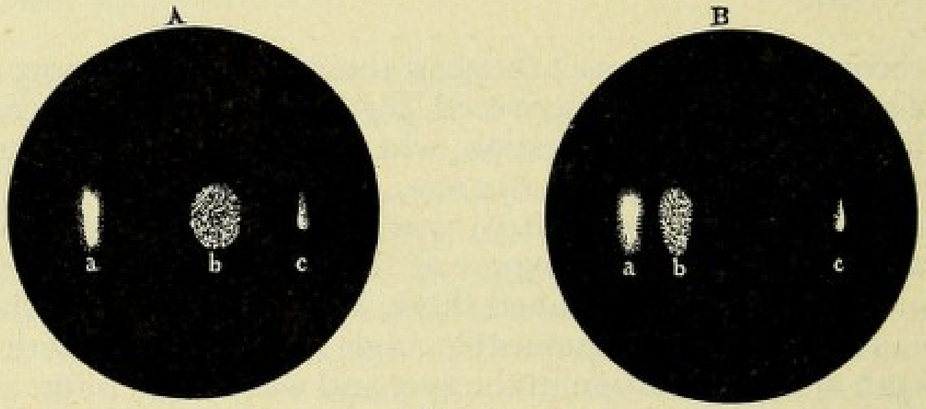

Fig. 1.

A represents their situation in the eye accommodated for distance; B in the eye accommodated for near objects. In both *a* is the reflected image of the cornea; *b* that of the anterior surface, and *c* that of the posterior surface of the lens. Cramer viewed them magnified 10 or 20 times. He thus convinced himself that the image *b* reflected by the anterior surface of the lens is, in accommodation for near objects, considerably smaller, and he thence correctly inferred that the anterior surface of the lens increases in convexity, that the radius of curvature diminishes.

Subsequently Helmholtz, who, independently of Cramer, had discovered the true principle of accommodation, has stated that also of the little inverted image *c* formed by reflexion on the surface of the vitreous humour, not only the apparent, but the actual size diminishes a little in accommodation for near objects, and that, consequently, the posterior surface of the lens, too, increases in convexity, although this increase is very slight.

As to the change in situation of the curved surfaces of the lens, this can be determined from the alteration of place of the reflected images. If we compare Fig. 1, A and B, we shall see that in B the image *b* reflected by the anterior surface of the lens, is approximated much more to the reflected image of the cornea *a*, than in A; and Cramer hence inferred that the anterior surface of the lens, which had become more convex, now comes also to lie closer to the cornea.

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It is, indeed, true that we do not see the images exactly in the direction of the point where the axis cuts the surface of the lens, because both the incident and the reflected ray is refracted by the cornea in front. But in consequence of the symmetry of the cornea . . . and the symmetrical position of the eye and the flame with respect to the axis, the deviations so produced are equally great on both sides, and the above inference, therefore, remains quite correct.

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Cramer did not observe any displacement of the posterior image. He thence inferred that the situation of the surface did not alter. This inference was hazardous, so long as it was not ascertained how far the change of form of the lens in accommodation might have influence on the place where the image was seen. Now, however, since the mathematical investigation of Helmholtz has shown, that in consequence of an incidental compensation, such an influence does not at all, or scarcely exist, we are really justified in concluding, from the unaltered situation of the image *c*, that the posterior surface of the crystalline lens in accommodation does not change its situation.

The changes in the dioptric system, observed in accommodation for near objects, therefore, consist in: 1. That the anterior surface of the lens becomes more convex and approaches the cornea, both these alterations taking place to a considerable degree; 2. That the posterior surface of the lens becomes a little more convex, but, notwithstanding, remains at a nearly equal distance from the cornea.—Besides the changes here described, none others occur in the dioptric system in accommodation. In the first place, Dr. Knapp has proved that the changes occurring in particular persons in the crystalline lens, are, in general, sufficient to account for their range of accommodation; and, in the second place, I have satisfied myself that where the crystalline lens is absent, even in young people, not the slightest trace of accommodating power remains. . . .

Note to § 3

In order to observe the reflected images, Cramer made use of an instrument, by him called the *ophthalmoscope*, a term which is now generally and more correctly applied to the eye-speculum. This instrument I have so modified that it can be used for measurements, and I have given to it in this form the name of *phacoidoscope*, which word fully expresses its object. The most essential elements of this instrument are (fig. 2):

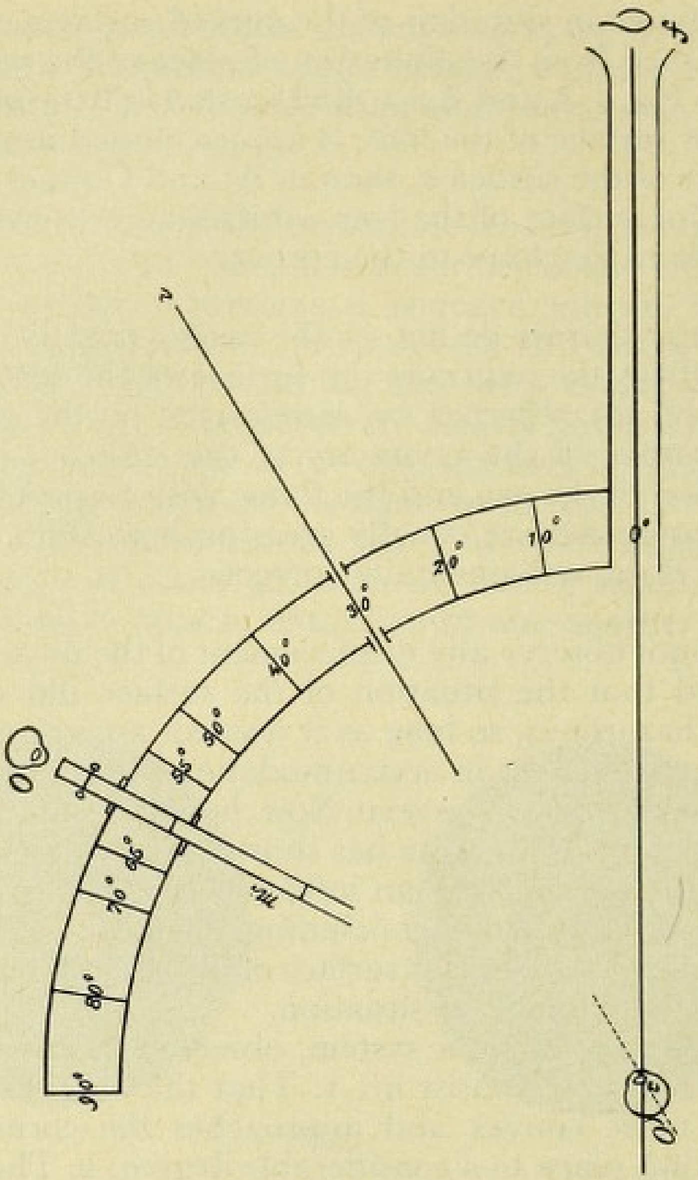

Fig. 2.

1. A horizontal quadrant, divided into degrees; 2. A flame *f* reflected in the observed eye O′; 3. A microscope *m*, through which the observer's eye O sees the observed eye O′ magnified from 15 to 30 times, and in which the slit between two movable vertical surfaces present in the eye-piece, serves as a micrometer; 4. A sight *v*, capable of being placed at different distances from the eye. The flame impinges unchanged upon 0°, the sight and the microscope can turn horizontally around the middle point from which the quadrant is described; the observed eye O′ is so placed, that its crystalline lens coincides with the middle point of this quadrant. We can thus alternately fix the sight, placed near the eye, and a distant point situated in the direction of the sight, after having first given a proper position to the microscope and to the sight.

The flame remains, as has been said, in the direction of 0°. If the microscope be now placed at 60° and the sight close to 30°, we shall usually, on altering the accommodation, see very distinctly the displacement and change of size of the middle image. Properly speaking, the sight ought not to stand at 30°, but at about 5° or 6° from it, as the observed eye must look 5° or 6° more inwards. The axis of vision lies, viz., in general, to the outside of the line of vision (that is the line extending from the yellow spot to the fixed point), and the line of vision must therefore be turned inwards, in order to direct the axis of vision to 30°. If we wish to determine the position of the surface of reflexion of the lens from the distance between the reflected images *a* and *b*, the direction of the axis of the cornea must first be sought in order to place the sight correctly with respect to it.

Helmholtz constructed a peculiar instrument, called by him the *ophthalmometer*, for the purpose of determining the magnitude of the reflected images. This instrument is one of the great treasures for which we are indebted to his genius.

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The mode of measurement with the heliometer, which enables astronomers accurately to determine minute dimensions of the planets in constant motion, suggested its construction to Helmholtz. These measurements are accomplished by doubling the images; the same is true of the ophthalmometer. Objects which are seen through a plate of glass, bounded by perfectly flat and parallel surfaces, held obliquely to the line of vision, appear to be in some measure laterally displaced, and this displacement increases with the magnitude of the angle of incidence of the rays of light upon the plate. On this simple fact depends the action of the ophthalmometer.

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The application of the ophthalmometer to the measurement of the clear reflected images of the cornea is very easy. We observe that in accommodation for each distance the magnitudes of the images, and consequently the radius, remain unalterably the same.

On the anterior surface of the lens the image is too weak and too ill-defined, to allow of the measurement of double images thereof with the ophthalmometer. Helmholtz therefore produced, close to the reflected image of the lens, a changeable reflected image on the cornea, and made this last equal in magnitude to the first, of which he could accurately judge with the naked eye. The magnitude of that of the cornea can then in every case be calculated or measured.

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The little inverted image of the posterior surface of the lens is well defined. In this instance the ophthalmometer was again applicable, and Helmholtz satisfied himself that the radius of curvature in accommodation for near objects here becomes a little smaller. . . .

In order to ascertain the place of the anterior surface of the lens, Helmholtz determined that of the margin of the pupil which lies against the lens. The position of the posterior surface, in the determination of which the ophthalmometer again rendered good service, was deduced in a rather complex manner, from that of the reflected image. These determinations of the places of the surfaces of refraction might, as has been already observed, also be obtained with the phacoidoscope.

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§ 4. *On the Mechanism of Accommodation*

So soon as the changes which the dioptric system undergoes in accommodation had become known, physiologists were in a position to investigate, with some hope of success, the mechanism whereby those changes are produced.

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But, notwithstanding all these efforts, it cannot be said that any theory brought forward has as yet been fully proved: the utmost we have attained to is, that by exclusion, the limits wherein our views may range have been much restricted.

It has been in general tacitly assumed that the accommodation for distance, and even for the farthest point of distinct vision, is purely passive,—that in it only relaxation of the parts which actively produce accommodation for near objects takes place. I believe that this idea was in all respects fully justified. But, if we endeavour to explain the mechanism of accommodation, it is, as a preliminary question, so important, that it may well be specially treated of, the more so, because some advocate an active accommodation also for distant objects. The grounds on which it may, in my opinion, be maintained that accommodation for near objecs only is active, while that for distant objects is passive, are the following:

1. The subjective sensation; for myself this is conclusive.

2. The phenomena produced by mydriatics. If we drop into the eye, a solution of one part of sulphate of atropia in 120 of water, the pupil, after ten or fifteen minutes, begins to dilate, and soon afterwards the nearest point of distinct vision removes farther and farther from the eye. At the end of forty minutes all action is destroyed, and the eye remains accommodated to its farthest point. The muscular system for accommodation is now paralysed, and paralysis, that is, the highest degree of relaxation, is thus proved to be equivalent to accommodation for the farthest point. Now, did we assume the existence of a distinct system, working actively in accommodation to the farthest point, we ought to maintain—1st, That this system is not paralysed by atropia,; 2nd, That it is by this agent brought into a condition in which it is incapable of relaxation. This supposition would not be quite absurd. Something of the kind is said to occur in the action of atropia upon the iris: the circular fibres of the latter are thereby paralysed, but at the same time its radiating fibres are said to be brought into the condition of spasm, so that the pupil becomes much wider than in cases of paralysis of the sphincter, and is also not at all or scarcely capable of further dilatation by irritation of the sympathetic nerve in the neck[1]. But though the supposition is not absurd, it is nevertheless far-fetched and little admissible. That it is incorrect appears further:

3. From the phenomena attending paralysis of the oculo-motor nerve. In this affection the power of accommodation is not unfrequently wholly lost. This condition may occur with paralysis of some or of all the muscles governed by the oculo-motor nerve; but it may also exist quite independently. In it the refraction corresponds to the original *farthest point*, as cases of recovery have satisfactorily proved to me. The pupil is immovable and dilated, although not highly so. On instillation of atropia, the diameter becomes much greater, but the refraction of the eye remains unaltered. Accommodation for the farthest point corresponds, therefore, to total paralysis. In imperfect paralysis (paresis of accommodation) the nearest point is always removed further from the eye, the farthest remaining unaltered. Cases of paralysis, where the farthest point should be approximated to the eye, do not occur: they

[1]See De Ruyter, *De actione Atropæ Belladonnæ in iridem*, Trajeni ad Rhenum, 1856. Kuyper, *Onderzoekingen betrekkelijk de kunstmatige verwijding van den oogappel.* Utrecht, 1860.

should necessarily occur, did a muscular system exist, actively producing accommadotion for remote objects.

4. The lens, enclosed in its capsule, has an important property, which must here be expressly pointed out. It possesses a high degree of elasticity. On gentle pressure its form is easily altered, but it immediately regains its original form when the pressure ceases.

Hence, too, it appears, that only the mechanism of accommodation for near objects is explicable by muscular action, and that the return to accommodation for distant objects occurs spontaneously (with the co-operation of elastic parts) when the active muscular operation ceases. The efforts of myopic individuals to see distinctly at a greater distance, are confined, as we shall subsequently observe, to diminishing the circles of diffusion, by excluding a part of the pupil: they produce no true accommodation—no change of the dioptric system.

Now the accommodation for near objects must take place through the intervention of muscular action. The accommodation is produced voluntarily, and we know no voluntary movement without the intervention of contractile—of muscular elements.

Before physiologists were acquainted with the changes of the dioptric system, they often attached importance to the *external* muscles in the production of accommodation. Now that we know that the accommodation depends on a change of form in the lens, this opinion seems scarcely to need refutation. That with converging lines of vision, through the action of the musculi recti interni, we are capable of producing a higher degree of accommodation than is attainable by parallel lines, proves only that the muscular action of accommodation and the contraction of the musculi recti interni are associated: we can by no means thence infer that the musculi recti interni have a direct influence upon the accommodation. That they do not possess this, I learned from cases where the musculus rectus internus was completely paralysed, and the accommodation nevertheless had its normal range. The same might already have been inferred from the fact, that when the near object fixed upon lies to the side, the rectus internus in one eye is not active, and, nevertheless, accommodation for near objects in this case equally takes place. Many instances further occur, where the accommodation is wholly destroyed by paralysis, without the external muscles of the eye being in the least impeded in their action; and, finally, some cases are on record of paralysis of all, or of nearly all, the muscles of the eye, and of deficiency of the same, without diminution of the power of accommodation. We hence conclude that the external muscles of the eye exercise no direct influence on accommodation.

The contractile elements, which produce the accommodation, must consequently be situated exclusively *in* the eye. Now we are acquainted, in the eye of the mammalia, solely with unstriped muscular fibres or fibre-cells: there are no striped muscular fibres or fasciculi. These last, however, replace the former in the eye of birds, and therefore we may attribute to the unstriped muscular fibres the same signification and the same voluntary action. Indeed it is as little strange that fibre-cells should here be subject to the will as that the striped fibres of the heart should be withdrawn from it. Furthermore, if we consider that Cramer saw accommodation for near objects supervene on galvanic irritation of the eye of various animals, deprived of its external muscles, and that paralysis of the iris and paralysis of accommodation almost always go hand in hand, there can be no doubt that internal muscular elements, under the control of the ciliary nerves, by their contraction produce the accommodation.

Now the muscular elements known to exist in the eye of the mammalia are (fig. 3):

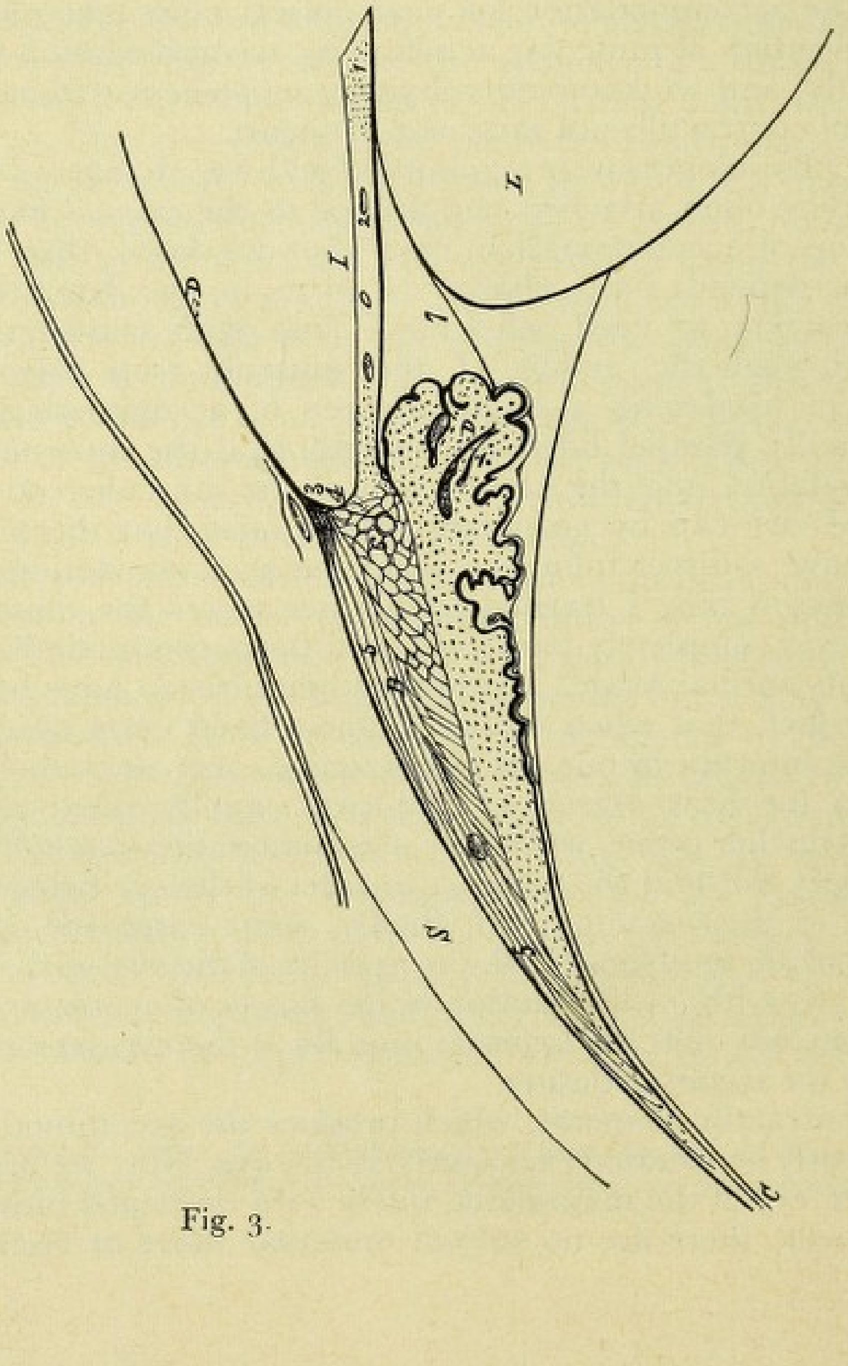

Fig. 3.

1. The muscular fibres of the iris. The circular fibres (sphincter pupillæ (1)) are easily seen and isolated, most easily in white rabbits or rats.

Independent radiating fasciculi of fibres are less easily demonstrated. The vascular trunks (2), which likewise have a radiating direction, possess a distinct muscular layer; and it is generally difficult to prove that the fibrous bundles found do not belong to the vessels.

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I have shown with certainty from experiments on white rabbits, that the bloodvessels of the iris, on irritation of the sympathetic nerve in the neck, become narrower while the pupil dilates. As to the connexion between these two phenomena, I do not venture to give an opinion.

2. The ciliary muscle.

That the organ formerly known under the name of ciliary ligament is of a muscular nature, has been proved, independently of one another, by my esteemed friends Bowman and Bruecke. The fibres arise in great part from the outer layers (3) of fibres, in which the membrana Descemetii (D) subdivides, while the innermost layers of these fibres spread as ligamentum pectinatum on the iris. The muscular fibres form fasciculi, of which the most external, connected in long extended networks, run backwards parallel to the upper surface of the sclerotic (S) and pass into the several laminæ of the choroid (C). Internally (6) the meshes of the nets become gradually shorter, and finally, mostly spread out in a circular direction, so that the fasciculi here acquire rather a circular than an antero-posterior direction. This innermost portion of the ciliary muscle is connected with the choroidal tissue in the place where the corpus ciliare (P) passes from without inwards. If we cut out a piece of the conjoined membranes, and with a pincers seize the whole breadth of the portion of the iris near its insertion and tear it off, the innermost part (6) of the ciliary muscle remains attached to the outer surface of the ciliary process, while the most external portion (5) continues lying on the sclerotic and connected with the extreme outer layers of the choroid, which are not torn off. We can thus divide the muscle into two parts, as is described in Von Reeken's dissertation (1855). The networks of the fasciculi of the innermost portion possess, as is there also represented, a more circular direction. H. Müller has subsequently described these as a separate muscle. He has the merit of having thereby directed attention to this innermost part. That it does not, however, deserve to be considered as a separate muscle, is clearly shown by the above-described gradual transition from the one direction to the other.

3. In other elements also of the eye of the mammalia, contractility has been suspected, though not demonstrated. Max. Langenbeck has assumed the existence of a musculus compressor lentis immediately around the lens. Others, however, have not succeeded in finding this.

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In the choroid, Schweigger has found cells presenting quite the appearance of ganglionic cells, and it seems that they must really be considered as such; and Heinrich Müller appears inclined to attribute contractility to the choroid. Each of these views is, however, still problematical.

From this sketch it seems most probable, that no contractile elements, except those of the iris and of the ciliary muscle, can come into play in accommodation. Accordingly Cramer thought that the change of form of the lens might be explained by the action of the iris: simultaneous contraction of the circular and radiating fibres producing pressure on the lens, and thus giving to the part of the crystalline corresponding to the pupil greater convexity, and causing it to protrude through the pupil. Pathology has, however, shown that the iris takes no direct part in the accommodation of the lens. It may be adherent to the cornea, leaving a space between the iris and the lens; it may float without tension in the aqueous humour (iridodenosis); it may be in part removed by iridectomy; it may even be wholly absent, without the power of accommodation being perceptibly disturbed.

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It therefore remains only to attribute to the musculus ciliaris the important quality of accommodation-muscle.

Thus far we have arrived by exclusion. But the mechanism whereby the contraction of this little muscle alters the form of the lens is ... not yet satisfactorily and convincingly brought to light.

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I shall here confine myself to a short statement of the views of Helmholtz, who numbers the most adherents, and of H. Müller. Helmholtz, by measurement during life, found the lens, in accommodation for distance, thinner than it occurs in the dead body. It is said that this may depend on elongation of the lens (fig. 3, L), through tension of the Zonula Zinnii (7), which is stated to be present during life, certainly as a result of the pressure of the vitreous humour. It is further stated that after death, when the pressure ceases, the tension may diminish and the lens consequently become thicker. But during life the action of the ciliary muscle may effect the same. It is evident that the outermost layers of the ciliary muscle, in contracting, must cause the origin at the fibrous layers (3) of the membrana Descemetii and the termination at the choroid (C), both of which are elastic, to approach one another. According to this, the iris (I), which is mediately connected with the anterior part of the ciliary muscle, recedes in accommodation for near objects; and, on the contrary, the place of insertion in the choroid will advance a little forwards. Now with this the origin of the Zonula Zinnii is connected; and as, therefore, the latter at the same time advances, its tension ceases, and the equator of the lens becomes smaller, the lens itself becomes thicker in the middle, and its two surfaces are rendered more convex. Helmholtz supposes that to this may be added a pressure of the iris, which may make the equatorial surface of the lens arched anteriorly, and thus increase the convexity of the anterior surface and diminish that of the posterior.

H. Müller's theory is based upon his anatomical investigations of the ciliary muscle. He distinguishes, as we have seen, a circular muscle capable of exercising pressure on the margin of the lens, and thus of rendering the lens thicker, while it would at the same time draw the periphery of the iris backwards. Moreover, he attaches, with Helmholtz, importance to the relaxation of the Zonula Zinnii. Lastly, he sees in the action of the most external layers of the ciliary muscle a means of augmenting the pressure of the vitreous humour, of pushing the lens forwards, of diminishing the increased convexity of the posterior surface, and, by the resistance of the simultaneous contraction of the iris, of increasing that of the anterior surface.

Against these two theories I have difficulties which I shall not further develop. It would, moreover, be easy to bring forward other hypotheses, but from this too I shall refrain. I am afraid of depriving this work of the character I desire, above all, to see attached to it,—the character of exact science.

Note to §4

One point I shall take leave to remark upon is, that in the case of acquired aniridesis with normal range of accommodation, described by Von Graefe, in accommodation for near objects, no displacement of the then visible ciliary process was observed; that, moreover, nothing is mentioned of the possibility of a direct pressure of the ciliary muscle on the margin of the lens; and, finally, that nothing is said of any diminution of the circumference of the lens, although the increased convexity of its anterior surface is proved from the reflected images. On former occasions I have also in vain endeavoured, after iridectomy, in which the margin of the lens became visible, to satisfy myself of the diminution of the circumference of the lens in accommodation for near objects.

. . . .

What we must, in the first place, therefore, endeavour to clear up is the question, whether the circumference of the lens, in accommodation for near objects, becomes perceptibly smaller? The answer will have great influence on our further considerations.

§ 5. *Range of Accommodation*

In all the investigations respecting the cause and mechanism of accommodation, observers appear not to have thought of defining the range of accommodation under various circumstances, and of seeking a simple numerical expression for the same. And yet the necessity for such existed almost still more for the oculist than for the physiologist. If it be desired to investigate the accommodation, whether in reference to the changes observed in the eye, either at different periods of life, or with respect to myopia, hypermetropia, asthenopia, strabismus, paresis, etc., it is evidently necessary to have an easily comparable standard of its magnitude or range.

Had the necessity been felt, it would not have been difficult to have provided for it. The knowledge alone of the distance R from the farthest point of distinct vision, and of the distance P from the nearest, is sufficient. With the knowledge of these distances the range of accommodation 1 : A may be found by a very simple formula.

The formula is

$$\frac{1}{A} = \frac{1}{P} - \frac{1}{R}$$

The distances P and R may be calculated from the nearest point *p*, and from the farthest point *r* of distinct vision to a point situated about $3'''$ behind the anterior surface of the cornea in the eye, called the anterior nodal point k'. The latter coincides in the eye nearly with the second nodal point k'', both of which may therefore here be considered as one point. This point corresponding nearly to what is termed the optical centre, has a very important signification; the rays, which in front of the cornea are directed to the node, in the vitreous humour continue parallel to their primitive direction, and also nearly exactly directed to the same point; these rays may therefore be considered not to have been refracted. This is represented in the subjoined figure 4.

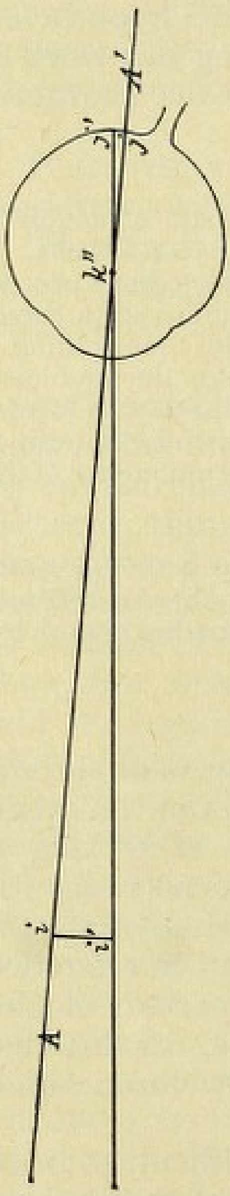


Fig. 4.

If we connect the corresponding points of the object and image by right lines with one another, these all, just as i' j', pass through the point k'', and they are therefore called lines of direction; *the posterior nodal point k'' is consequently the point of decussation of the lines of direction.*

The meaning of the formula for the range of accommodation

$$\frac{1}{A} = \frac{1}{P} - \frac{1}{R}$$

is easily understood. In this formula, A is the focal length of a lens, which gives a direction to the rays from the nearest point of distinct vision *p*, as if they came from the farthest point *r*.

. . . .

Consequently A is the focal distance of the auxiliary lens, of which the eye avails itself in accommodation, and as the power of a lens is inversely proportional to its focal distance, 1 : A expresses the range of accommodation.

It is convenient to represent the value of A in Parisian inches, especially as the focal distance of lenses is usually stated in the same, and this applies also more particularly to spectacles[1]. (p. 27).

. . . .

The same form of expression I now apply to all lenses. The power may always be regarded as inversely proportional to the focal distance F, and therefore find its expression in 1 : F. If the focal distance be negative, it becomes — 1 : F. Glasses of 1/10 of —1/8, &c., therefore mean glasses of ten Parisian inches positive, eight Parisian inches negative focal distance, &c. We shall subsequently see that the degrees of anomalies of refraction may be expressed in a similar mode, and that it is thereby at the same time shown, by what glasses they may be neutralized.

We have above seen that the range of accommodation is contained in the formula

$$\frac{1}{A} = \frac{1}{P} - \frac{1}{R}$$

Therefore it is necessary to possess a simple method of determining the points p and r with sufficient accuracy for practical purposes. The determination of r is accomplished with a nearly parallel state of the the lines of vision, that is, by fixing with both eyes an object at least 5 mètres distant. We know, namely, that when the lines of vision converge, accommodation necessarily takes place, and that consequently the true farthest point in total relaxation of accommodation cannot thus be found. As an object we may use groups of vertical black lines, each line 2 1/2 millimètres thick and 10 millimètres fro mone another, and examine whether they can at the distance of five mètres be seen with perfect accuracy with the naked eye, or whether the sharpness of the object can be increased by glasses. If no improvement is attainable by glasses, r lies at least 5 mètres distant, which may here be equally represented by an infinite distance ∞.

Where nearsightedness exists, concave glasses, with negative focal distance, are required to obtain perfect accuracy: in this case we determine what is the weakest glass of this nature with which the sharpest possible vision is obtained.

Let us illustrate this by an example. A nearsighted eye, to see accurately at a distance, needs a glass of 15 Parisian inches negative focal distance, placed at a quarter of an inch in front of the cornea, that is, half an inch before the nodal point k' in the eye, then R= 15 1/2 Parisian inches.

In place of the above-mentioned black lines we may, in the determination, make use of definite letters or numbers, whereby, by causing them to be named, we may obtain still more objective certainty with what glass they are accurately seen. . . . In Dr. Snellen's system of test-types, each number corresponds to the number of feet at which a sharp-sighted eye distinguishes them.

[1]In the boxes of Glasses, prepared by Paetz and Flohr, of Berlin, for oculists, they are defined in Prussian inches, which are less than Parisian inches. In England, English inches are employed, one English inch being equal to about 0·94 Parisian inch, and differing but little from the Prussian. In practice a reduction will rarely be necessary.

. . . .

The determination of the nearest point is effected by means of a wire optometer. This consists of a little frame (fig. 5), of the size represented in the figure, in which some fine black wires are vertically extended and wherewith a measure, capable of being rolled up, is

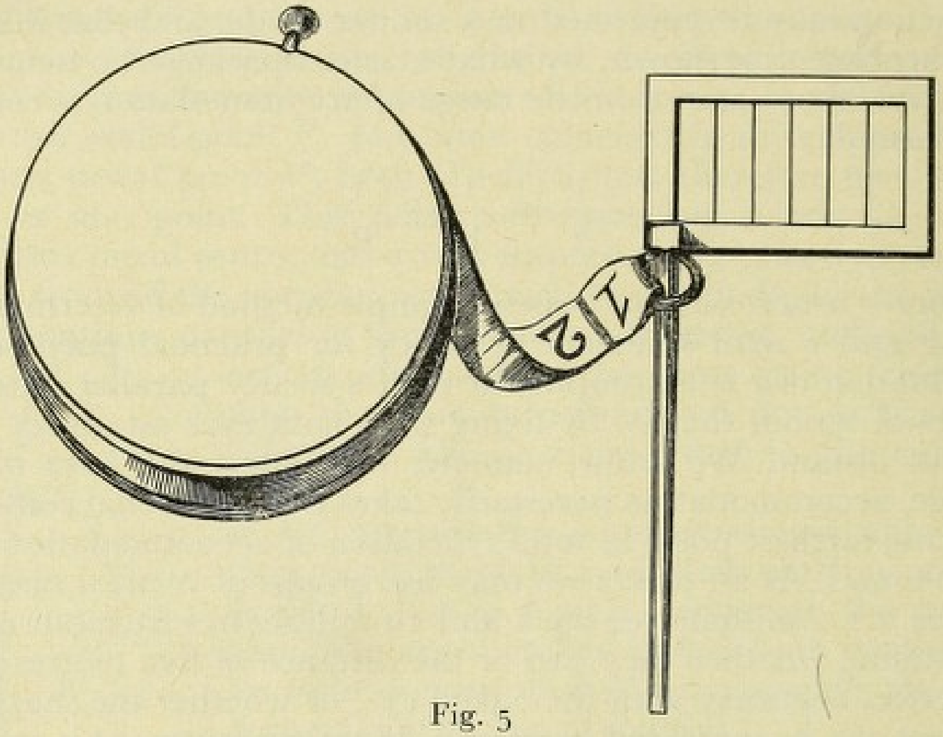


Fig. 5

connected, the scale commencing at the frame, and the bobbin *c* being applied to the temple, on a line with the anterior surface of the cornea. This bobbin is, by moving the frame out from the eye, unwound until the vertical wires are seen with perfect accuracy. It is, indeed, possible to determine by means of such wires with sufficient accuracy whether they are exactly seen, as by a slight deviation the margins lose their sharp outlines, and more of these lines appear. The persons examined for the most part state this very easily. The reading of print, capable of being distinguished at given distances in due accommodation and by a sharp eye, may be used to control the result.

Most optometers are based upon the principle of the well-known experiment of Scheiner: through two openings or slits, placed closer to one another than the diameter of the pupil, the object, for example a wire, is seen, and this appears double if the eye is not accurately adjusted to this distance. If we now cause any one to look into such an optometer and to determine when he sees the wire single, we shall in general obtain a distance to which the person easily accommodates his vision, but this distance will not correspond to either the nearest or the farthest point.

. . . .

Only when a person has learned to control his power of accommodation, and can voluntarily bring it into the condition of the highest action and of perfect relaxation, can we with such optometers successively determine his farthest and his nearest point of distinct vision. But such voluntary control of the power of accommodation is acquired only by great practice. Ordinary individuals accommodate for their farthest point only when they actually look at a distant object, and for their nearest only when they very distinctly see an object approaching, whose diminishing distance they meanwhile observe and follow in their imagination. Then, by the effort actually to see the object distinctly as long as possible, the greatest possible tension of the power of accommodation is excited. Such an approaching object is the frame above described, while in the optometer, the distance of the object not being known, no stimulus to tension is created.

If greater accuracy be desired, as in observations intended for the solution of scientific questions, it is advisable to employ another instrument, which shall be described in treating of the relative range of accommodation.

The partial dependence of accommodation on the convergence of the lines of vision has already been alluded to. In the determination of the nearest point this should be borne in mind. Theoretically we should, in order to be able to institute a comparison, always determine the nearest point at the same angle of convergence, as the farthest point is examined with parallel lines of vision. This would, however, be attended with great practical difficulties, and, as I shall hereafter show, would moreover lead to wholly incorrect results. The only thing required in this respect is, that in all the cases where the nearest point lies farther from the eye than 8″, the determination should be made with the use of such convex glasses, that the nearest point should be brought to about 8″ from the eye. It will then be necessary to calculate at what

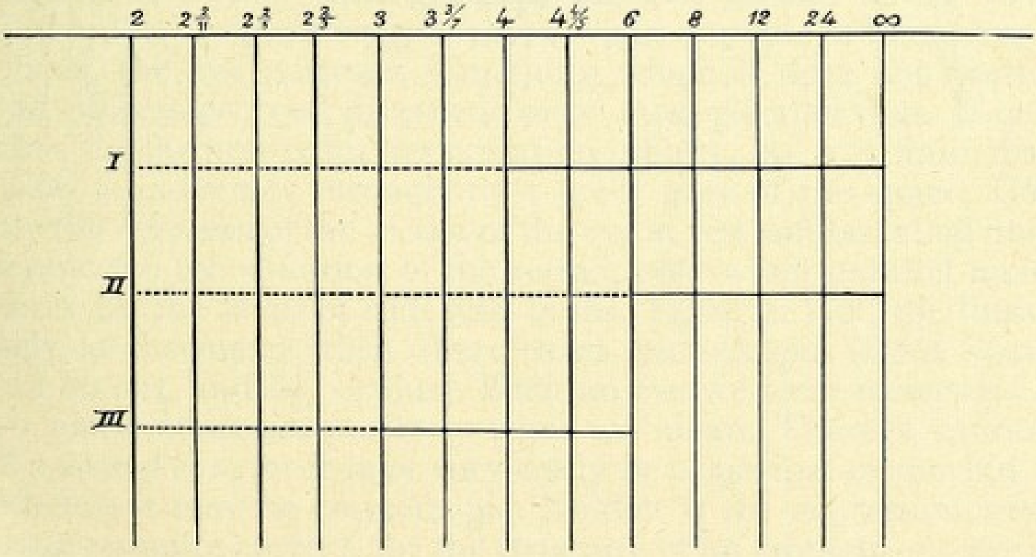


Fig. 6.

distance the eye should have been brought into this state of accommodation without the use of the convex glasses.

. . . .

Lastly, I would here state a method of expressing the *ranges of accommodation* by the *lengths of lines*, which exhibits at the same time the commencement and termination of the range of accommodation, that is the nearest and farthest points of distinct vision. Above parallel lines, situated at equal distances from each other (fig. 6), let numbers be placed, expressing the distances of distinct vision, and in such an order, that the distance between two lines may everywhere represent an equal range of accommodation, for example, 1/24. It is evident that in fig. 6 the differences of the distances from line to line always amount to 1/24 of the range of accommodation. . . .

A single horizontal line now immediately shows the extent and range of accommodation. In fig. 6 three such lines occur.

I. represents a person whose farthest point of distinct vision lies at an infinite distance, his nearest point at 4″. His range of accommodation is

$$\frac{1}{4} - \frac{1}{\infty} = \frac{1}{4}$$

and is expressed by six lines distance, each of 1/24 of this range of accommodation, consequently $6/24 = 1/4$.

II. has likewise his farthest point at an infinite distance, his nearest at 6 inches. His range of accommodation is

$$1/6 - 1/\infty = 1/6, \text{ expressed by } 4/24.$$

III. has his farthest point at 6 inches (he is therefore near-sighted) his nearest at 3 inches. His range of accommodation is

$$1/3 - 1/6 = 1/6;$$

corresponding to four lines distance

$$= 4/24 = 1/6.$$

. . . .
. . . .
. . . .

CHAPTER II

Defects of Refraction and Accommodation in general

§ 6. *Distinction between Defects of Refraction and of Accommodation*
Hitherto the defects of refraction and of accommodation have been more or less mixed up one with another. This confusion was an impediment to the clearness of description, which in this department particularly, is absolutely necessary to the correct appreciation of the subject. The ideas of refraction and of accommodation must therefore in the first instance be accurately distinguished from one another. . . .

By *refraction of the eye*, we understand its refraction in the state of rest; that is, the refraction which the eye possesses in virtue of its form and of that of its component parts, independently of muscular action, independently of accommodation. The term, therefore, applies to the refraction of the eye whose muscles of accommodation are inactive or paralysed.

. . . .

The farthest point of distinct vision corresponds to the state of rest of accommodation. Now, so soon as the action of accommodation occurs, the eye becomes adjusted to an adjoining point.

. . . .

The stronger this action is, the nearer is the accurately seen point. *Accommodation is, therefore, the voluntary action whereby the eye becomes adjusted to a nearer point than is the case in the state of rest of accommodation.*

Hence it appears, that refraction is dependent on the anatomical condition of the component parts of the eye; accommodation, on the contrary, depends upon the physiological action of muscles.

With regard to refraction, we call the structure of the eye normal, when, in the state of rest, it brings the rays derived from infinitely distant objects to a focus exactly on the anterior surface of the layer of rods and bulbs. . . . If convergent rays are also capable of being brought to a focus, the eye possesses something which it does not need: for from all objects proceed divergent or at most parallel rays. If on the contrary, the farthest point lies not at an infinite, but at a finite distance, vision is indistinct throughout a great part of the space. Consequently the *refraction* of the media of the eye at rest can be called normal in reference to the situation of the retina, only when parallel incident rays unite on the layer of rods and bulbs. Then, in fact, the limit lies precisely at the mean; then there exists emmetropia (from ἔμμετρος, modum tenens, and ὤψ, oculus). Such an eye we term *emmetropic*.

This name expresses perfectly what we mean. The eye cannot be called a *normal* eye, for it may very easily be abnormal or morbid, and nevertheless it may be emmetropic. Neither is the expression *normally constructed eye* quite correct, for the structure of an emmetropic eye may in many respects be abnormal, and *emmetropia* may exist with difference of structure. Hence the word *emmetropia* appears alone to express with precision and accuracy the condition alluded to.

. . . .

The eye may deviate from the emmetropic condition in two respects: the principal focus φ'' of the eye at rest may fall *in front of* or *behind* the most external layer of the retina. In the former case divergent, in the latter convergent rays come to a focus on the retina. In the first case, therefore, in the condition of rest, objects are accurately seen which are situated at a definite finite distance; in the second they are at no distance accurately seen, for the rays in falling upon the cornea must, in order to unite in the retina, already converge towards a point situated behind the eye. In the first case the farthest limit lies *within* the normal measure: the measure is too short, and the condition might, therefore, be called *brachymetropia*. In the second case, the boundary lies *beyond* the measure, and I have, therefore, called this state *hypermetropia*.

Hence it is perfectly clear, that brachymetropia and hypermetropia are two opposite conditions.

. . . .

In order to express that the eye is not emmetropic, we may use the word *ametropia* (from ἄμετρος, extra modum, and ὤψ, oculus). Brachymetropia and hypermetropia are both, therefore, referrible to ametropia.

Brachymetropia is evidently nothing else than *myopia*, and it appears preferable to use the word myopia, as being an established term. The word brachymetropia was formed only in contrast to hypermetropia, to which expression I thought it right to adhere.

Hence it is evident that myopia and hypermetropia are opposite conditions. That myopia is of very frequent occurrence, and is to be considered as an important condition, has long been admitted. Still more common, however, and more important in its results is hypermetropia, which has hitherto been for the most part either overlooked, or confounded with other states.

. . . .

The shortening of the focal distance, whereby nearer points become accurately visible, is the work of the muscles of accommodation. Under the maximum action of these muscles the eye is adapted to the distance P of its nearest point. . . . The range of accommodation diminishes, as shall hereafter be more particularly pointed out, with advancing years. At the same time R may remain almost unaltered, and P thus becomes greater. The result of this is, that in the emmetropic eye the nearest point is at a certain period of life removed so far from the eye, that more minute operations can no longer be well performed with near objects. This condition of the eye is called *presbyopia*. *Presbyopia therefore exists, when, in consequence of the increase of years, with diminution of the range of accommodation, the nearest point has been removed too far from the eye.*

Formerly writers were in the habit of contrasting presbyopia with myopia. Apparently this was quite correct. ... In myopia they found 'the mean distance of distinct vision' to be situated too near the eye, in presbyopia too far from it.

. . . .

On closer examination it appears, however, that such opposition is illogical. The fact is, that both in an anatomical and in a physiological point of view, myopia and presbyopia belong to very different categories. Myopia is based upon an abnormal construction of the eye; presbyopia is the normal condition of the eye at a more advanced period of life.

. . . .

Myopia, finally, rests upon an abnormal situation of the *farthest* point of distinct vision; presbyopia, on the other hand, on an altered situation of the *nearest* point. So little are myopia and presbyopia opposite conditions, that they may both occur simultaneously in the same eye.

. . . .

Hence we may consider it to be fully proved and demonstrated:

1. That myopia and hypermetropia are to be regarded as opposite conditions.

2. That it is illogical and unpractical to contrast myopia and presbyopia with one another.

With respect to presbyopia, this state is no anomaly, but rather the normal condition of the ... eye, at a more advanced period of life.

. . . .

Accommodation is, as we have seen, based upon a change of form of the lens, produced by contraction of the internal muscles of the eye.

Hence it follows, that anomalies of accommodation may be dependent:

a. On disturbance in the lenticular system.

b. On disturbance of the internal muscles.

Of the disturbance in the lenticular system the condition of total absence of the lens, which I have termed *aphakia*, comes almost exclusively under observation.

The disturbances of the muscles of accommodation are of a very varying nature. Principally we shall have to distinguish:

1. The weakness which not unfrequently manifests itself by definite phenomena after different exhausting illnesses.

2. The more or less complete paralysis, which, probably without exception, is connected with a similar condition of the M. sphincter iridis, and often occurs only as a part of the paralysis of the oculomotor nerve.

3. The spasm, which occurs much more rarely than the paralysis, and, like the latter, is based upon a direct or indirect abnormal action of the nervous system.

Besides these rare forms of spasm, we shall observe, as a very ordinary phenomenon in hypermetropia, a persistent increase of contraction of the muscles of accommodation dependent upon habit. This subject shall, therefore, be treated of in speaking of hypermetropia.

Moreover, it is here to be noticed in general, that the condition of refraction exercises an important influence on the ordinary use of the range of accommodation, and consequently upon accommodation, itself. The modifications so produced cannot be separated from the states of refraction on which they depend, and they therefore come with them under consideration. For this and other reasons it was necessary to give an idea of the subject of accommodation, before passing to the description of the anomalies of refraction.

From the foregoing, it appears that our principal distinction is based upon the situation of the farthest point of distinct vision. Thus we obtain a classification of the anomalies of refraction, which of itself excludes a confusion of the latter with the anomalies of accommodation.

The question naturally arises, whether a classification resting on the nearest point of distinct vision, that is upon *P*, may not also be observed. On a little reflection it will, however, be seen, that this would lead to constant confusion of the anomalies of refraction and of accommodation. Indeed *P* depends upon both factors, both on the refraction of the eye at rest, and on the range of accommodation. Consequently two eyes, in which *P* is similar, may, with respect to refraction and accommodation, present great differences: it is only necessary that the differences compensate one another in the two factors. A myopic eye with a small, and a hypermetropic eye with a great, range of accommodation, may have their nearest point at the same distance as an emmetropic eye, with an average range of accommodation. Now, if they were classified according to their nearest point, all these different eyes should be referred to the same category.

. . . .

Lastly, the same eye should, in proportion as the power of accommodation diminished, belong each time to a different category. This is enough to prove that a classification of eyes, based upon the shortest distance of distinct vision, is entirely unpractical, and almost leads to the absurd. A classification according to the mean distance of distinct vision, which it has been attempted to make by contrasting myopia and presbyopia, is an illusion; for a mean distance of distinct vision does not exist, and what does not exist is certainly not to be defined. (Compare *relative* range of accommodation.)

On the contrary, a classification founded on the greatest distance of distinct vision is simple and logical. With the knowledge of *R* we perceive, in the first place, whether an anomaly of refraction exists. Taking the time of life into consideration, we can, moreover, thence nearly determine what *P* ought to be; and if *P* does not actually correspond thereto, we may infer the existence of an anomaly of accommodation.

§ 7. *Causes of the Defects of Refraction in general*

. . . .

On the cause of the anomalies of refraction the dioptric definition laid down does not throw any light. They are defined simply as disturbances of connexion in the relative position of principal focus and retina. On what anatomical or physiological deviation these disturbances of connexion may depend, is thus left undecided.

This would seem to be the place to treat of this subject in general. However, we here state only what is the rule. Deviations, of a peculiar nature, which occur only sometimes as exceptions, will come under consideration first in speaking of each of the anomalies in detail.

The rule is expressed in the annexed three figures. Fig. 7 is an emmetropic, fig. 8 a myopic, and fig. 9 a hypermetropic eye. It immediately strikes us, that in the myopic eye the axis of vision is longer, while in the hypermetropic eye it is, on the contrary, shorter, than in the emmetropic. To this almost exclusively it is to be attributed, that parallel incident rays in the myopic eye, come to a focus in front of, in the hypermetropic, behind the retina. Of this difference in length of the axis of vision we can even in life satisfactorily convince ourselves. Thus if we cause the axis of vision to be as strongly as possible directed outwards, we shall observe the slow alteration of the arching of the

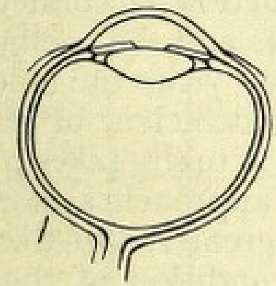


Fig. 7.

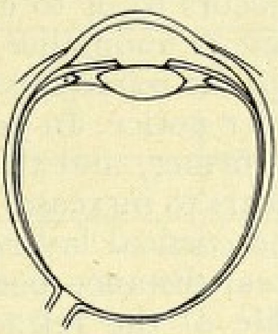


Fig. 8.

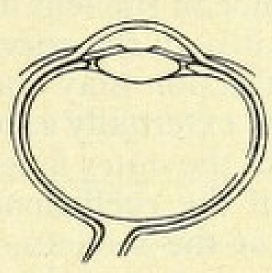


Fig. 9.

oval myopic, and the rapid change of the direction of the arching in the anteriorly situated equator of the hypermetropic eye. Moreover, the other axes of the myopic eye appear to be longer, while those of the hypermetropic are shorter than those of the emmetropic eye.

Myopia and hypermetropia might also be supposed to be dependent on many other causes. Anomalies of refraction might depend upon the curvature of the different refracting surfaces, as well as on the relative coëfficients of the refraction of light. Theories have not been wanting in reference to this subject.

The opinion has in the first place been rather generally entertained, that in myopia the cornea is more convex. So far as hypermetropia was known, it was supposed to be connected with too great flatness of the cornea, which was positively assumed to exist in presbyopia. And on external inspection it would really appear, as if in myopic individuals the cornea was more convex, while in those who are hypermetropic and presbyopic it is flatter than in emmetropic persons. This appearance proceeds from the fact, that in myopia the iris and the crystalline lens lie far behind the cornea, while in hypermetropia and presbyopia they are situated nearer to it. An observer is still further misled to assume a difference in the curvature of the cornea, as in a myopic subject the entire globe of the eye is more prominent, while in the hypermetropic it is more sunk in the orbit, as is often seen. But in truth, the curvature of the cornea in ametropia does not essentially differ from that of emmetropia, and the time of life also exercises scarcely any influence. Numerous measurements of the curval radius of the cornea have satisfied me on this point. They have shown me that, quite contrary to what it was thought should be expected, the cornea at an advanced period of life rather becomes a little more convex, and that in the extreme degrees of myopia, on the contrary, a somewhat flatter cornea is met with.

. . . .

Though in ordinary myopia the cornea is not more convex, it is evident that, *ceteris paribus*, a greater convexity of the cornea must give rise to myopia, and we shall hereafter see that in diseases of the cornea myopia is occasionally produced in this way.

Moreover, it naturally occurs to us to consider the principal focal distance of the lens as a cause of anomalies of refraction. In connection with it both the curvature of the refracting surfaces and the coëfficient of refraction may come under notice. In advancing years the lens becomes externally especially firmer, and thus the coëfficient of refraction of the outer layers appears to increase. If this actually takes place, and if the coëfficient of the cortical layers thus approaches more to that of the nucleus, the focal distance becomes greater. On this the diminution in advanced life of the refractive condition of the eye appears really to depend. But beyond this no facts exist, which give us a right to assume, that definite changes in the focal distance of the crystalline lens usually occur in definite anomalies of refraction. In some measurements of the surfaces of curvature of the lens from eyes of myopic persons, after death, I found no deviation.

. . . .

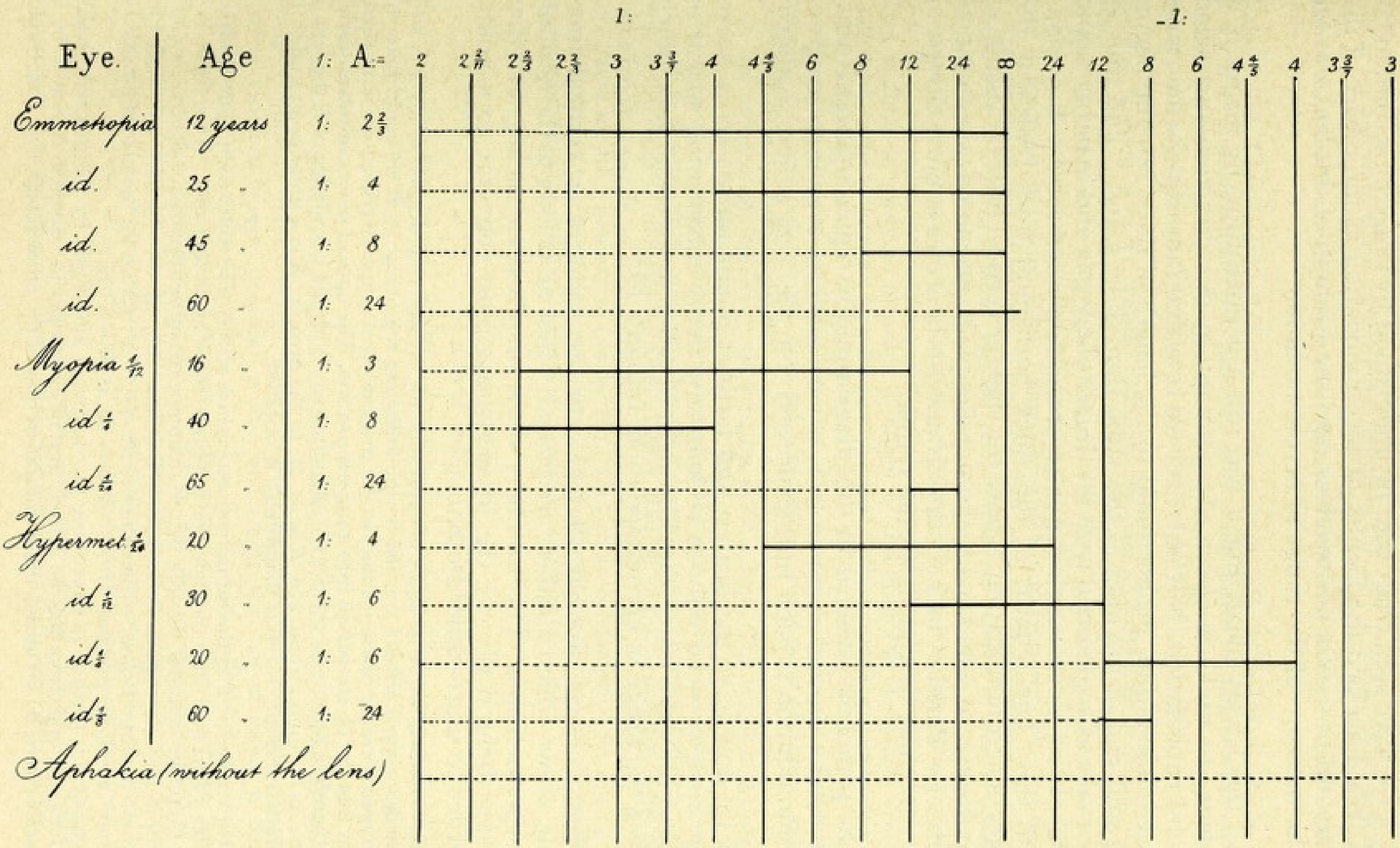
Now if the lens in myopic individuals evidently lies in general farther from the cornea than in emmetropic persons, the focus of the dioptric system must in the former lie even somewhat deeper than in the latter. . . . In hypermetropia, the lens being situated more anteriorly, must, *ceteris paribus*, bring the principal focal distance nearer to the cornea. . . . In both cases . . . the anomaly of refraction is rather compensated than promoted by the lenticular system.

As to modifications in the coëfficients of refraction nothing is known. From a theoretic point of view we must say, that the index of the cornea and aqueous humour being greater, and that of the vitreous humour being on the contrary less, the principal focus should be removed forwards.

The final result, therefore, remains what we laid down in starting: that *myopia usually depends upon an elongation, and hypermetropia upon a shortening, of the axis of vision.*

. . . .

§ 8. *Diagrammatic Representation of the Range of Accommodation, and of the Anomalies of Refraction and Accommodation*



Eye.
Age
1: A.=
1:
-1:
2
$2\frac{2}{11}$
$2\frac{2}{5}$
$2\frac{2}{3}$
3
$3\frac{3}{7}$
4
$4\frac{4}{5}$
6
8
12
24
∞
24
12
8
6
$4\frac{4}{5}$
4
$3\frac{3}{7}$
3
Emmetropia 12 years 1: $2\frac{2}{3}$
id. 25 „ 1: 4
id. 45 „ 1: 8
id. 60 „ 1: 24
Myopia $\frac{1}{12}$ 16 „ 1: 3
id $\frac{1}{4}$ 40 „ 1: 8
id $\frac{1}{24}$ 65 „ 1: 24
Hypermet. $\frac{1}{24}$ 20 „ 1: 4
id $\frac{1}{12}$ 30 „ 1: 6
id $\frac{1}{4}$ 20 „ 1: 6
id $\frac{1}{8}$ 60 „ 1: 24
Aphakia (without the lens)

W. West, lith.

In § 5 we have seen what is to be understood by range of accommodation. We described the faculty of accommodation as the power of the eye to add to itself a positive lens, and the strength of this lens was for us the measure of the range of accommodation.

. . . .

All this is very clear. But it was still a desideratum, by means of a drawing, to make it easier. An attempt in this direction succeeded beyond expectation. Not only can we in a diagram express the range of accommodation, proportional to the length of lines, but the beginning and end of the lines at the same time show p and r, and thus at once make us acquainted with the degree of myopia and hypermetropia of the eye so represented. A glance at the appended table will demonstrate this. The lengths of the thick horizontal lines represent the ranges of accommodation. Above the slighter vertical lines the distances from the eye, at which acute vision takes place, are noted: the numbers exhibit (in Parisian inches) the distances whence rays must *diverge*, in order to come to a focus on the retina.

. . . .

The principle involved in this diagrammatic representation is this, that by the mutual distance of two vertical lines a definite range of accommodation is each time expressed; for this 1/24 is here assumed.

. . . .

If we now have the nearest and farthest points united by a transverse line, we need only to reckon how many intervening spaces of vertical lines the latter runs through, in order to ascertain how much $\times$ 1/24 the range of accommodation amounts to.

. . . .

Moreover, we observe, that also to the right of ∞ vertical lines occur, above which numbers are placed. These all belong to the domain of hypermetropia. The numbers show, in Parisian inches, at what distance behind the eye the incident rays must converge to a point, in order to unite upon the retina.

I have chosen the same mode of expression for the different degrees of myopia and hypermetropia. To this I was led by the following reasoning:— If we could place in the hypermetropic eye a positive, in the myopic eye a negative corrective lens, these might thereby be converted into emmetropic eyes. The optical power of the required lens therefore represents the degree of ametropia. With the knowledge of R the lens is given. In the emmetropic eye, R is $= \infty$; in the myopic, R is a finite magnitude; in the hypermetropic eye this magnitude is negative.

. . . .

Consequently, $1 : R$ is the numerical expression of the ametropia itself. The myopic eye has a lens of $1 : R$ too much, the hypermetropic has a lens of $1 : R$ too little. We may therefore consider myopia *M.*, in reference to emmetropia, as a positive, hypermetropia H., as a negative condition. Therefore, too, as the negative is included in the word hypermetropia, we need not write $H = - 1 : R$, but for the sake of simplicity we may use the expression $H = 1 : R$, as well as $M = 1 : R$.

Against this method of expressing the degree of ametropia by the dioptric power of a lens, the objection may be raised, that in ametropia the dioptric system is, by a corrective lens, by no means made similar to that of the emmetropic eye. Ametropia does not, in fact, depend upon a deviation in the power of the crystalline lens, but rather on a deviation from the normal length of the axis of vision. With a positive lens we therefore obtain, in hypermetropia, a stronger dioptric system with a shorter axis of vision; with a negative lens in myopia we obtain a weaker system with a longer axis of vision.

. . . .

Nevertheless, I have not hesitated to use this measure also for ametropia. In the first place, it recommends itself by its practical utility: not only is the degree of ametropia thus easily found by the definition of R, but with its expression is at the same time given the focal distance of the glasses by which it may be neutralised.

. . . .

Besides, nothing is easier than to calculate the length of the axis of vision, which about corresponds to different degrees of ametropia, and thence to make tables such as shall be found in the Chapters which treat of Myopia and Hypermetropia.

Thus I consider the method I have pursued to be fully justified. It is, indeed, new only in form, not in reality. What I term $M = 1 : R$ would formerly, if it were desired to express the degree of myopia, have been described as *a degree of myopia, for which glasses of $R - x$ Parisian inches' negative focal distance are required, in order to adjust the eye for parallel rays*. The value $R - x$ still needs some explanation. R is the distance from r to the nodal point k'. Consequently the corrective lens is supposed, in ametropia to lie in k', as well as the auxiliary lens, which expresses the range of accommodation. This is done on purpose, in order to admit of the distances of distinct vision of ametropic and emmetropic eyes being compared with one another, and registered in the same diagrams. If it be desired to neutralise the ametropia by an actual corrective lens, that is, by an eye-glass, we must always take into account, the distance x between the nodal point of the corrective lens and the nodal point of the eye, as shall hereafter be more fully explained.

A not unimportant question still remains to be solved. The range of accommodation we have set down as $= 1 : P - 1 : R$.

Now the query arises, whether the length of the axis of vision has influence on the value of $1 : P - 1 : R$, in other words, whether, on a given change of the crystalline lens, a difference in range of accommodation shall be found, according as the eye is emmetropic, myopic, or hypermetropic. The question is easily investigated. We take the diagrammatic (*schematisch*) eye of Helmholtz, in accommodation for distant and near objects, as our basis, and calculate R and P, and thence deduce the range of accommodation for different supposed lengths of the axis of vision.

	Length of the axis of vision	R in millimètres.	P	$1 : P - 1 : R$
Emmetropic	22·231	∞	136·62	1 : 136·62
Myopic	25·231	118·31	65·056	1 : 144·54
Hypermetropic	20·231	— 177	505·73	1 : 131·11

Hence it appears that an equal change of the crystalline lens produces, where the axis of vision is longer (myopia), a less, and where the axis of vision is shorter (hypermetropia), a greater value of $1 : P - 1 : R$. The difference is, however, but slight. With the supposed lengths of the axis of vision, R was, for the myopic eye$=4''$; for the hypermetropic eye$= -6''$; so that the myopia amounted to 1/4, the hypermetropia to 1/6; and with these high degrees of ametropia the deviation in the values of $1 : P - 1 : R$ amounted only, in the case of myopia, to about 6 per cent, and in that of hypermetropia to 4 per cent. For practical purposes these differences present no difficulty.

In this comparison of ametropic eyes with emmetropic, we started from the supposition that the dioptric system of the former agrees with that of the latter. This is, however, not quite correct. In general the crystalline lens lies, in the hypermetropic eye, closer to the cornea, in the myopic, farther from it. Now a change of form of the crystalline lens will have less influence on the distance of distinct vision, in proportion as the lens is situated farther behind the cornea. Consequently this influence will be less in the myopic, and greater in the hypermetropic eye, than in the emmetropic. In this we have therefore a second reason why a definite change of the crystalline lens shall represent in the myopic individual a less, and in the hypermetropic, a greater range of accommodation than in the emmetropic.

. . . .

§ 9. *Clinical Determination of Ametropia in general*

As we have already seen, and as shall hereafter more fully appear, both myopia and hypermetropia exercise a great influence upon the function of vision, and both are closely connected with numerous affections of the eyes of a different nature. Hence it is, that the ophthalmic surgeon must make it a rule, in every patient who applies to him, to determine the refractive condition of the eyes.

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I have long been accustomed to note this of all mij patients: in the lists in the Ophthalmic Hospital a special column is provided for the purpose. I have in numerous instances found the great advantage of this rule.

The determination itself is effected, alter some practice, with rapidity and certainty. Two methods have been employed. The first consists in testing the power of vision with glasses of known focal distance. The second in the determination of the refractive condition by means of the ophthalmoscope.

I. For the employment of the first method we require, in the first place, the necessary glasses from 1/80 to 1/2 and from — 1/80 to — 1/2; in the second place, the necessary objects for testing.

The pairs of glasses are kept loose in a box, with a spectacle-frame in which they can be placed. It is also convenient to have a black plate of metal of the same size as the glasses, which, placed in the frame, closes one of the eyes; by closing the eye with the finger, the accuracy of vision is easily lost for some moments, so that we cannot make the examination of this eye follow immediately upon that of the other.

The most suitable objects are letters and numbers. Dr. Snellen has drawn up these in a regular system, and has thus supplied a want which had long been felt. The principles kept in view by Dr. Snellen are the following:

1. Detached, separate letters, black on a white ground, in irregular sequence.

2. The letter, large Roman, square, the vertical strokes being 1/4, the horizontal 1/8 of the breadth of the letter.

3. Exclusion of some letters which are much more difficult to distinguish than others.

4. Ascending magnitudes from I to CC, the magnitude being pro-

portional to the number, so that CC is two hundred times larger than I; XX ten times larger than II, etc.

5. The several magnitudes ditinguishable by a sharp eye, in good light, at the distance of so many feet as the number amounts to. Thus II at 2 feet, VI at 6 feet, XX at 20 feet, etc., all seen at similar angles (of 5 minutes), are equally easily distinguishable by the eye exactly accommodated to the distance.

. . . .

In the examination for the determination of ametropia, we have to do only with R, and for this purpose we cause the patient to look at the distance of about 20 feet; while on the card intended for distance, even CC still occurs, thus it appears applicable as far as $S=1/10$. If S be still less, we bring the card nearer to the eye; finally, reckoning the fingers may be conveniently substituted for distinguishing letters.

For persons who cannot read, we may substitute reckoning vertical strokes. By this method, however, it is difficult to obtain results, and they are, moreover, not capable of comparison with those obtained with letters. It is therefore better to teach such patients to recognise a couple of letters and a couple of figures, which is easily done.

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In the determination of R with the aid of glasses, the distance x from the glass to the nodal point k of the eye is neglected. In using glasses with a long focal distance x has less influence; but when those with a short focal distance are employed, x must be taken into account. If we have to do with positive glasses, x must be deducted from the focal distance; if with negative, it must be reckoned with it. Thus, if myopia be neutralized by glasses of $-1/6$, and if $x=1''$, $M=1/7$; if hypermetropia be corrected by glasses of $1/8$, and if $x=1''$, then $H=1/7$.

. . . .

Therefore we must, as a final determination, with the myopic always try what is the weakest glass, which, held close before the eye, gives a defined image. In the hypermetropic we run less risk in taking a great value of x into account; but it is better in this case also, to make the final determination with a glass, which, held close to the eye, gives defined images. In high degrees of myopia, and where uncertain answers are given, the investigation is often shortened by ascertaining the influence of weak glasses, for example, of $1/40$ and $-1/40$, alternately held before the stronger negative glass placed in the spectacle frame.

II. In the second place, we may in a certain sense determine more objectively the refractive condition by means of examination with the ophthalmoscope. The great inventor of the instrument has not only pointed this out, but has also communicated the application of this method. It may be explained in a few words. According to well known laws, the rays proceeding from a point of the retiina, refracted by the media of the eye, shall have, on entering the air, a direction similar to that of the rays which, falling on the cornea, unite in the same point of the retina.

. . . .

Consequently the eye of the observer, in order to see accurately a non-inverted image of the retina of the emmetropic eye, must be adapted for parallel rays; on the contrary, it must be adapted for converging rays, in order accurately to distinguish that of myopic persons; and for diverging, in the case of hypermetropic individuals.

. . . .

It is best to practise one's self in voluntarily seeing with accommodation for one's farthest point (ascertained by investigation), and to try what glass we must place before one's eye, so as accurately to see the vessels in the retina of another. In order to be able to bring the most different glasses before the eye, I have had a ring made on the ophthalmoscope, adapted to hold the glasses of the spectacle box. My eye is emmetropic and is accustomed, in the use of all optical instruments, to adapt itself for parallel rays.

. . . .

If the eye of the observer be ametropic, the degree thereof is easily taken into account. If, for example, the same glasses as above had been necessary for an eye with $M = 1/18$, the eyes examined should have given $M = 1/9 - 1/18 = 1/18$, $H = 1/9 + 1/18 = 1/6$. *Vice versa*, where the same glasses were required for an observing eye with $H = 1/18$, the M found should have amounted to $1/9 + 1/18 = 1/6$, the $H = 1/9 - 1/18 = 1/18$.

. . . .

Generally speaking, this method is inferior in accuracy to the determination of vision with glasses of known focal distance.

1. It is for many observers difficult, in the use of the ophthalmoscope, entirely to relax their power of accommodation: if they are not certain of this, the method is inapplicable to them.

2. Without producing paralysis of accommodation, we are never perfectly sure that we determine the refraction in the condition of rest.

3. It is sometimes difficult, at least when strongly negative glasses are required, with a narrow pupil accurately to see the vessels of the retina.

4. The vessels which lie at different depths in the fibrous layer afford no perfectly correctly situated object for estimation.

5. Moreover, such a vessel is not a suitable object to determine with precision whether we see accurately. Consequently, the method in each case requires a great degree of attention.

6. The determination in the line of vision, which it chiefly concerns, is for the most part difficult of execution, because the place of the yellow spot is not well seen, or our estimation of the accuracy of seeing it is particularly difficult.

If this second method, therefore, is not equal to the first in accuracy of results, it nevertheless deserves our attention, because it is applicable in cases where the first wholly or partly fails us. This is, in the first place, true in all young children, likewise in the blind, and even in high degrees of amblyopia, where the knowledge of the refractive condition is sometimes of great importance. Further, by this method we can better and more easily ascertain the degree of ametropia for indirect vision than by the first: in many instances I have by it alone succeeded in satisfying myself that the myopia for indirect vision was less than when the patient looked in the line of vision. Besides, the want of fixation of a hypermetropic eye examined with the ophthalmoscope, sometimes gives rise to more complete relaxation of the power of accommodation, whereby hypermetropia, latent in trials of vision, may manifest itself. Finally, this method may be of great use in simulated ametropia.

Note to chapter II

In the commencement of this Chapter much stress was laid upon the necessity of drawing an accurate distinction between the anomalies of refraction and those of accommodation.

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In my work upon Ametropia and its results (*Ametropie en hare gevolgen*), Utrecht, 1860, as well as in my papers in the *Archiv f. Ophthalmologie*, B. iv., vi., und vii., I had prominently put forward, as the basis of a correct description and of a scientific explanation, the distinction just alluded to. Stellwag von Carion now thinks (*Zeitschrift der k. k. Gesellschaft der Aerzte zu Wien*, 1862) that I should have mentioned his merits respecting this point.

In his Essay, entitled *die Accommodationsfehler des Auges* . . . he opposes presbyopia to myopia, and subsequently passing over to hypermetropia (N.B., by him termed hyperpresbyopia), he begins by calling the latter a higher degree of presbyopia.

I regret not to find in Stellwag's work the merit to which he thinks he has a claim. Those of my readers who take an interest in the matter will please to consult his treatise. They may pass over the less successful mathematical introduction (compare with reference to it: Zehender, *Anleitung z. Studium der Dioptrik des menschlichen Auges*, Erlangen, 1856. p. 166), which deterred so many, myself among the number, from the earlier perusal of this essay.

The diagrammatic sketch of the anomalies of refraction and accommodation, in which the commencement and termination of the lines represent r and p, and the lenghts of the lines the range of accommodation, I first applied in the *Nederlandsch Tijdschrift voor Geneeskunde*, D. II., 1858. The idea of expressing the range of accommodation by a lens of definite focal distance, is to be met with so early as in the masterly work of Young (*Philosophical Transactions*, 1801).

CHAPTER III

Fuller Development of the Different Meanings of Range of Accommodation

§ 10. *Relation between Accommodation and Convergence of the Visual Lines; Meaning of* $1 : A$, *of* $1 : A_1$ *and of* $1 : A_2$.

So far as the range of accommodation for both eyes extends, the state of accommodation of the eye corresponds to a definite convergence of the visual lines. Thus the emmetropic eye, with parallel visual lines, is accommodated for infinite distance; with a convergence at 8″, for a distance of 8″, etc. Unmistakably, therefore a connexion exists between convergence of the visual lines and accommodation, to which Porterfield (1759) and John Mueller (1826) already directed attention. Both these observers, however, appeared to assume, that this connexion is absolute and causal; that a definite convergence is necessarily attended with a definite accommodation, and admits of no other; it was thought that only *beyond* the limits of accommodation a greater or less convergence was possible, to which the accommodation, respectively for the nearest and farthest point of distinct vision, should then still correspond. Now this is incorrect. Even Volkmann (1836) showed, that also *within* the limits of the range of accommodation such absolute dependence does not exist, and I (1846) gave further proofs of this by simple experiments, which were capable at the same time of determining the degree of independence. The experiments were made partly with convex and concave, partly with weak prismatic glasses. It is easy to convince one's self that both eyes together, as well without as with slightly concave or convex glasses, can accurately see an object at a definite distance, and that, consequently, without change of convergence, the accommodation can be modified. With equal ease, we observe that, in holding a weak prism before the eye, whether with the refracting angle turned inwards or outwards, an object can be accurately seen with both eyes at the same distance, and that, consequently, the convergence may be altered, without modifying the accommodation. When, therefore, it is required for the sake of distinct vision with both eyes, the connexion between convergence and accommodation can be, at least partially, overcome. I early stated the method of determining how far the independence existed. Some time afterwards it was applied with the requisite accuracy[1].

The question is very simple: it is only necessary to know R_1 and P_1 with parallel visual lines and with a series of converging degrees (to the maximum), and these we find, by a calculation from the nearest and farthest points, discovered by means of different convex and

[1]Conf. Mac Gillavry, *Onderzoekingen over de hoegrootheid der Accommodatie*. Diss. inaug., Utrecht, 1858.

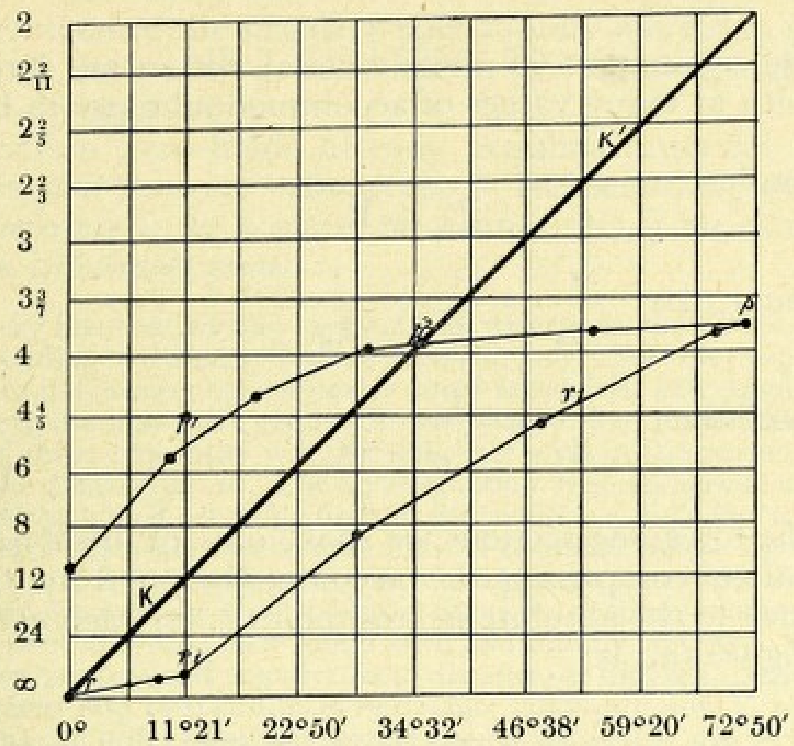

Fig. 10.

concave glasses. For accurate determination, however, a special optometer is required, which shall be described at the end of this section.

The results of the examination of the emmetropic eyes of a person aged 15, are represented in the annexed figure 10.

At different points of the diagonal $k\ k'$, intersection takes place between the transverse lines, before which, in Parisian inches, the distances are placed; and the longitudinal lines, under which the degrees of convergence of the visual lines corresponding to the distances are noted. The mutual distance of the visual lines of the two eyes in the parallel state amounted to 28 1/2″, in which case (compare the figure), at a distance of 12″, a convergence of 11° 21′, at a distance of 6″, a convergence of 22° 50′, etc., exists. The line $p_1\ p_2\ p$ represents, in the consecutive convergence, the course of the nearest point, the line $r\ r_1$ that of the farthest point. The dots in these lines are the points determined by investigation.

Now the figure shows that the eyes here supposed with parallel visual lines can accommodate from infinite distance up to 11″, with 22° 50′ convergence from about 12″ to 4″.16, etc. At p_2, where the line of nearest points cuts the diagonal $k\ k'$, we attain the shortest binocular distance P_2 of distinct vision. With still stronger convergence, the line $p_2\ p$ remains under the diagonal $k\ k'$, so that accommodation can no longer take place for the point of convergence. ... The absolute nearest point p lies ... 3″.69, but for this a convergence of about 70° is required, that is at a distance of about 2″. With this maximum of convergence all space for accommodation is lost, and therefore the lines $p_2\ p_1$ and $r\ r_1$ cut one another.

. . . .

By the determination of these several distances, three different meanings with as many values of accommodation are to be obtained.

I. The absolute, $\frac{1}{A} = \frac{1}{P} - \frac{1}{R}$

II. The binocular, $\frac{1}{A_2} = \frac{1}{P_2} - \frac{1}{R_2}$

III. The relative, $\frac{1}{A_1} = \frac{1}{P_1} - \frac{1}{R_1}$

. . . .

Now in the foregoing sections we spoke only of the *absolute* range of accommodation, comprising the accommodation from the absolute farthest point r to the absolute nearest point p, for each eye in particular: in the figure this is

$$\frac{1}{A} = \frac{1}{3{\cdot}69} - \frac{1}{\infty} = \frac{1}{3{\cdot}69}$$

The binocular comprises the accommodation from the farthest point r_2, for both eyes at once, to the nearest point p_2 for both eyes at once. In the emmetropic eye, r_2 coincides with r, and the binocular range of accommodation, to be deduced from fig. 10, is consequently,

$$\frac{1}{A_2} = \frac{1}{3{\cdot}9} - \frac{1}{\infty} = \frac{1}{3{\cdot}9}$$

Finally, the *relative* is the range of accommodation over which we have control at a given convergence of the visual lines. It represents the degree in which accommodation is independent of convergence, and is, for every convergence, measured by the distance between the lines $p_1\ p_2\ p$ and $r\ r_1$. On referring to the figure it now appears that, with increasing convergence, the relative range of accommodation becomes at first greater, then less, until at the maximum of convergence, where the lines mentioned meet one another (in p) it is $=0$.

. . . .

It is of importance further to observe, that the relative range of accommodation consists of two parts: a *positive* part and a *negative*. The diagonal $k\ k'$ represents the convergences of the visual lines: the part situated above this diagonal is the positive, that situated beneath it is the negative. The first represents what, reckoning from the point of convergence, we can accommodate still nearer, the latter what we can accommodate still farther off.

. . . .

A glance at the figure now shows further, that in the emmetropic eye at ∞ (parallel visual lines) $1 : A_1$ is wholly positive, that, with increasing convergence, the negative part rapidly increases, soon also at the expense of the positive, and that at 36° convergence $1 : A_1$ has become entirely negative.

The distinction here made already acquires practical importance from the fact, *that the accommodation can be maintained only for a distance, at which, in reference to the negative, the positive part of the relative range of accommodation is tolerably great.*

It is not in every one that we can satisfactorily determine the ranges of accommodation corresponding to different degrees of convergence. For this purpose two freely moveable, accurately seeing eyes of nearly equal refraction, and equal accommodating power, are in the first place required, and, in addition, some talent for observation. Each of these requisities was perfectly met with in the person aged fifteen, who supplied the data for fig. 10. The determination requires special care. As object we may take wires, which are to be finer in proportion as the point to be defined is nearer to the eye. Accurate results may also be obtained by the use of little holes (from $1''' : {}^1/_{20}'''$ to $1''' : {}^1/_6'''$ in diameter) in a black metal plate, with a background of dull glass turned towards the clear daylight. Soon the accommodation for the holes is no longer perfect, they lose their round form and rapidly emit rays. With different glasses of known positive and negative focal distance, at different degrees of convergence, the greatest and least distances of distinct vision are now to be determined. At the same time, in order to obtain correct results, care must also be taken that the distance of the glasses from the eye shall remain unalterably the same; lastly, that at each degree of convergence the axis of the glass shall nearly coincide with the axis of vision. In order to fulfil these conditions, an optometer has been constructed, partly in imitation of that of Hasner, Edlem von Artha .

§ 11. *Difference of the relative Range of Accommodation* $1 : A_1$, *according to the Refractive Condition of the Eye*

We closed the preceding section with a practical result, namely: that accommodation can be maintained only for a distance, when, in reference to the negative, the positive part of the relative range of accommodation is tolerably great.

In connexion with this point it is of special importance to show, that the relative range of accommodation in ametropic eyes is something quite different from that in emmetropic. The difference is of a twofold nature. In the first place, with a given convergence, the relation of the positive to the negative part of $1 : A_1$ is not the same; in the second, the lines $p_1\, p_2\, p$ and $r\, r_1$ have another form.

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. . . .

The diagram fig. 11, will make this plain. It contains the curves of the nearest and farthest points, as function of the convergence, both for the emmetropic eye E (the middle ordinary lines), and for the myopic M (the dotted lines), and for the hypermetropic, H (the striped and dotted lines); $1 : A$ is, in order to facilitate comparison, assumed $= 1/4$; and the maximum of convergence is taken at 59° 20′. The letters E, M, and H are placed before the farthest points, as defining the refraction; H_m (manifest hypermetropia) stands before r the *manifest*

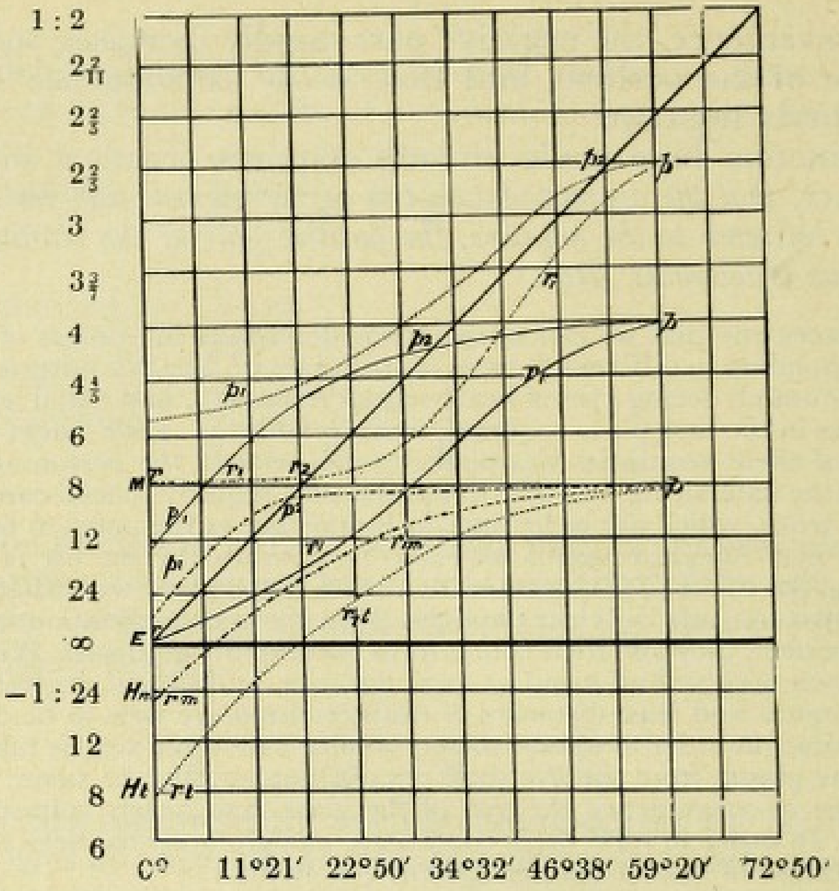

Fig. 11.

farthest point, H_t (total hypermetropia), before r_t the *absolute* farthest point. Now the study of this diagram shows:

1. That with parallel visual lines, the emmetropic eye can bring into action about 1/3, the myopic only 1/4·5, the hypermetropic, on the contrary, 3/5 of its total power of accommodation.

2. That, with slight convergence, the myopic eye can accommodate much less, the hypermetropic on the contrary, much more (but also must do so) than the emmetropic.

. . . .

3. That with stronger convergence, the accommodation of the myopic eye can still increase much, that of the hypermetropic only a little.

. . . .

The difference ascertained is practically of great importance. Thence it follows, namely, directly, that when the ametropia is neutralised by glasses (r brought to ∞), the eye by no means becomes equal to an emmetropic eye of similar range of accommodation. This is easily deduced from the above figures. It appears still more distinctly on reference to fig. 12, where the curves of fig. 11 are repeated, . . . but so that in all, r is brought to ∞[1]. The diagram shows that the neutralised

[1] As shall appear in § 13, the reduction of the ametropia is not entirely without influence on the form of the curves. This influence is, however, so slight, that here it may be altogether disregarded.

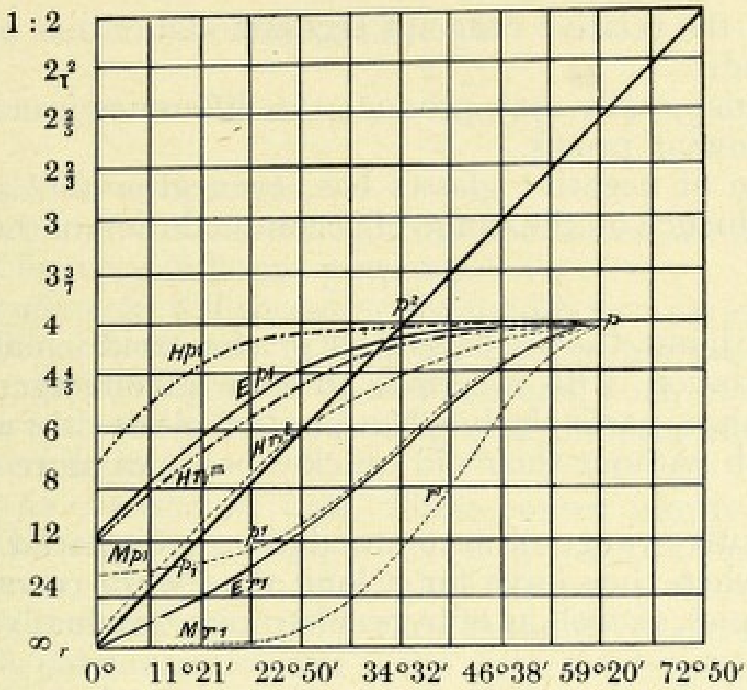

Fig. 12.

myopic eye has its binocular nearest point at 16″, so that $1 : A_2$ amounts only to the fourth of $1 : A$; and that *vice versa* for the hypermetropic eye the binocular nearest point p_2 is nearly equal to the absolute. Moreover, in the myopic, $1 : A_1$, even at from 8° to 9° of convergence, becomes wholly negative; in the hypermetropic, $1 : A_1$ is at more than 30° of convergence entirely positive. Hence proceeds for both eyes difficulty in binocular vision, under moderate convergence; for the reduced myopic, because, under these circumstances it accommodates too weakly, for the reduced hypermetropic, because it accommodates too strongly.

The cause of this difference is at once apparent; it is the result of practice. The myopic eye has learnt to converge in a certain degree, without bringing its power of accommodation into action in the same proportion as the emmetropic eye. Thereby the binocular farthest point (fig. 11, Mr_2), although seen at a tolerably considerable convergence, remains almost as far from the eye as the absolute farthest point *Mr*. But on the other hand, the eye has not practised itself with slight convergence, to bring a relatively great part of its accommodation into action, because it has no necessity to do so. The hypermetropic eye, on the contrary, found itself obliged, in order to see accurately, even with, parallel visual lines, to put its power of accommodation on the stretch and it has brought itself so far in that respect, that it is no longer in a position to become completely relaxed, that at least on every effort to see, the act of accommodation takes place involuntarily. As further, with increasing convergence, a disproportionately great part of the range of accommodation must always come into action, it is not strange, that the relative range of accommodation has been considerably displaced.

That practice really may produce the difference just described, we have the following proofs.

1. The use of negative glasses has, even after the lapse of a few hours, an influence on the range of accommodation of the emmetropic eye.

. . . .

On the other hand, the use of positive glasses rapidly makes the power of accommodation, with a certain amount of convergence, less: it is well known that, particularly when positive glasses are used too soon, reading much without their aid quickly becomes more difficult than before.

2. The relative range of accommodation is displaced in ametropic individuals when they have for a long time worn correcting glasses. That of myopics, as well as of hypermetropics, gradually tends to that of emmetropics.

3. In the diminution of the range of accommodation in advancing age, even before proper presbyopia has begun, the curves of the emmetropic eye approach to those of the hypermetropic. Fig. 13 is the faithful expression of the range of accommodation of an emmetropic individual aged 44. For vertical lines he has a trace of hypermetropia, so that *r* is found beneath. Further, to convince one's self that, with the required practice, the curve p_1 p_2 p especially has approached to that of a hypermetropic eye, we need only observe that with a convergence to 9″, nearly the maximum of accommodation is attained.

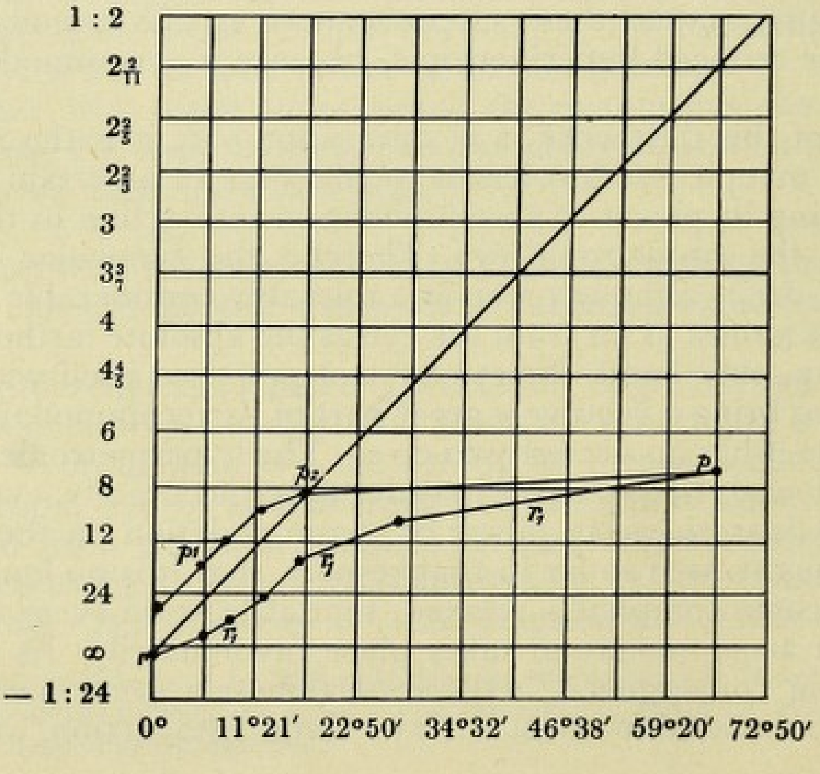

Fig. 13.

CHAPTER IV

Spectacles and their Action in general

§ 12. *Different Kinds of Spectacles*

In ophthalmic surgery different kinds of spectacles are in use, which are employed for very different purposes.

I. *Protecting spectacles.* Of these we distinguish two varieties:

a. Those which serve only to keep off the mechanical influence of foreign bodies, dust, fragments of metal, stone, coal, etc. They have nothing to do with the refraction of light in the eye, and call for no further comment here.

b. Spectacles for warding off light. These consist mostly of coloured glass, green and especially blue, which is less hurtful to the eye. In general, however, at least in daylight, the grey, so-called neutral glasses, deserve the preference. The white sunlight, reflected by different objects in their particular colours, is the natural adequate stimulus to the retina, and by good neutral glasses these rays are tolerably uniformly diminished. The same end opticians formerly attempted to attain (Fischer) by combining two glasses of complementary colours. It is desirable in every case that, so far as possible, the whole field of vision should be uniformly obscured, which is accomplished, with tolerable accuracy by the use of large, round glasses.

. . . .

In persons affected with irritation of the retina, or with photophobia in general, we may recommend the use of light-absorbing glasses, when these patients are obliged to expose themselves for a certain time to a bright light. In the house, with moderate light, they ought to lay them aside.

. . . .

In women, moderating the light, when necessary, by means of veils, is to be recommended.

II. *Stenopæic spectacles, stenopæic lorgnette, stenopæic apparatus.* Slight obscurations of the light-refracting media, especially those of the cornea, often produce great disturbance of the accuracy of vision. The cause of this is to be sought not so much in the reflection or absorption of a portion of the rays, as in the diffusion of the light passing through them. This is easily explained. From the entire field of vision rays fall on each local obscuration, and from the latter they spread further in all directions through the whole eye.

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This diffused light is very disturbing. Indeed the differences of illumination of the image formed by regular refraction are in consequence much more faintly distinguishable. Just as in looking through a real mist, the diffused light is added to the relatively weaker image, and therefore also spots give the impression, as if one were looking through an actual mist: the only difference is, that a mist is more perceptible for more remote objects, and that misty vision, produced by a spot, affects all objects alike, independently of distance. It is well known that obscurations produce much less disturbance, when the eye, turned from the light, contemplates a certain object. If a picture or another object be hung against the pier between two windows, and if it be illuminated through a window behind the observer, the latter will see the object much more accurately, and with more contrast of light and shade when the two windows are closed than when they are open.

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Even if there be no spots, some light is always diffused in the eye, and thus even the normal eye will, especially if the time of life be somewhat advanced, perceive, as it were, light crape, when, in the experiment just described, the windows are opened. We know further, that where obscurations exist, exclusion of the peripheric light with the hand, looking through a tube, etc., increases the accuracy of the images. Again, it is the warding off of the laterally incident light diffusing itself from the spot throughout the whole eye, which here acts beneficially. The practical rule hence deducible is this: *in order, where obscurations exist, to distinguish with relative accuracy, let the small portion of the field of vision, over which the observation is to extend, be properly illuminated, and let the remaining portion be kept as dark as possible.* These reflexions on the injurious effect of obscurations led me to the application of stenopæic remedies. Their object is to cut off the light which should reach the obscurations, and through an opening to give, so far as possible, entrance only to the light which is subjected to a regular refraction on the normal part of the refracting surface. The narrow opening is in them the essential part: hence the denomination stenopæic (from στενός, narrow, and ὀπή, a peephole). In order not to limit the field of vision more than is necessary, the opening must be as close as possible to the eye, and with a view still better to keep off all lateral light, it may be surrounded with a wall widening like a funnel. The opening may in general have the form and nearly the size of the clearest part of the portion of the refracting surface corresponding to the pupil: it may, according to circumstances, be round, oval, or slit-like. Rarely will the diameter be less than a millimètre; often it will amount to two or more millimètres.

The stenopæic apparatus, which is an indispensable item in the ophthalmic surgeon's means of investigation, is a very short cylinder, furnished with a handle, open at one end and indented towards the eye, and provided at the other with an opening, in front of which is a diaphragm, containing different smaller openings of various diameters, and capable of turning round, so that each of these openings can be seen in turn. There are also stenopæic apparatus provided with a slit capable of being widened and narrowed. With the aid of this apparatus we can examine whether the stenopæic principle increases the accuracy of vision, which is often of importance in a diagnostic point of view; moreover, we may acquire an indication whether it may be advantageously applied, and what size of opening is the most useful. Of the result obtained we may then make use in prescribing a stenopæic spectacle, or eyeglass. To spectacles for use in the streets, the stenopæic principle is in general not applicable, as the field of vision is too limited. On the other hand, such spectacles to which the requisite glasses have been fitted, are sometimes very serviceable for reading.

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If the part which has remained clear has an oblong form, a slitlike opening will be most suitable. In general, it is a great advantage in reading, when a horizontal slit effects the object; this should, therefore, always be tried. If the opacity is only on one side, we may obtain a great advantage by making an ordinary spectacle-glass opaque over the obscured part (for example, by applying a black lacker). In general the simplest stenopæic spectacles are those in which the preferable form of opening is left as the only part of the glass not obscured, in which also by opaque matter on the outside the light incident from that point can be warded off. The glass may in ordinary cases be flat, but otherwise according to the necessities of vision it should have a certain focus.

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Lastly, it may be mentioned (...), that the stenopæic eyeglass has also rendered me very essential service in the highest degrees of myopia, particularly when the accuracy of vision had at the same time suffered comparatively much. ... In such cases vision of near objects, at least with one eye, is attended with no other inconvenience than that the object must be brought very near the eye, to 3″ or less. But distant vision is extremely imperfect, and is comparatively little improved by concave glasses, which correct the myopia. If, with their aid, the images are more accurately seen, they at the same time become so much smaller, that an amblyopic eye still distinguishes little, and is, therefore, by no means satisfied. In such cases then, a stenopæic eyeglass with a small opening yields very good service. It here acts in a well-known manner, quite different from that treated of above, by diminishing the circles of diffusion. ... Now in high degrees of myopia the pupil is usually very wide, and the disturbance in looking at distant objects is, therefore, relatively very great. Precisely for this reason it is that a stenopæic eyeglass produces so great improvement. If a myopic individual looks through an opening of from 1/2‴ to 1‴ in diameter, he distinguishes at a distance as accurately as through glasses, which imperfectly neutralise his myopia, and he has the advantage that the objects appear larger. If an emmetropic person wishes to convince himself of this, let him hold a positive glass before his eye, so that it becomes myopic, and he will, on looking through an opening, obtain the effect described, and can estimate the partial neutralisation of the artificial myopia. In like manner we may also within the nearest distance of distinct vision, by diminution of the circles of diffusion, with the aid of a small opening, distinguish with tolerable accuracy, and thus view small objects much nearer to the eye, that is under a much greater angle. However, in either case we lose both in light and in extent of the field of vision. As to light, we lose the more, the smaller the opening is, and in myopia it is therefore often advisable not to have the opening very small, but with the stenopæic eyeglass to combine a glass, which partially corrects the myopia. With respect to the extent of the field of vision we lose the more, the farther the opening is from the eye. In combining a negative glass with the stenopæic eye-piece, the patient will therefore turn the small opening towards the eye, when his principal object is to increase the field of vision; on the contrary the negative lens, when he chiefly desires to obtain greater distinctness of vision.

III. *Prismatic glasses, prismatic spectacles.* Prisms are used, in order by refraction of the light upon two surfaces, to obtain the well-known spectrum. The angle, which the two refracting surfaces make with one another, is the angle of refraction of the prism. For the object mentioned a large angle is taken: most prisms are triangular, and each of the three angles then amounts to 60°. They are usually made of flint glass, in order, with considerable declination, at the same time to obtain a decided dispersion. For ophthalmological purposes, on the contrary, only slight declination is required, and we therefore use prisms with a smaller angle of refraction, from 3° to 24°; moreover, it is necessary to select a kind of glass, which, with reference to its refracting-power, presents but slight dispersion, for example, crown glass. ... In the position of least declination, the angles of declination, for the low numbers, are nearly the half of these refracting angles: for the higher numbers, they are somewhat more. If we wish to know these accurately, it is necessary to determine the deviations for each glass separately.

The declination of the light by prismatic glasses is the cause why objects, seen through such glasses, exhibit themselves in another direction.

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In this, however, the more refrangible rays, those on the violet side, undergo a greater, the less refrangible, those on the red side, undergo a less declination. Hence proceeds a disturbance by coloured margins to the objects, which is greater in proportion to the strength of the prism, and which, precisely in powerful prisms, it is hard to remove. In order to obtain a declination without dispersion, the prism must be made achromatic by being compounded of two prisms, C (fig. 14) of crown glass, F of flint glass, which, acting in opposition, completely remove each other's dispersion, but only partially destroy each other's refraction. Such achromatic prisms, however, soon become, when a declination of some

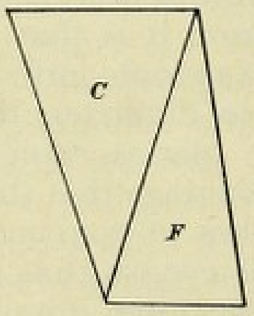

Fig. 14.

degrees is required, too thick and too heavy to be worn. This objection might perhaps be partly met, by having the prisms very small.

. . . .

So far, however, the achromatic prisms have not yet come into use.

What led to trying prismatic glasses, was a declination of the visual lines. The idea of making it possible to look with both eyes, in spite of this declination, occurred first to my friend Krecke, Doctor of Natural Philosophy, of Utrecht, whose idea I endeavoured to realize and to explain physiologically (1847). On experimenting with the glasses, three remarkable phenomena immediately presented themselves. In the first place it appeared, that one feels involuntarily impelled, by changing the direction of the visual lines, to remove the double vision which has taken place. If we hold the glass with the refracting angle inwards, then, in order to bring the double images into one, stronger convergence is required, and this is immediately almost involuntarily effected. On removing the glass, double images again exhibit themselves, which, by diminishing the convergence, are once more forthwith thrown together; only if the prism has been long held before the eye, a tendency to increased convergence continues for some time. In the second place it seemed, that the visual lines are usually capable of only very slight divergence, and that they can scarcely decline upwards and downwards, even under the pressure of the necessity of rendering the vision single.

. . . .

If, finally, the observer has, after long-continued efforts, succeeded in throwing into one the double images standing (in the last case) above one another, the double images which now arise on removing the prism, do not immediately run together again. Thirdly and lastly, we can convince ourselves of what has been stated above, that under the influence of a prism with the angle turned towards the inside or outside, the observer can converge more or less strongly, without being able to alter the tension of his accommodation.

These results, obtained with the aid of prismatic glasses, are of essential importance for the physiology, and for many points in the pathology of the eye. But beyond this, these glasses serve different useful purposes in ophthalmic surgery, which, partly previously foreseen, have been, especially by Von Graefe, practically tested. Thus they may be applied in the diagnosis of different anomalies of the muscles, and of the degree of these anomalies. Thus they may be used to correct slight incurable declinations of the visual lines, outwards, upwards, or downwards, whereby confusing double images are produced, or to remove the muscular asthenopia, depending on insufficient power of the musculi recti interni. Thus we may further, in paresis of a muscle, so far meet the disease by means of a prism, that in order to make the double images which have been brought near one another, run together, the muscles will become powerfully tense, which, for the alleviation of the paresis, appears to be no matter of indifference. Finally, what deserves to be here particularly mentioned, these glasses are also of importance in anomalies of refraction. They show, that hypermetropic individuals distinguish accurately with greater ease, when they, looking through a prism with the angle turned inwards, for the sake of single vision, can converge more strongly, a fact by which the origin of strabismus, in consequence of hypermetropia, is explained; and it will hereafter appear that we sometimes advantageously apply the principle of the prismatic glasses, by modifying the mutual distance of either the convex or concave glasses of spectacles, so that the eyes look through these glasses *at the side* of the axes, which, just like the use of a prismatic glass, modifies the direction in which an object is seen.

Glasses with spherical surfaces, ordinary convex and concave spectacle-glasses. — Glasses, which modify the limits of distinct vision, are called lenses. Of these we have two kinds, both of which are used as spectacle-glasses: converging lenses.

. . . .

A converging lens has its focal point φ'' on the other, a diverging lens on the same side as that whence the rays come. The first unites the rays into a real focus; the latter does not actually unite them, but causes them to assume a direction as if they had proceeded from the point φ'', . . . hence this point is called also a *virtual* focus.

Besides the above *biconvex* lenses, we have, as converging lenses, the *plano-convex* and the *concavo-convex* or *positive meniscus* (*with shorter radius of the convex surface*), as well as, in addition to the *biconcave*, as diverging lenses, the *plano-concave* and the *convex-concave* or *negative meniscus* (with shorter radius of the concave surface).

. . . .

To the menisci the advantage is attributed, . . . that, as Wollaston showed, the images suffer less, when the observer looks obliquely (under an angle with the axis) through them, so that the eyes can move more freely behind these glasses. They are therefore, also called *periscopic* (from περισκοπειν, to look around). However, we can also see satisfactorily in an oblique direction through biconcave and biconvex glasses, provided they are not too strong.

. . . .

When we add that under some circumstances the periscopic glasses are more liable to produce disturbance by reflexion on the concave surface turned towards the eye, and that they are, moreover, somewhat more expensive, we shall not be suprised that they have not wholly supplanted the biconvex and biconcave glasses.

Biconvex and biconcave spectacle-glasses are ground with equal radii of the two surfaces. The optical centre *o* lies then in the middle of the lens in the axis $A A_1$. Now the distance from the focus φ'' to this optical centre *o* is usually called the focal distance F. This is, however, not quite correct; F is, in fact, the distance from focus to *principal point.* For ordinary, not very thick lenses, with equal radii of the two surfaces, that is, for the ordinary biconvex and biconcave spectacle-glasses, this inaccuracy is of no importance; but in the case of menisci, we must ascertain the principal points, in order to know the position of the foci, and to be able to take into account the distance from focus to principal point as F.

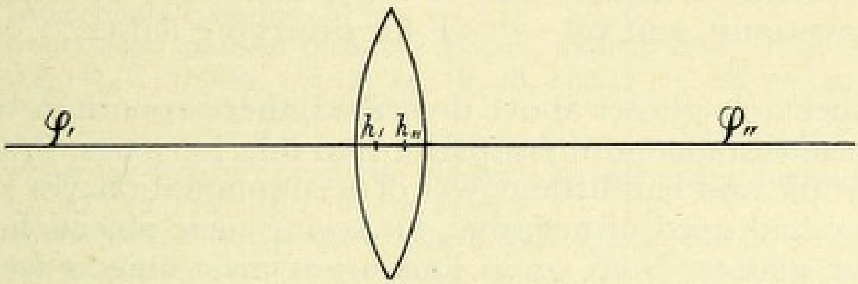

Fig. 15.

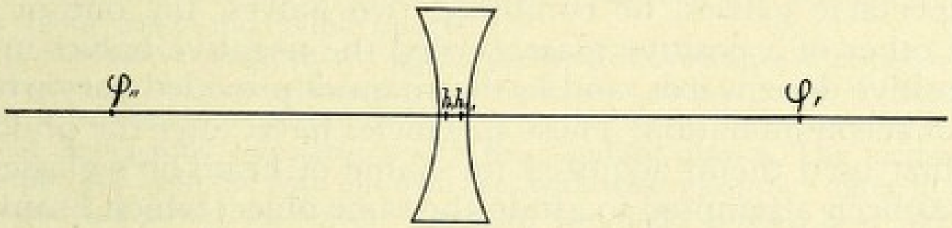

Fig. 16.

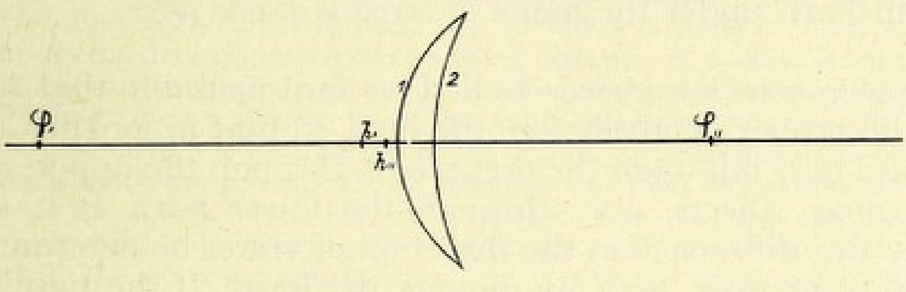

Fig. 17.

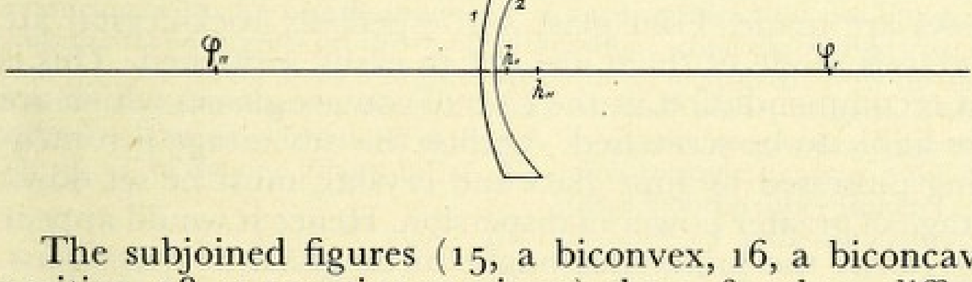

Fig. 18.

The subjoined figures (15, a biconvex, 16, a biconcave lens; 17, a positive, 18, a negative meniscus) show, for these different forms of lenses, the position of the first and second principal points h_1 and $h_{,,}$, and of the first and second focus $\varphi_{,}$ and $\varphi_{,,}$.

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For a lens standing in air $h_{,}\ \varphi_{,}$ is always $=h_{,,}\ \varphi_{,,}$, both=F.

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It will be understood that, even for these reasons, it is by no means indifferent which surface of these lenses is turned towards the eye. In speaking of the influence of the distance of the glass from the eye, I shall return to this point. . . .

The power (the converging or diverging power) of a lens is inversely proportional to its focal distance F. It may, therefore, be expressed by 1 : F for converging, and by — 1 : F for diverging lenses.

. . . .

Besides the spectacle-glasses above described, there are others with a difference of focal distance in the superior and inferior parts. Franklin was slightly myopic and had little power of accommodation; for seeing at a distance he had need of negative, for seeing near objects he had need of positive glasses. Now, as in looking at near objects we look through the lower, in looking at a distance we look through the upper half of the spectacle glasses, he combined two halves, the one of a negative, the other of a positive glass, turned the negative halves upwards, the positive downwards, and in this manner provided very well for his want of accommodation. These spectacles have, after the philosopher who first used them, acquired the name of Franklin's glasses. Recently it has been attempted to attain the same object which Franklin proposed to himself, by grinding in the upper part of the spectacle-glass, the surface turned from the eye, with another radius. The glasses are prepared in Paris under the name of *verres à double foyer*.

. . . .

In general these spectacles answer well. It is indispensable that they be placed at the proper height before the eyes, so that in looking at a distance the rays may fall upon the organ only through the upper, and in looking at near objects, only through the lower part. It is also necessary that the difference in the direction of vision be determined more by moving the eyes, than by moving the head. If the pupil be opposite the boundary between the two parts, vision will, of course, be very confused.

It is by no means a matter of indifference of what material the spectacle-glasses are made. Flint glass and especially rock-crystal are harder, and glasses made of them are not so easily scratched. This is particularly a recommendation in the case of convex glasses which are so much more liable to be scratched. Against the advantage just mentioned as being possessed by flint glass and crystal, must be set down the disadvantage of greater power of dispersion. Hence it would appear that for *strong glasses* the preference ought to be given to *crown glass*. This is especially true of concave glasses, and as to convex glasses of crown glass, their low price makes it easy, if they are scratched, to replace them with others.

Achromatic glasses are not available for spectacles; if glasses of short focal distance be required, achromatism is attended with too great weight, and if glasses of long focal distance be sufficient, even with the use of crystals, glasses do not prevent the dispersion of colour.

As the ophthalmoscope is important for the objective diagnosis of defects of the eye, so is a collection of spectacle-glasses for their subjective investigation. Such glasses are at once indispensable, not only for the determination of anomalies of refraction and accommodation, but also in many cases for that of the accuracy of vision, so that without them the examination of the functions of the eye is impossible.

The usual boxes contain:—

1. Twenty-eight pairs of biconvex glasses, namely of 2, 2 1/4, 2 1/2, 3, 3 1/2, 4, 4 1/2, 5, 5 1/2, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 22, 24, 28, 36, 40, 48, 60, 72, and 100 inches positive focal distance.

2. Twenty-eight pairs of biconcave glasses of the same focal distances, but negative.

3. Twelve (or sixteen) prismatic glasses with refracting angles of 3°, 4°, 5°, 6°, 7°, 8°, 9°, 10°, 12°, 14°, 16°, 18° (or to 24°).

4. A frame with elastic rings, in which these glasses can be used.

5. Some quadrangular pieces, 6 inches long, 1 1/2 inches broad, of different shades of blue glass, capable of being held before both eyes at once.

6. A glass of carmine-red, well adaped, in case of a false position of the visual lines, to colour one of the double images.

On the convex and concave glasses the focal distances are inscribed with a diamond. The same is the case with many spectacles met with in trade. With respect to these last, however, we must not depend upon the mark, but must always determine the focal distance by comparison with the standard glasses. The method is extremely simple. We examine with our own eye, with what glass they agree in diminishing or magnifying power. As object we employ two slight parallel lines. We hold the glass tolerably far from the eye (about a foot), and so far from the paper, that we see the two lines accurately through the glass. We now hold the standard glasses for comparison in the same plane with the glass to be examined, and we shall then be able to determine, with sufficient precision, to which of these it corresponds.

The direct determination of the focal distance of a glass is more difficult. The simple measurement of the distance, at which, behind a convex glass, the solar image is exhibited upon a screen, gives the value only approximatively. The same is of course true of the determination of the conjugate focal distances of a flame and its image, whence the principal focal distance can then be calculated. Different other methods are stated which lead to a more correct result. I obtained very accurate determinations by measuring the magnitudes of an object and of its dioptric image, both with the aid of the ophthalmometer. As object I employed three small openings in a very thin blackened metallic plate, behind which was placed, in front of an opening in a large screen, the globe of a brightly burning lamp.

. . . .

We now first measure the magnitude of the object. As the reader is aware, measuring with the ophthalmometer is accomplished by doubling the image and reading off the degrees on the ophthalmometer, when the double images are removed from another by the breadth of the object to be measured. Now no object is capable of more accurate measurement than three small points of light. Thus we can very perfectly determine (method of Bessel, in use in astronomy), when, on doubling (fig 19), 1′ of the one image (1′, 2′, 3′) comes to stand exactly in the centre between 2 and 3 of the other image (1, 2, 3), and the distance *x y* is then measured as object.

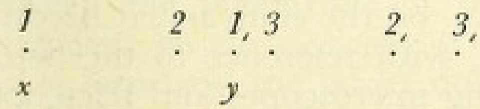

Fig. 19

. . . .

Now knowing the magnitude of the object which we have been able to measure accurately by the method just described, we next seek the magnitude of the dioptric mage formed of it by the lens, whose focal distance we wish to ascertain. For this purpose we place the latter in the lens-bearer l, bring this to a distance from the object (the plate P) equal to the double of the nearly known focal distance of the lens.

. . . .

While we see the dioptric image, we at the same time observe, whether it coincides in magnitude with the object. In this case the points of light will occupy the same place in reference to one another (fig. 19), as that at which the object was measured, that is, 1′ will stand in the middle between 2 and 3. If it appears that the dioptric image is larger, we remove the plate xx' from P: if on the contrary it is smaller, we approximate xx' to P, until the position of the images is precisely the same as it was in measuring the object. When this has been attained, we have only with the nonius to read off the exact distance of the lens from the thin plate P, in order to know the double focal distance of the lens. Indeed, when object and dioptric image have the same magnitude, both are at an equal, and in fact at the double focal distance from the respective principal points of the lens, and if the latter be a biconvex lens, with equal radius of its two surfaces, likewise at an equal distance from its optical centre.

. . . .

The focal distance of concave glasses can be ascertained with tolerable accuracy, by selecting the convex glass, which when combined with the concave, removes all effect of the latter.

. . . .

The nature of the material of which the glasses are prepared can be best ascertained by determining the coëfficient of the refraction of light. In order to calculate this, according to the simple formulas, we must know the focal distance and the radius of the two surfaces of curvature. The mode of determining the focal distance, with the aid of the ophthalmometer, has been explained. The same instrument may serve for deducing the radius of curvature from the magnitudes of the catoptric images. The method is the same as that used for the determination of the radius of the cornea. If in this mode we determine the cöefficient of refraction, we shall find, that many lenses are considered to be pebbles, which consist of flint glass, or even of simple crown glass.

§ 13. *Direct Influence on Vision, of Glasses with spherical Surfaces*

When such glasses are held before the eye, they are to be considered as an integral constituent of the dioptric system of the organ. We shall now, *in the first place*, consider the glass to be centred with this system, that is, that the centres of curvature of its surfaces lie in one axis with the centres of the surfaces of curvature of the eye. If this be not the case, certain deviations will result, which we shall consider at the end of this section.

Now the immediate consequences of placing a glass, with positive or negative focus, before the eye, are these:

. . . .

1°. *The greatest and least distances of distinct vision, P and R, undergo a modification.*

. . . .

2°. *The range of accommodation is altered.* By the use of negative glasses it becomes greater, by the use of positive, on the contrary, it becomes less. Much more still does it diminish, with reference to the actual distance of the objects observed, in using microscopes and telescopes.

. . . .

In the use of the compound microscope we see an aërial image (formed by the object-glass) through a lens (the eye-glass). This aërial image possesses, as a simple calculation shows, an extraordinary depth in relation to the slight depth of the object. Since it, moreover, lies very close to the eye, and is seen through a lens, the accommodation of the eye in relation to the difference in depth, that we can see of the observed object, is reduced nearly to *zero*. The great depth of the aërial image possesses, however, this advantage for microscopic observation, that of the object a definite surface is accurately seen, and what lies only a little above or beneath appears very diffused, and therefore has no disturbing influence.

In the use of telescopes also, the accommodation of the eye is almost entirely removed. For with a telescope which enables us to see an infinitely remote object, with relaxation of accommodation, we can, with the greatest tension, see only at a very great distance; and this difference requires of the eye without any glass scarcely any change of accommodation. But even the accommodation, of which the telescope itself is capable, by altering the distance between the eye-glass and the object-glass, represents, in the difference in distance of the objects which are distinguished, only an extremely slight range of accommodation.

. . . .

3°. *The region of accommodation alters in position and extent.*

By *range* of accommodation we undertsand a dioptric value, as being proportional to the focal distance of the lens, which expresses the difference of accommodation for P and for R. The *region* of accommodation on the contrary, is only the expression of the distance between r and p, and is therefore $= R - P$. . . . Evidently a completely different region of accommodation may correspond to the same range of accommodation, and *vice versa*.

. . . .

We now see at once, that, while the absolute range of accommodation undergoes only a slight modification by spectacles, the region of accommodation is quite altered by them.

. . . .

Glasses increase the region of accommodation, when they make r approach to ∞, and on the contrary diminish it when they remove r from ∞.

. . . .

4°. *The magnitude of the retinal images does not continue the same.*

A comparison of the angles, under which objects, accordingly as they are viewed with or without auxiliary glasses, exhibit themselves to the eye, can without further determination, take place only so far as the object at the distance at which it is, can be accurately seen both with and without these glasses.

. . . .

In all these cases we can easily satisfy ourselves, that glasses with negative focus diminish the images, while those with positive focus magnify them. The demonstration of this is very simple. The relation between the magnitude of the retinal image and the object B, is dependent on the position of the nodal point k. The more the latter moves forwards, the larger does β become, in relation to B; the more backwards, the smaller it becomes. What the eye can now do by accommodation, that is, by alteration of its crystalline lens, scarcely displaces the nodal point, because the latter lies in the crystalline lens itself. On the contrary, so soon as an auxiliary lens is placed before the eye, *k* moves forwards, if it be a positive, backwards if it be a negative lens, and the more so for the same lens, according as the latter is further removed from the eye. The amount of this displacement is easily calculated.

. . . .

With glasses of shorter focal distance (common magnifying glasses), the amount of enlargement cannot be in this manner determined. The object must then be held closer to the eye than it can be accurately seen without the lens, and the magnitudes of the images are consequently no longer comparable. In this case we are, therefore, compelled to start from an accommodation for a definite point, and to calculate how large the retinal image under the circumstance is; this magnitude we can then compare with that of the accurate retinal image obtained with the aid of the lens, while the object is brought to the distance of distinctness of the eye armed with the lens.

. . . .

5° *The determination of the distance, magnitude, and form of the objects undergoes a change.*

In order to demonstrate the influence which positive and negative glasses exercise on our estimation of distance, magnitude and form, it is necessary to trace, in what manner, without the use of glasses, this estimation is established.

. . . .

In the first place, we observe that the estimation of distance and that of magnitude are correlative. Three cases are to be distinguished. 1. We know the true magnitude of the object, and thence form, by the magnitude of the retinal image, our opinion as to the distance; 2. We know the distance and base thereupon our opinion of the magnitude; 3. Distance and magnitude are both imperfectly known, and through reciprocal influence an idea is developed, which brings both into connexion with one another, and thus at the same time more accurately defines them. The connexion just mentioned between our estimation of distance and of magnitude is particularly striking when we project the ocular after image of a flame upon a wall, in which case we suppose the flame larger, in proportion as we withdraw from the wall, and smaller in proportion as we approach it, notwithstanding that the retinal image of course remains unchanged.

. . . .

Exceptionally the consciousness of the required accommodation comes into play, even when we look round in nature, where there is no want of objects of known magnitude, and where numerous other means of deciding are at the service of the mind. I observed this, many years since, in myself (1851). As a phenomenon, namely, of diminished power of accommodation, in consequence of the instillation of a weak solution of belladonna, I saw all objects too small, because I supposed them nearer to me, and Warlomont has also communicated an example of the same (1853). In paresis of accommodation too, produced by other causes, the same has once occurred to me.

. . . .

In the foregoing we assumed a knowledge of the true form of some objects, and the direction of some lines or surfaces. This knowledge, indeed, is scarcely ever wanting. In a room we see surfaces, which we may consider to be nearly horizontal or perpendicular, and numerous objects which present to us vertical and horizontal lines. From the angles which these surfaces and lines form on the perspective retinal images, we deduce our judgment. In nature the ground we walk upon, the horizontal water surface, ascending trees, houses with their frames and windows, lastly, man himself, are sufficient starting-points. Therefore also we judge tolerably correctly even what is seen only with one eye from one point.

. . . .

Now on this judgment, deduced from the perspective projection, the use of positive and negative glasses exercises an influence. The cause of this is easily seen. In fact, in using positive glasses, the objects appear to us not only larger but nearer, and the distance in depth between two objects . . . is thus shortened, there is, therefore, an enlargement of the object with diminution of its depth; the reverse takes place in the use of negative glasses.

. . . .

Hypermetropics observe this most distinctly, . . . and most of all persons, who replace the lost crystalline lens with positive spectacles. They suppose all distances to be less, and therefore see objects less deep.

Myopic individuals experience the opposite influence, but somewhat less distinctly, because without the negative glass they did not see remote objects accurately, and the comparison is therefore less perfect.

. . . .

But the phenomena appear much more striking in using the Dutch telescope, for instance, when we look through an ordinary double opera-glass with one eye, and close the other. Let us thus look at a small table. The retinal image of course preserves its form: if the glass magnifies *n* times, the image is only *n* times larger in all its dimensions. But we see the table broader and shorter at whatever distance we endeavour to suppose it to be. Often we have difficulty in supposing it to be short enough. Then it is, of course, too broad behind. . . . This we sometimes correct by, in our thoughts, making the table rise a little; and those persons also do this, who in aphakia wear a convex glass, so that on flat ground they suppose they are running up a hill.

The phenomenon is particularly striking when we look with the opera-glass at an ordinary book, lying at a short distance on the table. The book immediately becomes square, although the retinal image retains the same form, it often remains somewhat broader at the upper edge, loses this when in our imagination it acquires an inclination, and the letters of the title are now broad and low, while before they were decidedly oblong.

If we now turn the opera-glass round: the retinal images, while retaining the same form, have become diminished, and the dimensions in depth, contrary to our former observation, are very considerably increased; even the leaf of the table and the book appear to become narrow above.

All this takes place in using one eye.

The estimation of relative distances, in monocular vision, becomes more correct and certain when the head, or even the body moves, so that the objects are seen successively from different points. In this manner, in fact, a parallax is created between objects placed at different distances, which apparently change their relative places, whereby the relative distances even of simple free points can be estimated.

6°. *Stereoscopic vision with two eyes is modified.* From what has been said under 5°, it is evident, that the estimation of distance and of solidity of objects, even using only one eye, is tolerably perfect. This must here be remembered, for the beautiful discovery of Wheatstone has been found so important, that it finally appeared to make us forget what a single eye can do. Two eyes, however, can certainly do more. At least when near objects are concerned, the solidity of the object can be estimated with more certainty, . . . and a peculiar sensation of the solid is developed in us, which the monocular person seems not to be acquainted with.

This depends upon two causes.

The first is, that in connexion with the distance between the two eyes, in fixing a definite point of an object, the retinal images of the two eyes are not equal and uniform, in consequence of which most points are seen as double images, whose deviation corresponds to the difference in distance of those points.

. . . .

The second cause is: the successive fixing of the different points of the object (Bruecke). In fact we are perfectly conscious (at least, if the movement does not run through large angles), whether, in passing from one point to another, single vision requires more or less convergence, according as the fixed point is less or more remote than that previously fixed.

. . . .

We shall best satisfy ourselves of this, if by holding a carmine glass before one eye, it colours one of the double images, and if we now look in succession at points of light situated at different distances. We then observe also, that with a rapid movement of the visual lines, the required change of convergence is for a moment exceeded, and is then quickly corrected.

Now the use of convex and concave glasses modifies the two factors of stereoscopic binocular vision.

As concerns the first factor, we observe, that the glasses modify the magnitude, and consequently the apparent distance, without producing a corresponding modification of the difference between the retinal images of the two eyes. This difference decreases, accordingly as the distance of the objects increases. While, namely, the angle, under which an object exhibits itself, is inversely proportional to its distance, the parallax of stereoscopic vision, and therefore also the difference between the two retinal images, are, inversely proportional to the *square* of the distance.

. . . .

Thus it is proved, that the retinal images of the two eyes differ less, accordingly as the distance from the object is greater. With convex glasses, and especially with an opera-glass, the object is now seen larger and apparently nearer; but the difference between the two retinal images appears only equal to what it was in looking with the naked eyes. Consequently the object exhibits, in reference to its magnitude, too slight a depth. The reverse takes place in the use of concave glasses, which exhibit the objects smaller, and therefore apparently at a greater distance. Thus the first factor is altered.

As to the second factor, it is dependent on the first . . ., and therefore there is no necessity to treat separately of it.

From these considerations it appears, that, in the use of glasses, stereoscopic vision with two eyes modifies our judgement in the same sense, as takes place for each eye separately. An apparent magnifying, namely, of the dimensions, perpendicular to the axis of vision, in both cases, causes us to estimate the depth as relatively less, and *viceversa*; on a diminution of these dimensions, we are led to infer a relatively greater depth. However, in this the modification of the perspective projection for each eye separately is of much greater importance than the modification in the binocular vision.

Attention must still be directed to a few subordinate points, relating to the influence of glasses. I allude, in the first place, to the apparent movement of objects, when the observer, *by moving his head*, passes from one object to another. If we see, namely, through the glass, the objects under a smaller angle than with the naked eye, we must turn the head to a comparatively great degree, in order to direct the visual line alternately to the one or to the other edge of the object, and thus the latter appears to fly before the movement of the head. . . . If the same does not take place *in moving the eye* behind the glass, this is to be ascribed to the fact, that a person, in looking obliquely through the glass, no longer sees the object in the direction in which it actually is, whereby the want of harmony between the magnitude of the retinal images and the movement required to make them pass over a point of the retina, is compensated: without this compensation, we could not have said, on the preceding page, that the second factor of stereoscopic vision lies included in the first.

. . . .

In the above (under the 6th head), our views were based upon the doctrine of the identical or corresponding retinal points. Of late this has been much disputed. It therefore appears necessary here to explain myself upon this subject. In eyes whose visual lines exhibit no morbid deviation, the existence of points which project the impressions received upon each other into space, is not to be denied. In this sense the points in the same meridians equally remote, upwards or downwards, to the right or to the left, from the fovea centralis . . ., may be considered as sufficiently corresponding. The identity, however, is not absolute. The images of two circles, of somewhat different magnitude, the one received on the right, the other on the left retina (whether through the stereoscope or by convergence), so that the lines may coincide in the fovea centralis, project a circle, whose magnitude is the mean between the two actually present. . . . So far Wheatstone was undoubtedly right, when his discovery made him reject the theory of the identical retinal points. So far, also, the statement made above, that every variation in the form of the retinal images gives rise to double vision of the points not falling upon corresponding parts, is to be corrected.

But the controversy of the identical points has been carried still further. Some began by wholly denying the mental projection of the retinal images into space. This denial would not have been made, if observers had always distinguished between two different things: the projection of the *field of vision* and the projection of *a point in* the field of vision (. . .). The projection of the field of vision depends on the position of our eye and the direction of the visual line. . . . In what part of the field of vision we project a certain point, is, on the contrary, determined by the place which its image occupies on the retina.

In this manner every projection in the normal condition is explained. Thus it is also understood how, with accurately directed eyes, of which direction the observer is conscious, corresponding points of the retinas project the impressions received on each other. This may still continue under abnormal circumstances. In recent paralysis, for instance, of a muscle, we estimate the direction of the visual line incorrectly, and we consequently project the field of vision, and with it each point of the field of vision, in a false direction.

. . . .

If the deviation is not great, we speedily find the directly-seen object of the properly directed eye as indirectly seen on the deviating one, and thus *double vision* is the result. But in every case confusion arises also in direct vision, which becomes particularly great, if accidentally a strongly illuminated part of the field of vision forms its image on the yellow spot of the deviating eye. However, we occupy ourselves almost always with the more illuminated parts of the field of vision, and the result thereof is, that in general the image on the yellow spot of the properly-adjusted eye excels in clearness that of the deviating eye. This makes it easier to neglect the image of this last eye. . .

So far the law of the identical points holds good. But now it happens, particularly in cases of strabismus divergens, that we become conscious also of the direction of the deviated eye. This is the case when one continues to use this eye in its turn. In these cases, an object is still fixed in general with the eye, whose muscles act normally. If we now hold a second object in the visual line of the deviated eye, and request the person to fix it, the eyes sometimes remain completely at rest. The patient can thus occupy himself alternately with the one or with the other object, which respectively forms its image on the one yellow spot or on the other, and he knows perfectly in what direction each is. In this case, it is in the first place remarkable with what certainty he distinguishes with which eye he observes anything: he who has two good, regularly-moving eyes, is not at all aware of this; we can ascertain in which eye we have muscæ volitantes, only by closing one. But, in the second place, it hence appears most distinctly, that in such a person the corresponding points have lost their mutual relations. Indeed, what impinges on the two yellow spots is projected in very different directions, and likewise what touches on similarly directed meridians in points equally removed from the yellow spot. Now the reason why originally corresponding points are projected in different directions is clearly none other than *that the whole field of vision is projected in another direction:* the projection of the different points of the same retina has, with respect to one another, continued the same.

. . . .

From the foregoing thus has appeared, that the deviation of the visual line, produced by muscular anomaly, which originally gives rise to false projection, may become known to us by experience, with which each eye begins its independent projection. . . .

An organically necessary similarity of impression of corresponding points of both retinas, which should lead to an equally necessary similarity of direction of projection, is therefore out of the question. But, nevertheless, what we at first put forward remains true, whether it be congenital or the result of practice, that in eyes whose visual lines exhibit no morbid deviation, certain corresponding points of the retinas project the impressions received on each other into space.

. . . .

In the beginning of this section I stated, in investigating the action of glasses, that I provisionally assumed, that the axis of the glasses coincided with the visual axis. This is certainly almost never exactly the case. Firstly, the glasses in a pair of spectacles are not placed precisely so, that the distance of their two axes should be exactly equal to that between parallel visual axes, and, moreover, in being placed before the eyes they easily come to stand somewhat higher or lower than the visual axes; or the glasses, and therefore also the axes, have, when the head is perpendicular, a certain inclination. Secondly, every movement of the eye immedately alters the relation between the visual lines and the axes of the glasses.

The question now is, what is the result of this deviation?

In the first place, when the axis of the glass is parallel to the visual axis, but is displaced in one or other direction, we obtain also a displacement of the object seen through the glass. We satisfy ourselves of this, by pushing a convex or concave glass before the eye, so as to look always parallel to the axis, but alternately through the centre, and through the edges of the glass. If the glass be convex, the displacement occurs in the opposite direction to that of the glass, if it be concave, in the same direction.

. . . .

Hence it follows, that, if the two convex glasses of a pair of spectacles stand too close to one another, the objects are for both eyes displaced more outwards, and thus less convergence is required; the reverse is the case, when the glasses stand too far from one another. The opposite, of course, takes place, when concave glasses are in question. In either case the change of convergence required is less, the weaker the glasses are, and the less they are pushed to the side. For many years I have advantageously made use of such eccentric placing of the glasses, where otherwise, in insufficiency of one or other muscle, combination with a weak prism was indicated. Nor will it easily happen, that, in doing so, we exceed the limits, whereby the acuteness of the images suffers too much.

If, however, we desire to encroach as little as possible upon the convergence of the visual lines, corresponding to the distance, we must, as had been correctly shown by Giraud-Teulon and Knapp, regulate the distance of the glasses according to the reciprocal distance of the visual lines. We have then, as Knapp has remarked, to attend particularly to the axes of the glasses, for these do not always correspond to the centre.

In order now to find the axis, we have only to ascertain what part of the glass we have to hold before the eye, in order to see a vertical line, even when the glass is made to revolve, unrefracted as well through, as under or above the glass. However, we need not be too careful in regulating the axis. Whether, in order to see an object, a little more or less convergence must be employed, is often rather a matter of indifference.

. . . .

We have only to take particular care, that in spectacles worn out of doors, we have not so short a distance of the axes of the concave, nor so great a distance of those of the convex glasses, that in looking to a great distance a divergence of the visual lines should be required, which might easily cause difficulty. A difference in height of the axes, which should cause a mutual deviation of the visual lines in a vertical direction, we must above all avoid.

In the second place, as to looking through the glass under an angle with the axis, we have already observed that this is unavoidable in the use of spectacles. The deviation thence proceeding is of two kinds. In the first place, the object directly seen exhibits itself in another direction than that in which it actually is.

. . . .

But, in the second place, the objects are seen less accurately. Besides the ordinary aberration, in fact, a new and very important one occurs. Of this we may convince ourselves, by looking at a point of light through a convex or concave glass held obliquely before the eye, and, better still, by receiving on a screen the dioptric image of a point of light formed by an obliquely-placed convex lens. This image has a clear eccentrically-situated point, whence the light spreads chiefly to one side in the form of a fan, so that it reminds one of the appearance of a comet. In treating of astigmatism I shall return to this subject. Here it may only be remarked, that the diminished accuracy of the images, especially when strong glasses are in question, renders it imperatively necessary to attend to the direction of the axes. If spectacles be used only for distance, the axes must be placed nearly parallel and horizontally; on the contrary, in spectacles used only for near objects they require to converge proportionally, and to be directed downwards. This, when strong glasses are required, produces a difficulty of making use of the same frame for every distance, even in these cases, where the range of accommodation still admits of the use of the same glasses. The inclination of the axes can be sufficiently modified by placing the spectacles. But the convergence of the axes cannot be altered, without bending the frame. Therefore convergence must correspond to the mean distance, at which the spectacles are used, whereby, during their use, a certain margin in the convergence of the visual axes is least excluded.

Note to Chapter IV

. . . .

Spectacles are among the most indispensable instruments for man. For many they extend the power of vision to an infinite distance, and others would, for want of spectacles, at a certain time of life see themselves completely shut out from the occupations to which, in a busy society, they are called. If we add that spectacles laid the foundation for the invention of the microscope and telescope, whose mighty influence is powerfully exemplified in the development of most natural sciences, we shall not view these simple instruments without respect.

. . . .

The use of stenopaeic apparatus was introduced by me (. . .). It is true, that in mydriasis use was sometimes made of small openings; but it did not occur to any one to remove, by their means, the injurious effect of obscurations.

SPECIAL PART

I. ANOMALIES OF REFRACTION

CHAPTER V

The Emmetropic Eye

§ 14. *Definition of the Emmetropic Eye; the Diagrammatic Eye; the Simplified Eye*

The emmetropic eye is that, the principal focus of whose dioptric system is, in rest of accommodation, found in the retina (fig. 20). Of infinitely remote objects, which send out parallel rays, this retina

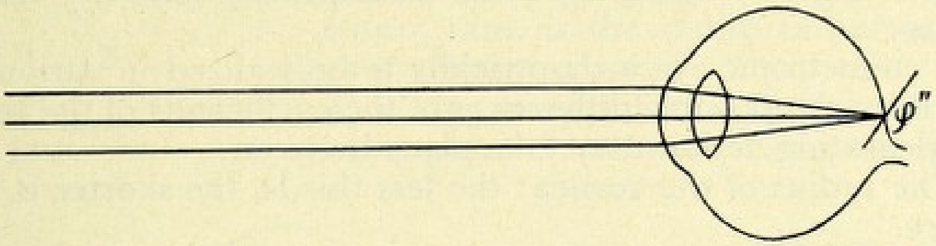

Fig. 20.

therefore receives *accurate images*, to be improved neither by convex nor by concave glasses, and by means of its accommodation it sees equally accurately at relatively short distances. No other refraction of the eye is capable of giving to the region of accommodation so great an extent.

That this condition is to be regarded as the normal, we have already shown. Singularly enough, for a long time the opinion was rather generally entertained, that almost every eye is more or less myopic; that at an infinite distance, apart from the imperfect transparency of the air, it is only exceptionally that objects can be distinguished under the same least angle of vision as at a moderate or short distance. This opinion is an error. By far too often does the eye deviate in the opposite direction from the standard, and can, with hypermetropic structure, bring converging rays to a focus on the retina.

If the emmetropic eye is to be considered as the typically normal eye, another question is, whether it is at the same time the ordinary eye, and whether, therefore, ametropia is the exception.

In an absolutely mathematical sense no single eye is perhaps to be called emmetropic. In the first place, I have never met with an eye whose focal distance in the different meridians was absolutely the same; in general, as shall be more fully shown in the Chapter on Astigmatism, the focal distance is shorter in the vertical meridian of the eye than in the horizontal. But, apart from this, here, if anywhere, we must allow a certain latitude to the rule. Slight degrees of M, for example $M = 1/120$, in which, at the distance of 10 feet ($= 120''$) vision is still perfectly accurate, are almost always unobserved. Slight degrees of H are in youth not even to be proved . . .: indeed, whenever a deficiency of refractive power exists in the eye, when in a state of absolute rest, it is supplied by the accommodation. And even if the eye in paralysis of accommodation should be emmetropic, the tone of the accommodation alone effects a slight degree of M. Consequently, the actually emmetropic vision requires, in a certain sense, a minimum of H, and that minimum is capable of no accurate determination, because to the tone itself a certain latitude, perhaps from 1/100 to 1/40, must be allowed.

In this sense, and it is practically the only correct one, the majority of eyes of young persons are undoubtedly emmetropic.

Finally, should the question be proposed, whether E is the most desirable condition: as concerns myself, I should give the preference to a slight degree of M, and I shall subsequently state my reasons for doing so.

The emmetropic eye is dioptrically to be realized in various modes. Apart from the possible differences of the coefficients of the refraction, a compensating action may take place between

a. The radius of the cornea: the less this is, the shorter is the focal distance.

b. The form of the crystalline lens: the more convex its surfaces, the shorter is its focal distance.

c. The position of the crystalline lens: the more anteriorly it lies, the more, *ceteris paribus*, has it a shortening influence upon the focal distance of the whole system.

d. The length of the visual axis: it needs only to correspond to the condition, resulting from *a*, *b*, and *c*, to make the eye in each case emmetropic.

However, each of the factors mentioned, by itself presents in the emmetropic eye, comparatively little difference.

. . . .

Hence we are completely justified in assuming a diagrammatic eye, and for the sake of different calculations, starting therefrom. The values assumed by Listing were somewhat modified by Helmholtz, who considers the crystalline lens to be a little flatter, and its position to be rather more anterior. . . .

Following Listing's example, we may go still a step further in the simplification: it is, in fact, allowable to reduce the compound dioptric system of the eye to a single refracting surface, bounded anteriorly by air, posteriorly by acqueous or vitreous humour, and this reduced eye, where the greatest accuracy is not required, may be made the basis of a number of considerations and calculations.

. . . .

The right to this simplification we derive from the minuteness of the distance between the two nodal points and between the two principal points of the dioptric system of the eye; this distance amounts to less than one-fourth of a millimètre. It is evident that neglecting this will cause only a very slight difference. We thus obtain, besides the two focal points, as cardinal points, only one principal point, *h*, and one nodal point, the latter being the optical centre, *k*: that is, we retain simply the cardinal points of one simple refracting surface, whose centre of curvature is *k*. . . . Hence results such a simple position of the cardinal points, that we can without difficulty imprint them on our memory, and make many calculations even without the use of figures To this I attach great importance, because our ideas thus gain so very much in clearness.

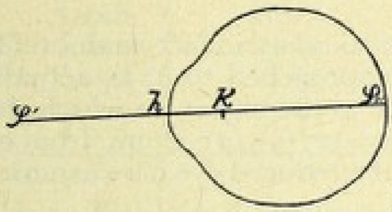

Fig. 21

Fig. 21 represents the reduced eye in its true dimensions.

k is the optical centre.

h is the principal point.

$k\,h=5$ mm. is the radius of curvature of the refracting surface.

$\varphi_{\prime\prime}$ is the *posterior* focus, that is, the focus of rays, parallel in the air (compare fig. 22).

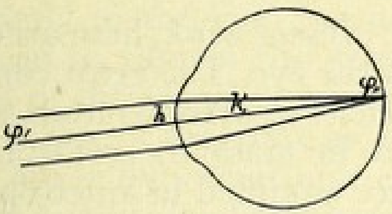

Fig. 22

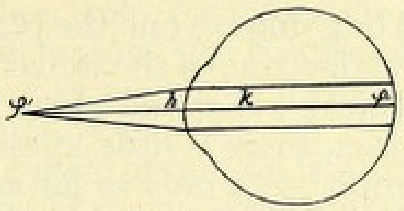

Fig. 23

$\varphi_{\prime}$ is the *anterior* focus, that is, the focus of rays, parallel in the vitreous humour (compare fig. 23).

$h\,\varphi_{\prime\prime}=F_{\prime\prime}$ is the posterior focal distance$=20$ mm.

$h\,\varphi_{\prime}=F_{\prime}$ the anterior focal distance$=15$ mm.

Therefore the coefficient of refraction $n' : n=4{:}3$, as being $=F_{\prime\prime} : F_{\prime}=20 : 15$.

The meaning of the reduction thus made is this: that for the ordinary eye we substitute one with a cornea, whose radius of curvature is only 5 mm., while behind this is merely vitreous or aqueous humour, without crystalline lens, and with a length of visual axis of 20 mm. In such an eye retinal images would have the same magnitude, the same distincteness, and the same position which they exhibit in the emmetropic eye with its cornea of nearly 8 mm. radius of curvature, its crystalline lens of a little more than 43 mm. focal distance, and its visual axis of a little more than 22 mm., and it can, thereforee, really be substituted for this last.

. . . .

Note to § 14

The reduction assumed in round numbers scarcely differs from that found by calculation from the diagrammatic eye of Helmholtz; in place of the

calculated values,	we assumed,
$F_{\prime}=15{\cdot}036$	15
$F_{\prime\prime}=20{\cdot}113$	20
$h\,k=5{\cdot}077$	5·

In connexion herewith we assumed, as coefficient of refraction, in place of 103 : 77, 100 : 75 = 4 : 3, which values stand to another = 308 : 309.

. . . .

We can, in reference to the reduced eye, form a very good idea of the accommodation.

We may assume:

$$r = 4{\cdot}5 \text{ mm.}$$
$$F_{,} = 13{\cdot}5$$
$$F_{,,} = 18.$$

Here, now, $\varphi_{,,}$ lies at 2 mm. before the retina: the visual axis has, in fact, maintained its length of 20 mm. . . . . On the other hand, k has approached to h, as actually takes place in the accommodation. We find the distance to the object for which this eye is accommodated to be ($13{\cdot}5 \times 18 = 243$, and $243 : 2 = 121{\cdot}5$) 121·5 mm. from $\varphi_{,}$, and consequently 139·5 from k, that is about 5″, so that the reduced eye here assumed represents an emmetropic eye, using 1 : A = 1 : 5.

. . . .

§ 15. *Centre of Motion and Movements. Angle between the Axis of the Cornea and the Visual Line*

It would be going beyond the plan of the present work, here to enter into the whole doctrine of the movements of the eye. The great complexity of the subject . . . would alone be sufficient to deter us from so doing. But, besides, there is little application to be made thereof in reference to ametropia; and only so far as they are modified in ametropia, have we here to deal with the functions of the emmetropic eye. As to the mechanism of the movements, a modification with respect to two points is to be noted, which is of importance for our object: *a.* with reference to the position of the centre of motion; *b.* with reference to the extent of turning round the vertical axis.

Respecting the position of the centre of motion numerous investigations have been made, among others by Volkmann, Mile, Burow, and Valentin. These investigations yielded rather discordant results, but as the eye does not differ much from a globe, and is in great part contained in a globular cavity, these observers agreed that the centre of motion should be situated about in the middle of the visual axis. The discrepancy of the results obtained is attributable in part to the methods of investigation employed, but in part, no doubt, also to the difference of the eyes. Since, in fact, it was shown, that ametropia depends principally on a difference in length of the visual axis, it must even *à priori* have been supposed, that the distance at which the centre of motion lies behind the cornea, should, in ametropia undergo a modification, and I therefore thought it necessary to investigate that subject. The investigation took place in concert with my friend Dr. Doyer, according to a method described at the end of this section.

. . . .

In this place I give in the subjoined table only the averages of the results obtained for emmetropic, myopic, and hypermetropic sybjects.

From the table it appears:

	a	Position of the Centre of Motion				f
	Length of the visual axis.	b Behind the cornea.	c Before the posterior surface of the sclerotic.	d In percentage proportion.	e Behind the middle of the visual axis.	Angle between the axis of the cornea and the visual line.
	mm.	mm.	mm.		mm.	
E.	23·53	13·54 :	9·99 =	57·32 : 42·46	1·77	5°
M.	25·55	14·52 :	11·03 =	56·83 : 43·17	1·75	2°
H.	22·10	13 22 :	8·88 =	59·8 : 4·02	2·17	7°·5

1st. That in the emmetropic eye the centre of motion is situated at a considerable distance (1·77 mm.) behind the middle of the visual axis.

2nd. That in myopic individuals the centre of motion is situated more deeply in the eye, but also farther from the posterior surface, and indeed so that in the eyes of such persons the relation between the parts of the visual axis, situated before and behind the centre of motion, is nearly the same as in the emmetropic eye.

3rd. That in hypermetropic eyes the centre of motion is situated not so deeply, but relatively very much closer to the posterior surface of the eye.

. . . .

Now it appears that in the emmetropic eye the visual line cuts the cornea to the inside of its axis. This had already been ascertained by Senff, and was confirmed in a small number of eyes by Helmholtz and Knapp (1859). We found it as a rule in more than fifty eyes. I had, however, previously (1860) observed, that in myopic individuals the angle α is less than in emmetropic persons, and that in the highest degrees of M the cornea may be cut by the visual line, even on the outside of its axis. The investigation carried on with Dr. Doyer showed further, that, contrary to what was observed in M, the angle α is in H particularly large.

This gives, considering the position of the eye in emmetropic subjects to be normal, in hypermetropics apparent strabismus divergens, in myopics apparent strabismus convergens, which, when once one is aware of it, is very evident, and contributes much to the peculiar physiognomy of myopic and hypermetropic persons.

. . . .

Note to § 15

. . . .

Some years ago I thought I had found, in the measurement of the displacement of a reflected image on the cornea, a simple and accurate mode of determining the centre of motion.

In the first place I ascertained, with the aid of Helmholtz' ophthalmometer the radius of curvature in the middle of the cornea. Subsequently I endeavoured, from the displacement just alluded to of a reflected image, to deduce how far behind the centre of curvature the centre of motion was situated.

. . . .

If the accuracy of this determination left nothing to be desired, there was another difficulty. The cornea is not a spherical surface. Its curvature approaches much more nearly to the ellipsoid, and the eccentricity of the ellipse, obtained as a horizontal section, seemed great enough, to exercise an influence upon the position of the reflected image. Professor Van Rees had the goodness to calculate this influence, and it appeared, that in consequence of actually established eccentricity of the elliptical meridians of the cornea, a deviation arises, which, in the calculation, may produce, for the position of the centre of motion, a difference of 2, or even of 3·6 mm. Hence the application of the method was very limited. Indeed, the ellipse of the horizontal section must always be determined, and this determination requires so much time, that it is difficult to apply it to a great number of eyes. The method is here communicated, because in those cases in which the ellipse is determined, it is not unserviceable in the control of other methods.

. . . .

Subsequently I succeeded in discovering a method, in using which the form of the elliptical section of the cornea has not to be taken into consideration. In concert with Dr. Doyer, I have applied this method to a great number of eyes. We were, in fact, not satisfied with knowing the position of the centre of motion in the normal emmetropic eye; we wished to inquire what differences in that respect myopic and hypermetropic eyes exhibit.

The method consists in this:— *That we determine how great the angles of motion (with equal excursions on both sides) must be, in order to make the two extremities of the measured horizontal diameter of the cornea coincide alternately with the same point in space.*

The horizontal diameter of the cornea was measured with the aid of the ophthalmometer.

. . . .

In order further to determine the arc which the cornea must describe, in order to traverse the lenght of its own transverse diameter in space, a ring was suspended before the eye to be examined, in which a fine hair was perpendicularly stretched. It was now merely necessary to try how many degrees (. . .) must be sighted at each side, in order, while the head was immovably fixed, to make each of the margins of the cornea alternately coincide with the hair. The number of degrees ascertained corresponded to the angle which the eye had described from the centre of motion. It very soon appeared, that in normal eyes, this angle amounted to about 56°.

. . . .

In many cases, especially in myopic persons, the mobility of the eye was too limited to make the cornea traverse the required space. In this case we used a ring, provided with *two* extended parallel threads, whose mutual distance was accurately determined. This usually amounted to 3·02 mm. The sights were now so placed that the one thread coincided alternately with the inner margin, the other with the outer margin of the cornea. In order to know the space traversed, it was now necessary only to substract the distance of the threads from the previously ascertained breadth of the cornea, and this value was further made the basis of the calculation.

. . . .

We do not conceal from ourselves, that after this investigation, much remains to be done with respect to the determination of the centre of motion of the eye. In the first place, we have not yet examined how far the centre of motion may be regarded as a fixed, unalterable point. Our investigations extend only to horizontal motion, and almost always to an equal amount. We can therefore answer only for the accuracy of the direct determination—*that of the distance between the base of the segment of the cornea and the centre of motion, in rather extensive movements in the horizontal plane.*

§ 16. *Acuteness of Vision modified by Age*

With the increase of years, the eye undergoes a number of changes of different kinds.

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With these anatomical changes, different disturbances of function are combined. The principal of these are diminution of the accuracy of vision and lessening of the range of accommodation.

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We have already seen, that the determination of the state of refraction must go hand-in-hand with that of the accuracy of vision. We there became acquainted also with the test-types of Dr. Snellen, the utility of which has become more and more evident to me.

. . . .

$S = 1$ was assumed by Snellen as sufficient accuracy of vision. This held good for young subjects. It was to be anticipated, and indeed was already known by experience, that even without extraordinary defects, the accuracy of vision at a certain age begins to diminish. In order to be able to use it as a standard in morbid conditions, it was therefore necessary that the accuracy of vision proper to each period of life should be known. This subject has been recently investigated by one of my pupils, Dr. Vroesom de Haan (1862). S was determined in 281 persons from seven to eighty-two years of age. Placed at first at too

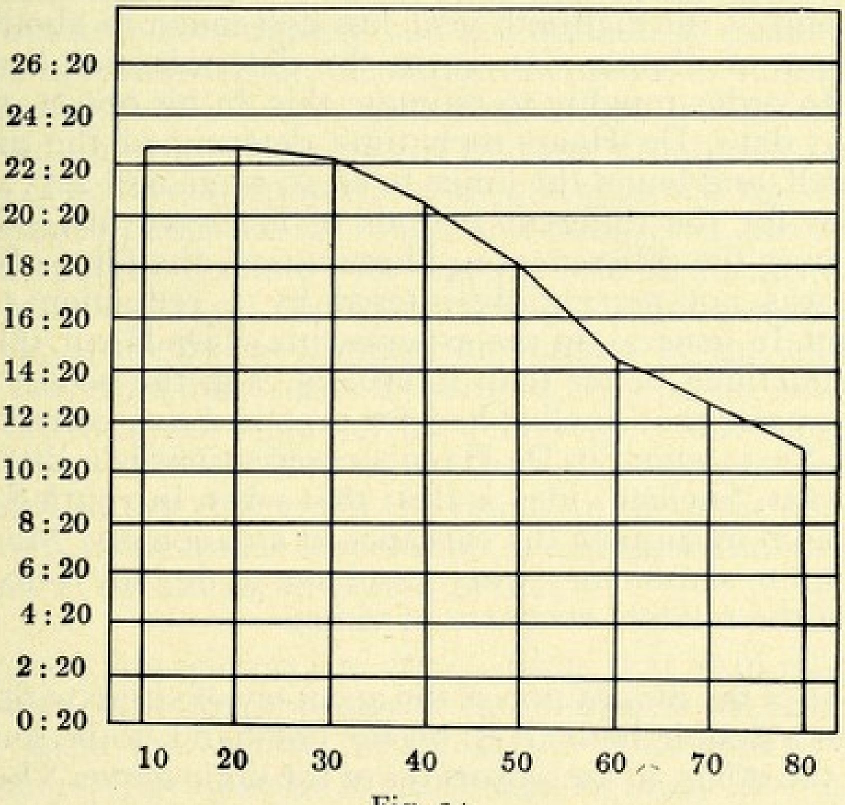

Fig. 24

great a distance, the persons under examination approached until they correctly indicated V, A, C, and L. These letters are the most easily recognisable, and De Haan could confine himself to them, because he usually had to make on each person only one good trial, and therefore needed no great variety. Subsequently I determined the relation between the distinguishing of all the letters adopted by Snellen and of the four used by De Haan, found that it was as 5 : 6, and reduced accordingly the S found by De Haan. It is to be found thus reduced in fig. 24.

. . . .

Astigmatism $> 1/40$ and ametropia were carefully excluded—the latter so far that $M > 1/50$ and manifest $H > 1/60$ are not taken in. At an advanced period of life, $H = 1/20$ was still admitted, because it may in great part be considered as hypermetropia acquisita. In each case the ametropia was corrected by a glass held close before the eye. All eyes were carefully examined externally, many also with the ophthalmoscope; all without exception being so examined in reference to which any suspicion of anomaly existed. If the slightest defect were found, they were excluded.

In the first place it was ascertained, that the individual difference is very great. Cases occur in which, after reduction, $S = 1{\cdot}6$ to $1{\cdot}7$; in youth very few where S is $< 0{\cdot}8$. . . . It is not until calculations are made for each decennial period that the course, as fig. 24 shows, becomes more regular. Further, we see that at the thirtieth year, S is still almost unchanged; thenceforward, however, it diminishes rather regularly, and at the eightieth year has descended to about one-half.

The degree of illumination is, in the determination, not without influence. In order roughly to estimate this, in his observations made on different days, De Haan each time determined the accuracy of vision himself, and found the limits to be 19·5 : 20 and 22·5 : 20. As the observations for the different periods of life were divided tolerably uniformly over the differences in illumination, the form of the line of curvature was not perceptibly altered by a reduction to uniform illumination. In general, in the experiments of De Haan, the illumination was something better than it usually is in the oculist's study. It therefore appears that Snellen has, for practical use, correctly selected the rule as $S = 1$, which in De Haan's observations is a little exceeded for young eyes. Snellen's idea is this: that when in youth S is $= 1$, we have no reason to suppose the existence of an anomaly. Moreover, the method is quite satisfactory where we have to do only with the determination of the relative accuracy of vision.

The cause of the diminution of the accuracy of vision with increasing age rests on a double basis: it is, on the one hand, to be sought in the media, on the other, in the apparatus of the optic nerve. The first gives rise to less accurate images on the perceptive layer of the retina; the second renders perception and conduction more imperfect.

As to the media, even examination with the ophthalmoscope in general shows that with the increase of years they lose the great transparency and homogeneousness in virtue of which the fundus of the young eye exhibits itself with such striking clearness. The cornea indeed changes the least, if we exclude the arcus senilis, which, on account of its eccentric position, throws but little diffused light into the eye, and indeed less in proportion as the pupil becomes narrower in advancing years. The crystalline lens, on the contrary, by degrees reflects much more light, which, thrown anew on the anterior surface of the cornea, returns partly into the eye: on focal illumination, the separation of its sectors becomes more distinct, its irregular astigmatism increases, the polyopia monocularis, in imperfect accommodation, becomes (notwithstanding the diminished diameter of the pupil) stronger and more irregular, the colour of the crystalline lens is yellower, and entoptic investigation exhibits, over the whole, more disturbance of homogeneousness. The vitreous humour also loses some of its perfect clearness, at least at an advanced period of life; it becomes richer in membranes collecting into folds, in corpuscles and filaments, as both microscopic and entoptic investigations have proved to me: in consequence of these we have an increased number of muscæ volitantes. Finally, the diminishing transparency of the retinal layers comes under notice.... However, with respect to direct vision, this has, while the bulbs of the fovea centralis lie almost naked, but little importance. The senile changes of the apparatus of the optic nerve itself have been but little investigated, and it is difficult to estimate their influence. The best known is the formation of vitreous elevations, globules and groups of globules (warty granulation), on the anterior surface of the choroid, in connexion with the limiting structureless membrane of the same. The formation in question was observed by Wedl (1853) then I accurately described it (1854), and discovered and represented the instruction of the globules with pigment into the locally atrophying retina. H. Mueller (1855) considers these formations as simple thickenings of the structureless limiting membrane of the choroid. The function of the retina must suffer from them; they occur, however, only to a small extent in the region of the yellow spot, and scarcely before the sixtieth year, after which they soon become constant. Undoubtedly other less well-known changes in the retina, in the optic nerve, and in the brain itself, come under observation as causes of diminished acuteness of vision at an advanced period of life.

All the foregoing has reference to direct vision, that is, to vision of fixed objects. Outside the fovea centralis the acuteness of vision rapidly diminishes. Even the surface, which at the same time is seen with *perfect* acuteness, appears to be so small, that its image does not occupy the whole fovea centralis. The diminution of the acuteness of vision in the parts of the retina remote from the yellow spot, has been investigated by Aubert and Förster. At a certain angle ($12^\circ.5$ to 20°), they found that acuteness nearly inversely proportional to the angle of deviation; at greater angles S diminished much more rapidly. Rather strange and unexpected is the result, that smaller letters and numbers are indirectly distinguished under lesser angles than larger ones: in other words, that in looking at near objects, S is, in the peripheric parts of the retina, greater than in looking at some distance.

In different morbid states the acuteness of vision diminishes by no means in equal proportion, in direct and indirect vision. Not unfrequently the disturbance is confined to the region of the yellow spot, with perfectly normal S in the peripheric parts of the retina; in other cases indirect vision alone has suffered, and even in the periphery limitation of the visiual field may occur, without direct vision having suffered. It is therefore of much importance to have formed an opinion also as to the accuracy of vision in the lateral parts. For practical purposes the observer possesses the power of comparison with his own normal eye. On closing one eye, the observed eye looks to the left and the observing eye to the right, or *vice versa*, at each other, and taking care that the observed eye does not deviate, the observer now exhibits, about in the plane which is perpendicular to the visual lines, in the middle between the observing and the observed eye, different objects—his fingers, cut-out letters and numbers, &c.—and thus by comparison in corresponding parts, he soon estimates the degree of disturbance in the periphery of the retina. In order to obtain accurate knowledge, we should be able to follow the method of Aubert and Förster.—Limitation of the field of vision is determined by projection on a sheet of blue or black paper, as shall be more fully described in treating of M.

In the foregoing, the method was stated of determining the acuteness of vision for *practical purposes*. The formula $S = d : D$ gives, however, neither the absolute measure of the distinguishing power of the retina, nor mutually comparable relative values. The absolute measure we shall learn immediately, when we come to speak of the determination of the acuteness of vision as a *physiological value*. That the relative values are not comparable, Snellen has already observed. If an image has double the magnitude, it has not at the same time double distinctness. This we should be allowed to infer only in case the acuteness of vision was equal over the whole retina, in case the larger letter, used for testing diminished *S*, was at the same moment equally accurately seen by the normal eye in all its parts. This, however, is not so. Therefore, also, when the image must have double the magnitude to be recognised, we cannot say that the acuteness of vision is really reduced to half. Perhaps it would be correct to assume that the acuteness of vision is inversely proportional to the number of percipient retinal elements which are required, in a linear dimension, to the distinguishing of the image. But, on the one hand, this prejudges the question, whether the accuracy of vision diminishing towards the periphery depends actually on the greater distance from one another of the several percipient elements; and, in the second place, the principle could not be practically applied, in consequence of the difficulty of determining the number of percipient elements. Hence the method adopted appears to me to be the only one available. The objection we made, based upon the unequal value of the parts of the retina, on which a larger image is formed, is in great part got rid of when we consider that this larger image is not seen with immovable eyes fixed upon one point, but is inspected consecutively in its different parts by the fovea centralis: the different impressions thus received by the most acutely seeing part of the retina are then combined, in order thence to deduce an idea of the form of the whole. The physiological value of the acuteness of vision being an angular distance, it is evident that the values of *S* are to be calculated as inversely proportional to the linear dimensions of the images required for the distinction, and, consequently, to the squares of their superficies.

In all times letters and numbers have been preferentially employed by ophthalmologists in the investigation of the power of vision. A regular system was, however, for a long time wanting. Stellwag von Carion proposed very useful letter-tests, on a good principle. Smee (1854) ... adopted a series of letter-tests. Ed. von Jaeger (1854) conceived that the ophthalmologist needs tests on a greater scale, and his well-known *Leseproben*, although not based upon correct principles, were soon generally adopted. But the need of a better system, which should admit of the acuteness of vision being expressed by a number, was still generally felt, and Dr. Snellen has the merit of having supplied this want. Neither has Giraud-Teulon been behindhand. He, led by about the same reflections, has devised a similar system, which he lately laid before the Ophthalmological Congress at Paris.

In contrast to this determination of *S*, suitable for practical purposes, I above placed the determination of *S* as a physiological value.

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The first exact appreciation of the physiological question we find in Hooke's work. (1705). He investigates the angular distance required to observe two fixed stars separately, and he found that, among a hundred persons, scarcely one is in a position to distinguish the two stars, when the apparent distance is less than 60 seconds. Subsequently, similar investigations were carried on by Mayer (1754) and in our own time by Volkmann (1846), Harting (1848), Weber (1852), Bergmann and Helmholtz, for the most part with parallel lines or with gauze. It is evident that, for two minute points of light to be seen separately, the centres of their images must lie farther (about one and a-half times) from one another than the breadth of a percipient retinal element.

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In using stripes and wires, not only the interspaces, but also the thickness of the stripes or wires come under consideration, and in the calculation Helmholtz has therefore assumed the angle, corresponding to the sum of a line and an intespace—that is, to the distances of the central points of the two adjoining objects: the retinal elements must then, at least, be less than the retinal images corresponding to this angle. Harting and Bergmann have some measurements in which the angle thus calculated is less than 60 seconds. Almost invariably, however, it amounts to from 60 to 90 seconds. By using the extremely thin cobweb filaments, the angle in Harting's experiments proved much greater (2 to 3 minutes) than when metallic gauze with thicker filaments was employed. To this cause, no doubt, it is also to be attributed that Volkmann, who made use of cobweb filaments, found particularly high values. The cones in the fovea centralis have, according to Schultze, when shrivelled, a thickness of 0·0020 — 0·0025, in the recent state probably of 0·0028 mm. at the basis; according to H. Mueller, of 0·0025 — 0·0030. An angle of 60 seconds gives a retinal image of 0·0044. This is equivalent to the thickness of one and a-half rods, and therefore completely confirms,in connexion with what has been above remarked, the hypothesis from which we started, that each cone of the fovea centralis can separately project the received impression; the peculiar undulating curves, too, represented by straight lines, before becoming accurately recognisable, are explicable from this hypothesis. Hence it follows also that each cone has its distinct nerve-fibre.

For practical use in those labouring under affections of the eyes, the method here laid down for physiological objects is not applicable. In practice it is absolutely required that the person examined should give a proof that he actually ditinghuises, as is done by the naming of known figures, letters, numbers, etc. I formerly endeavoured to attain my object in this respect by causing the patient to determine what direction the stripes had on a card, which was turned, behind the opening of a diaphragm, around its centre. The distance at which the determination was every time effected with precision should, as I supposed, present a very simple measure of the accuracy of vision. It appeared, however, that the inclination of the lines had a great and insuperable influence on the distinctness of their direction, a fact undoubtedly connected with irregular astigmatism. This circumstance rendered the method useless.

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The inspection of objects existing in our eye we call *entoptic observation* (Listing). In ordinary vision, only obscurities which lie close in front of the retina can throw circumscribed shadows on that membrane. Under certain circumstances, however, irregularities remote from the retina become definitely perceptible. This occurs, when homocentric, and especially nearly parallel light, passes through the vitreous humour.

. . . .

Thus, if we hold before the eye, at a distance of about 13 mm., a thin black metal plate, furnished with a small opening of 0·1 mm., and if we look through this opening towards the bright sky or the globe of a lamp, the retina receives a circle of light of the form, and of about the magnitude of the pupil, without inversion, and therefore inversely projected, on which all irregularities are represented. Particularly shadows which are formed, but also diffraction-lines are to be seen thereon, and the effect of the refraction of light by some corpuscles is also not to be mistaken. We can distinguish:

1. The *muco-lachrymal spectrum*, dependent on tears, mucus, fat globules and bubbles of air, moving on the cornea; on the edges of the eyelids pushed before the pupil, whose lashes are also accurately represented, we see stripes, dependent on the layer of moisture.

2. The *spectrum of the vitreous humour*.—Particularly for the parts situated closer to the retina, the light needs less to be homocentric, and it is therefore advantageous, in order to be less disturbed by the spectrum of the crystalline lens (see 3), to take a somewhat larger opening. On an extremely finely granular ground (optical effect of the granular layers of the retina on the layer of rods?) every one sees with the greatest distinctness the movable *muscæ volitantes*. We distinguish

a. Isolated little circles,—some with dark, others with pale contours and bright in the centre, mostly surrounded with a slender ring, from 1/28 to 1/120 mm. in diameter, from 1/3 to 3 or 4 mm. from the retina. They appear particularly, and, it would seem, from the under side, on a rapid movement of the eye from beneath upwards interrupted by a sudden arrest, and they then again slowly descend: in the horizontal direction they have little, in the vertical they have 1 1/2 mm. or more mobility, and alter but little their distance from the retina.

b. Pearly strings, from 1 to 4 mm. in length, by from 1/33 to 1/190 mm. in breadth, the slightest close to, the broadest and darkest more remote from the retina, all occurring at from 1/4 to 3 mm. distance from this membrane. In the state of rest the same pearly string has for seventeen years always existed unchanged in form nearly in the visual line of my right eye. The most of them are, however, in rest, retracted upwards (apparently downwards), in order with the above-described movement to appear again, twisting in various modes.

c. Coherent groups of little circles of various sizes, some pale, some darker, more opaque than the other forms: these are, in ordinary vision, usually observed as muscæ volitantes. Many are connected with short pearly strings, and move with these; some have the appearance of convoluted pearly strings.

d. Plaits, under the form of bright little bands, bounded by two rather dark, but not accurately marked, lines. They exhibit themselves either as twisted fibres, or as parallel little bands, connected to one another in some invisible mode, or as an irregularly rolled-up membrane of constant form. They hover and move chiefly in a vertical plane, at from 2 to 4 mm. from the retina. Besides this form, extended membranes occur, some situated close behind the lens, with plaits, which attain a breadth of 1/23 mm., some removed only from 2 to 4 mm. from the retina, with slighter plaits of 1/60 mm., while at a distance of from 4 to 10 mm. from the retina, none whatever are met with. They appear when the visual axis is moved to the side, but especially on a powerful, suddenly-interrupted, movement from above downwards. Hereupon the membranes situated close behind the lens apparently rise upwards, while, on the contrary, those situated near the retina descend, so that in the visual axis they pass one another. But we now often see the plaited membranes become more and more indistinct, without its being evident that they recede from the field of vision, and yet, on repeating the movement, they each time appear afresh distinctly. Hence follows what on accurate study is more fully confirmed, that these membranes have only apparently an extensive motion, and that what, on superficial inspection, we should be inclined to look upon as a movement of the whole membrane, is merely the continuation of the folds, which on motion are formed at the periphery, and towards the extremity of the membranes lose their defined form. The cause of the difference in direction, in which the movement of the membranes and the propagation of the folds take place, is to be sought in the fact of location, in front of or behind, the centre of motion.—If we look with the pupil artificially dilated, or hold the illuminating point close before the eye, so that we can see tolerably well at the side of the visual line, we observe that, particularly on powerful lateral, suddenly interrupted movements, still more membranes appear tolerably close behind the lens, which rarely extend to the visual line, and here terminate with irregular points, sometimes torn off in rays. *These membranes increase and become less transparent in advanced life, especially where myopia exists.*

Having, in the manner to be stated hereafter, determined the position in depth of these different forms, I succeeded in finding, on microscopic examination, with Professor Jansen (1843), some, and subsequently with Dr. Doncan, all forms in the vitreous humour of the human eye. In the investigation the vitreous humour was transferred with the hyaloid membrane uninjured to a hollow glass; the vitreous humour soon becomes flat, and viewing it from different sides, we can, with tolerably strong lenses, search it all. Of the muscæ volitantes, which every one can see entoptically in himself, I have not here reproduced the representations. They are microscopically perceptible in the vitreous humour:

α. Pale cells, and débris of cells in a state of mucine-metamorphosis (fig. 25*a*, close to the visual axis in the posterior part of the vitreous humour; *b*, more laterally in the vitreous humour). These correspond to the isolated circles described under *a*.

β. Fibres furnished with granules (fig. 26), corresponding to the pearly strings; we found them less generally than the large number of those strings should have led us to suppose.

γ. Groups of granules with adherent granular fibres (fig. 27), corresponding to the groups described under *c*.

Fig. 25.

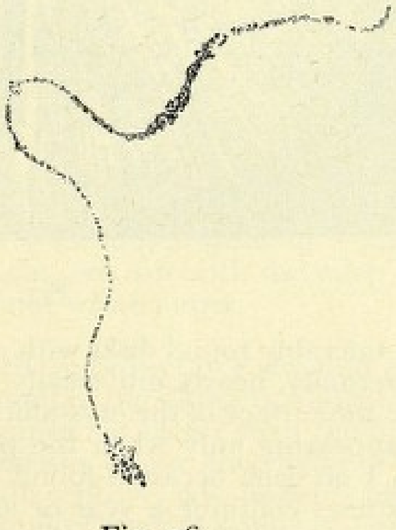

Fig. 26.

Fig. 27.

δ. (Fig. 28) membranes, situated chiefly to the side, close behind the lens, numerous in the vitreous humours of old persons, corresponding to those described under *d*.

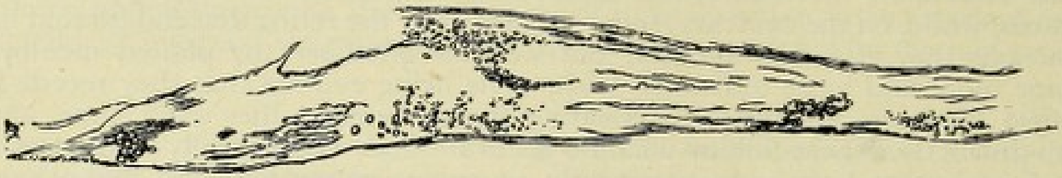

Fig. 28.

3. *The spectrum of the crystalline lens.*—For observing this, more perfectly homocentric light, and therefore a very small opening, is necessary. The whole circle is then less illuminated, and covered, as it were, with a crape (Fig. 29, my right crystalline lens in mydriasis). We find here:

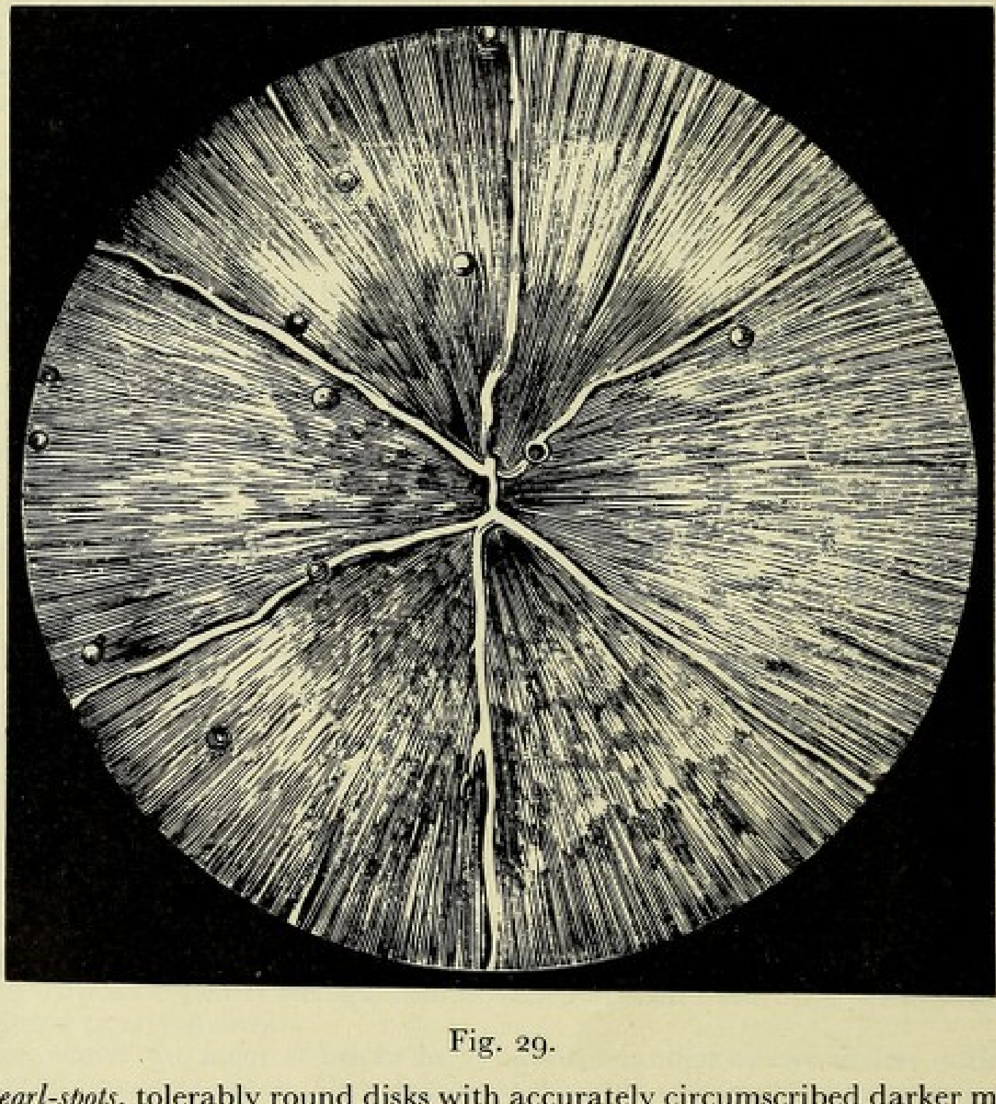

Fig. 29.

a. Pearl-spots, tolerably round disks with accurately circumscribed darker margins, but brighter internally, nearly universally occurring in every eye; the majority are situated close to the surface of the crystalline lens, in great part eccentrically placed, and therefore appearing only when the pupil is artificially dilated. Examining at different times, I on each occasion found others; they may be developed in a few days, and sometimes continue a year or longer; in general their number increases with the advance of years. They are microscopically visible as large globules among the superficial fibres of the lens, which they, as it were, push out from one another.

b. Black, or rather opaque spots, usually round, but sometimes of irregularly angular, or oblong form, not so common as the pearl-spots. I have also seen them, on microscopic examination, rather superficially, as white, granular, opaque corpuscles, almost always in the boundaries of the sectors of the crystalline lens. They appeared not to be dependent on fatty metamorphosis.

c. A radiated figure, more or less regular, usually with ramifications proceeding about from the centre; the rays exhibit themselves, sometimes as black, but ordinarily as white lines with dark boundaries. If we remove the point of light from the eye, these lines pass into the well-known rays, exhibited by a star or point of light for which the eye is not accommodated, and these correspond again to the manifold images, under which a point, for example, a fine white granule (. . .). These phenomena are connected with the composition of the lens of so-called sectors, which, as Helmholtz showed, can be very well seen with the magnifying-glass, with lateral focal illumination, in the living eye. *All these irregularities of the lens increase with the time of life, and partly explain the diminished acuteness of vision.*

Of all the entoptic objects observed, we can easily determine the position in point of depth, according to a method, to which I was led by those of Sir David Brewster and of Listing. Instead of looking through one, we look through two openings of 0·1 mm., placed at from 2·5 to 3 mm, from each other. Two cylinders of light, each in itself homocentric, then penetrate the eye, under such an angle, that the circles on the retina cover one another nearly by half. We therefore see them as fig. 30. In each circle the entoptic spectra are now to be seen.

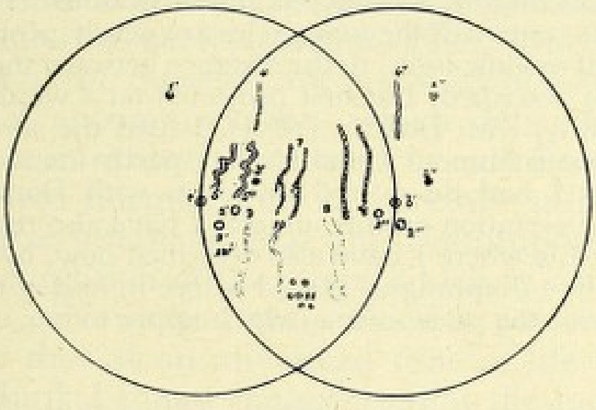

Fig. 30.

. . . .

We now see, without further demonstration, that the distance of the double shadows, is in the same proportion to the distance of the entoptic objects from the retina, as the mutual distance of the centres of the two circles, to the distance from the plane of the pupil to the retina = from 18 to 19 mm.

. . . .

The measurement of the projected images is most easily effected by the method *à double vue*, in use in micrometry: looking through the two small openings (which may for that purpose occupy the place of the object-glass in a microscope-frame) downwards on a mirror reflecting the light, we can with the other eye project and measure the forms on an adjoining sheet of white paper.

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Taking into account the distance at which we project, we also find easily the magnitude of the shadows, which, both on account of the diffractionlines and of the imperfect homocentricity of the light, prove somewhat larger than the objects.

In conclusion, a word respecting the history of our knowledge of entoptic phenomena. Dechales (1690), a Jesuit of the 17th century, saw, as being highly myopic, his entoptic spectrum in the cirlce of diffusion of remote points of light, and comprehended and described what he saw. He showed, on correct principles, that muscæ volitantes, observed during ordinary vision, must depend either on corpuscles situated near the retina, or on morbid parts of the retina itself. The observation of the true motion of muscæ volitantes by Andreae (1825), Prévôts (1832), Sotteau (1842), and others, should have been sufficient to solve the dilemma raised by Dechales; but, nevertheless, the truths and errors, taught by Morgagni (1722), were perpetually repeated. Since 1760, as we read in Mackenzie (1845), observers had begun to study the muscæ volitantes both through a small opening, and with the aid of lenses. Mackenzie himself gave a very creditable description of the muco-lachrymal spectrum observed in this manner, and of that of the vitreous humour, but without making use of Brewster's method of determining the distance from the retina. Sir David Brewster had previously, however, by using two points of light (the dioptric images of two flames, towards which he looked through a powerful dioptric system), as an *experimentum crucis* doubled the shadows, and thus given a direct proof of the position of the objects in the vitreous humour producing muscæ volitantes, and even made a calculation of the position of one of his muscæ volitantes. This was followed by the treatise of Listing (1845), who fully developed the theory, discovered the spectrum of the crystalline lens, and deduced the position of the objects in the eye from their parallax in the motions of the eye: thus, as is easily conceived, the shadows of corpuscles, situated in the plane of the pupil, on movement of the visual line, maintain their place in the circle of light, while those in front of that plane thereupon exhibit a positive, those behind it, a negative parallax, which parallax is greater as the distance from the plane in question is greater. Listing's method is not very applicable to movable corpuscles. That of Brewster presented difficulties in the projection, and the calculation was uncertain and troublesome, until I pointed out (1847, 1849), that the centres of the two circles are nearly proportional (the crystalline lens causes a slight modification) to the distance between the pupil and the retina. In my method above described, I at first projected on a white paper on which the sun shone, subsequently, with Doncan (1854), I used the *méthode à double vue*. The corpuscles in the vitreous humour I had already partly found with my friend Prof. Jansen; subsequently I had discovered all forms with Doncan, who, under my direction, wrote his dissertation on this subject; I have also repeatedly seen those of the crystalline lens.—Elsewhere I have also described how, by means of a lens with a pupil (an opening in a diaphragm) placed before it, and of two little lights in the focal plane of that lens, the phenomena, which apply to our method, can be made visible on a screen.

Sir David Brewster closes his paper with the following striking words:

. . . .

'Few symptoms prove so alarming to persons of a nervous habit or constitution as muscæ volitantes, and they immediately suppose that they are about to lose their sight by cataract or amaurosis.' Often, alas! this anxiety is even still kept up by ignorant practitioners. But nothing is easier than to convince such gloomy patients, who have usually already acquired some knowledge of the eye, that the seat of the phenomenon is to be met with in the vitreous humour, and not in the nerve: they readily comprehend the signification of the double shadows by comparison with an experiment with two lights, which can give double shadows of an object on a wall, only when the object does not lie against the wall. Under what circumstances complaints of muscæ volitantes may have a dangerous signification, shall be pointed out in treating of myopia.

I formerly wrote a detailed essay on the employment of entoptic investigation in the diagnosis of defects of the eye. Now that (thanks to the valuable invention of Helmholtz) the ophthalmoscope is in our hands, the importance of the entoptic mode of examination for diagnosis is thrown completely into the shade.

§ 17. *Range of Accommodation, modified by Age. Presbyopia. Hypermetropia acquisita*

The refraction of the eye, and still more the range of accommodation, become modified with the increase of years. The diminution of the power of accommodation first takes place; it is perceptible long before the refractive condition of the eye in the state of rest has undergone any modification: for the distance R of the farthest point continues long unchanged, while P, that of the nearest point of distinct vision, becomes gradually greater and greater. Thus the range of accommodation diminishes.

The progressive removal of *p* is a fact of universal experience. People are, however, generally of opinion that this retrogression commences first about the fortieth year. But this is an error. Not until about that time of life, under some circumstances, does the retrogression of *p* make itself felt as a *disturbance* in the normal eye, and therefore attention is then first directed to this so-called weakness of the eye; but already in youth—nay, even before puberty—*p* moves considerably back. This change affects all eyes without distinction, as well the myopic (provided it be healthy) as the hypermetropic and the emmetropic eye.

In the first place, it may here be asked, in general, how and from what cause it is, that at so early a period of life, while all the functions, and especially that of the muscles, are in a state of progressive development, the power of accommodation, which depends upon muscular action, already loses in extent? As it must be admitted, that the ciliary muscle has continued normal, and is therefore still in full force, we come readily to the inference that the diminution is to be sought exclusively in the condition of the parts, which in accommodation are passively altered. . . . Now the organ which is passively altered is the lens. . . . We know that at an advanced time of life the lens is firmer than in youth. I think I may even assert that the increase of firmness commences at an early period. Now, it is in consequence of this greater firmness that the same muscular action can no longer produce the same change in the form of the lens. . . .

After the power of accommodation has considerably decreased, a slight diminution of refraction gradually takes place. This appears from the fact that now also *r* begins to remove from the eye.

. . . .

At the fortieth year, it has not at all, or has scarcely commenced, and it is not until the sixtieth or seventieth year that it is distinctly present in an originally emmetropic eye. On account of the simultaneously diminished range of accommodation, the visual lines being parallel, the eye can then frequently not be accommodated, even for remote objects, and a positive glass is therefore required also for distance.

The doubt might be raised, whether . . . in all those cases in which, at a later period of life, H is observable, an equal degree of latent H did not already exist in youth. . . . We are, however, justified in declaring this doubt to be unfounded. Sometimes a certain degree of H is developed in relatively so short a time, especially when traces of obscuration arise, and, as it appears, also in glaucoma, that there is no ground whatever to assume the original existence of the same degree of H. Moreover, I have in myopia also occasionally satisfied myself of the presence of a diminution of refraction. Finally, and this in itself is convincing, at an advanced period of life H is much more common than in youth. The question therefore is, on what the diminution of refraction depends . . . It seems to me that the cause is to be sought in the lens.

. . . .

This, if I am not mistaken, is to be sought chiefly in a more uniform firmness of the several layers of the lens. Even Thomas Young remarked, and it has been more fully demonstrated by Senff, Listing, and others that with the laminated structure, with refractive power diminishing towards the periphery, the lens has a shorter focal distance than a lens of similar form, and composed wholly of a substance of the refractive power proper to the nucleus of the lens, would have. If, consequently, with the advance of years, the outer layers become more solid, a greater focal distance must be the result. Now, the existence of this increase of solidity is evident from the increasing reflection in advanced life on the anterior and posterior surfaces of the lens, a reflection which is proportional to the difference in refractive power between the outer layers of the lens and the aqueous or vitreous humour; and it is also capable of being established by anatomical investigation. But, in addition to this, in advanced life the lens appears to become flatter, on which account the radii of curvature of its surfaces, and its focal distance, are increased,—I have satisfied myself that the cornea does not become flatter, and I have no reason to assume that the visual axis should become shorter, except in the most extreme old age. I therefore believe that the cause of the state of diminished refraction must be sought in the above-mentioned changes in the lens. In favour of this view is also the circumstance that the diminution of refraction at last goes hand in hand with the diminution of the power of accommodation: indeed this points to a common origin, and we have above seen that the latter depends upon a hardening of the lens.—The vitreous humour I have not compared, with reference to its refractive power, at different times of life. It is self-evident that, as its anterior surface is concave, an *increase* of its refractive power must move the posterior focus of the eye *backwards*.

As I have above remarked, the changes in accommodation and refraction occur in each form of the eye. We have here to subject to a more accurate examination only those which take place in the emmetropic organ.

Fig. 31 represents the course of the nearest *p p*, and of the farthest points *r r*, and consequently that of the power of accommodation in the emmetropic eye, ad different periods of life. The figure needs but little explanation. The numbers, to the left, indicate, as before, the distance in Parisian inches, for which accommodation can take place; those, which are lower than ∞, have, as in the previous figures, a negative

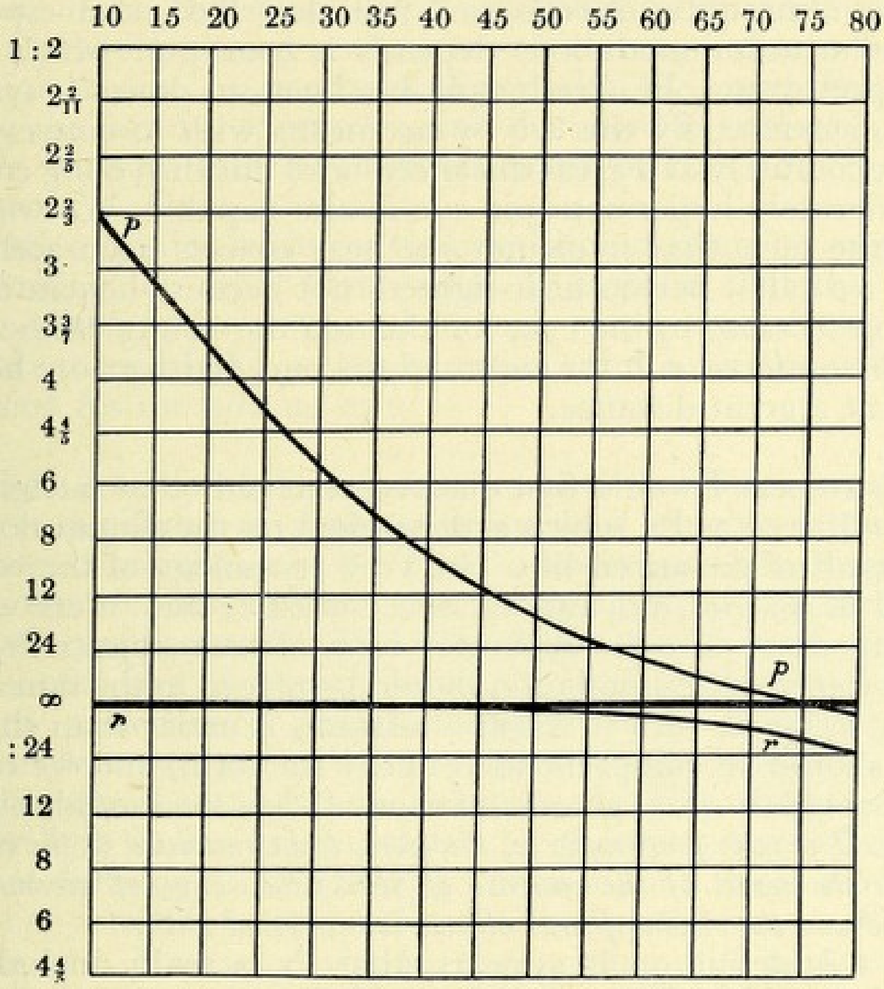

Fig. 31.

signification: they represent the distance at which the converging rays, for which the eye is accommodated, come to a focus behind the nodal point. The numbers placed above the figure, indicate the age, expressed in years.

. . . .

From the figure it directly appears, that, even from the tenth year, at which the observation becomes possible, *p* approaches the eye, and indeed with tolerably uniform rapidity, so that at the thirtieth year 1 : A has fallen to about one-half what it was at the tenth year. From this time the descent appears to take place somewhat more slowly, but nevertheless to proceed incessantly to the most advanced time of life. The course of the farthest point is quite different. Up to the fortieth year it remains at the same height; but from that time an extremely slow descent occurs, the emmetropic eye becoming, at the fiftieth year, somewhat hypermetropic, which H at the eightieth year amounts to from 1/24 to 1/10. This acquired hypermetropia may, finally, become absolute, that is to say, that not only accommodation for divergent, but even for parallel, rays becomes impossible.

. . . .

On the diminution of refraction just described, and especially on that of the accommodation, depends a condition which has been termed presbyopia, Pr. Presbyopia has been set down as synonymous with *farsightedness*. By this we by no means wish to convey, that the eye sees accurately at a great distance, for of this the young emmetropic and moderately hypermetropic eye is also capable. We wish only to express the fact, that it cannot see near objects accurately. In like manner we call a person near-sighted, not because he can distinguish small objects close to the eye, for this too the young emmetropic eye enjoys in common with the near-sighted one, but because he does not see well at a great distance.

. . . .

In this respect I would first observe, that only that farsightedness is to be considered as Pr, which is dependent on the diminution of 1 : A, as the result of advanced life. The very etymology of the word, compounded of *πρέσβυς*, old, and *ὤψ*, eye, indicates this. Were we to term every impediment to the accurate vision of near objects Pr, paralysis of the power of accommodation should be placed in the same category. Even H, so far as with it vision of distant, is easier than that of near objects, should be comprehended under the term, and we have made it clear enough to what great confusion of ideas we should, by so doing, give rise. *The term presbyopia is, therefore, to be restricted to the condition, in which, as the result of the increase of years, the range of accommodation is diminished and the vision of near objects is interfered with.*

From this definition it appears, that Pr is really included in the diminution of the range of accommodation dependent on advancing years. Still Pr is the normal quality of the normal, emmetropic eye in advanced age. It is, therefore, properly speaking, no more an anomaly than are grey hairs or wrinkling of the skin. Were it an anomaly, it should be much less one of refraction than of accommodation.

But where are we to place the commencement of presbyopia? If we consult the line *pp'* of fig. 31, representing the emmetropic eye at different times of life, it appears that, from youth up to extreme old age, *p* removes with tolerable regularity more and more from the eye, and that, consequently, the vision of near objects becomes progressively more and more difficult. . . .

Hence it follows, that in fixing a limit of Pr, we cannot avoid being arbitrary. In the eye itself, no reason is to be found, for making a definite distinction between presbyopic and non-presbyopic. Now, if the boundary be artificial, it must be conventional.

This, however, leads us to the question, whether it is necessary to speak of Pr, and whether we should not rather confine ourselves to fixing 1 : A, in connexion with the degree of M or of H, where these are found. Undoubtedly this mode would be scientifically satisfactory. Nevertheless we should, in my opinion, meet with but little response, were we to get rid of so generally known and extensively employed a word. I believe also that by so doing we should confer no favour upon practice. In practice a word is required, which may indicate the condition in which the eye, at an advanced period of life, must, for ordinary close work, use positive spectacles, and this word is *presbyopia*.

However, with all this the commencement of Pr is not yet defined. That this must be done, is evident.

Our social condition requires that we should often be engaged in reading, writing, or other close work. It is plain that the average magnitude of the forms employed in such work, is closely connected with the accuracy of the power of vision, and with the distance of distinct vision for the normal eye.

. . . .

The common employment of spectacles has, therefore, exercised an influence on the limits of distinct vision, with which we must allow presbyopia to commence. . . . We have to investigate how long the eye fulfils the requirements of the assumed standard. . . . In the fortieth year ordinary type presents no difficulty whatever to the emmetropic eye. In the forty-fifth year the notes, printed in smaller characters, are not unfrequently passed over, and the book is in the evening probably somewhat earlier laid aside. We now soon begin to observe, that an object, to be very accurately seen, is removed a little further from the eye; a clear light is also sought, rather for the purpose of diminishing the circles of diffusion, in imperfect accommodation, by narrowing the pupil, than of obtaining more brilliantly illuminated images. Ordinary occupations are, however, even in the evening still performed uninterruptedly without remarkable exertion. . . . The binocular nearest point p_2 now often lies at about 8″ from the eye. At this point I have already placed the commencement of presbyopia. I think too that I must now keep to it. In the following §, however, we shall see, that this does not always, and indeed not even in general, involve the use of spectacles.

If we have agreed upon a definite distance as the commencement of Pr, this may serve also to fix the degree of the presbyopia. This is done in a very simple manner. If p_2 be situated at n Parisian inches from the eye, then, assuming the above mentioned limit, $\mathrm{Pr} = 1/8 - 1/n$. . . .For this glasses of about $1/8 - 1/n$ are required . . . to neutralise the presbyopia.

. . . .

To be quite accurate, we should be able to determine the degree of Pr from the glass, with which, by means of direct experiment, p_2 is brought to 8″. But, it will be seen still more precisely in the following §, that the determination of the degree of Pr possesses only a subordinate value, on the one hand, because the commencement of Pr is conventional, on the other, because the accommodation complicates the condition, and this, as well as the accuracy of vision, influences the practical application: we should, therefore, take care not to attach to determination of the degree of Pr the great importance, which is connected with that of the degree of M and of H.

Thus far we have treated exlusively of the Pr of the emmetropic eye. But the hypermetropic and the myopic eye are also subject to the same. The first must be called presbyopic, so soon as in the use of glasses, which neutralise the H, p_2 lies farther from the eye than 8″. As to myopics, we hold to the definition given of Pr, and therefore let this first commence, when the distance of p_2 amounts to more than 8″. Hence it follows that it is only to the slight degrees of M, that Pr in the ordinary sense of the word, can belong. . . . To this we must add, that in the slight degrees of M it occurs much later than in the emmetropic eye. Herein the myopic finds a compensation for what he loses, with reference to the vision of remote objects. The advantage is not small. Up to the sixtieth or even the seventieth year of our age, not to need spectacles, in order to see accurately whatever comes immedately under our eyes, is a great privilege. This privilege belongs to a M of from 1/10 to 1/14, in which degree the eye is not threatened with any special dangers. With slighter degrees of M a good deal of this privilege is still enjoyed. This is a condition which may well be envied by emmetropic eyes. I never found a normal eye which participated in the same advantage. Many persons, however, suppose that they are so highly privileged. Almost daily it occurs that at fifty-five years of age the distance of p_2 lies at only from 8″ to 10″, and spectacles are not yet thought of. Such people consider themselves a lucky exception. They are extremely proud of their sharp sight. The inquiry whether they are near-sighted is answered in the negative with a smile of self-complacency. At a distance of twenty feet hang Snellen's letter-tests: XX and XXX they do not recognise, XL not at all or scarcely; L and LX are the first which are easily recognisable to them. Not until they try glasses of — 1/50 or — 1/36 do they well distinguish XX, or at least XXX, with accurate contours. Reluctantly they acknowledge themselves beaten. They are consequently somewhat myopic! It is true they had always attached a wholly different meaning to the idea of M. For the oculist it is, however, important to have proved the existence of this slight degree of M. He learns from it to recognise the unchangeable, the legitimate amount of the range of accommodation attached to each period of life, and he can sometimes also turn this knowledge to his advantage. Thus when we inquire into the hereditary nature of M, its existence in the parents is often denied, yet almost in the same breath it is added, as a proof of their excellent sight, that up to their fiftieth year, nay even longer, they still read and wrote in the evening without spectacles, and—we know what inference is to be drawn. If, on the other hand, a person comes to us, who in order to continue his close work, in his thirty-fifth or fortieth year evidently has need of positive spectacles, we shall almost always find, that a slight degree of H lurks in him. If its degree were somewhat greater, the difficulty would have earlier manifested itself more distinctly, under the character of asthenopia.

The more I investigate the subject, the more fully I am convinced, that at a given time of life the range of accommodation is an almost law-determined quantity. If there are no favourable exceptions, the unfavourable are connected with definite defects, the commencement of cataract or glaucoma simplex, exhausting diseases, and paresis of accommodation. Of this we shall treat from a clinical point of view, in the following Section.

. . . .

§ 18. *Treatment of Presbyopia*

. . . .

Presbyopia announces itself. Seldom do we hear at the same time that work fatigues. The complaint is rather that vision is not accurate: the letters *n* and *u* are not easily distinguished; the numbers 3, 5, and 8 are confounded; a stroke is seen double, a point sometimes multiple, etc.

. . . .

Inconvenience would have arisen even earlier, if the diminution of accommodation had not been accompanied with diminution of the diameter of the pupil. Thus also the small pupil of the old man makes the loss of the power of accommodation lighter to him: to this he is indebted for the fact that, even at distances for which he is not accurately accommodated, he still distinguishes tolerably well. In full daylight, in the open air, a person can often, even in advanced presbyopia, read ordinary type, and this always succeeds on looking through a small opening.

. . . .

The fact is significant, because hence it follows that in commencing presbyopia convex glasses are usefull less by correcting the accommodation, than by increasing the sharpness of the retinal images. The eye already puts its accommodation rather strongly upon the stretch (still more powerful tension has no proportionate effect) without any hinderance or fatigue whatever. Aided by weak glasses, the eye continues the tension almost in the same manner. The result is therefore, that the eye now sees more accurately: the letters become black, confusion ceases, and the person rejoices in a distinctness of vision, of which he had almost lost the idea.

The correction, by means of positive glasses, in the commencement of the effort, of diminished accuracy of vision of near objects, is the characteristic mark of presbyopia

From this, it may be stated in one word, the vision of hypermetropics is evidently distinguished. These obtain perfect accuracy of sight, but only at the cost of so great a tension as they are not able to maintain, and therefore they obtain it only for a short time; weariness of accom-

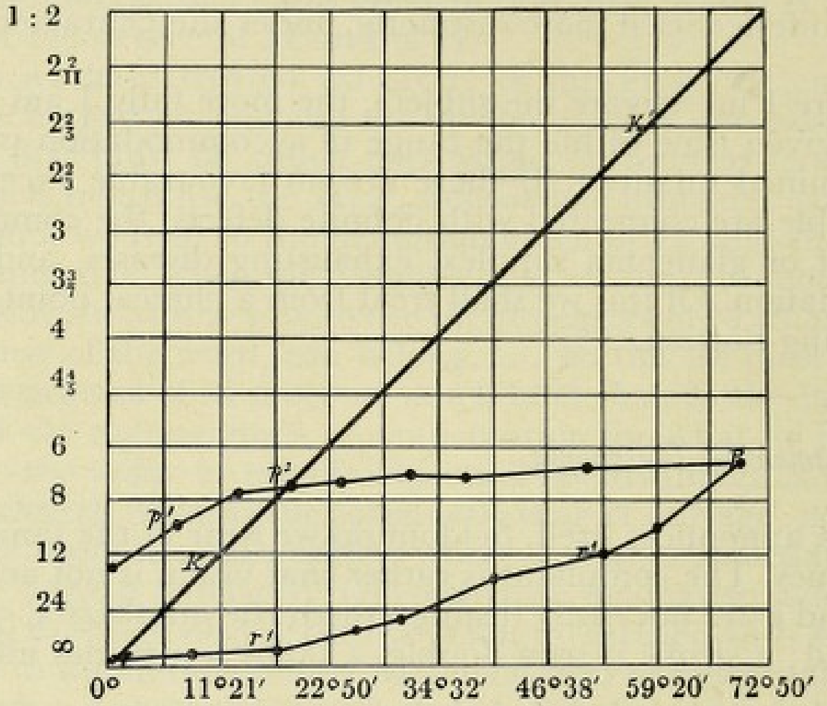

Fig. 32.

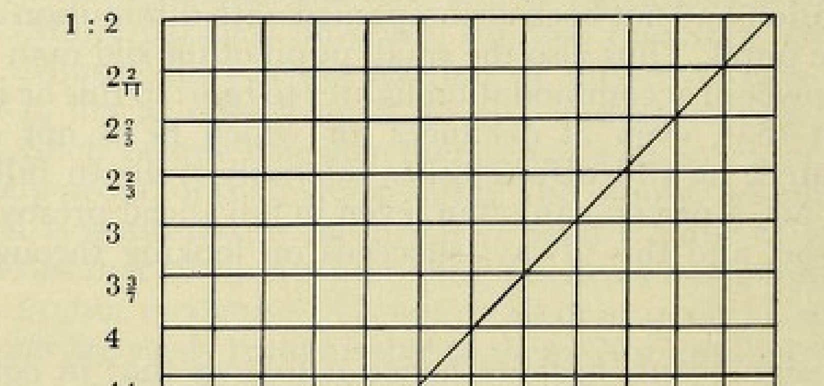

Fig. 33.

modation (asthenopia) ensues. In the hypermetropic individual convex glasses aid the accommodation, in the presbyopic they at first rather increase the sharpness of the retinal images.

So soon as, by diminution of accommodation, in ordinary work the required accuracy of vision begins to fail, there is need of convex glasses. The test is, that with weak glasses of from 1/80 *to* 1/40, *at the same distance as without glasses, the accuracy of vision is manifestly improved.*

The opinion is rather general that we should refrain as long as possible from the use of convex glasses. . . . We have here to do with a prejudice which perhaps finds some support in vanity. It is asserted: practice of accommodation is desirable. . . . But we forget that we were obliged to practise more and more, as years have rolled on. . . . The annexed figures 32 of a man of thirty-four (Dr. Doyer), and 33 of a man of forty-four (myself), . . . demonstrate this most evidently. And is it not *à priori* to be considered absurd, at nearly fifty years of age, to commence a more powerful gymnastic system than youth was ever called to?

Strangely enough! people have fallen also into the opposite fault. Some have thought, by the early use of spectacles to be able to preserve their power of vision: they have recommended and employed 'conservative spectacles'. If I am not mistaken, self-interest had something to do with this recommendation. . . . Light blue spectacles also, which have been sometimes recommended as 'conservative spectacles', are, under ordinary circumstances, objectionable for a healthy visual organ.

. . . .

Easy as it is to decide whether a necessity exists for the employment of convex glasses, so difficult is it to establish rules for ascertaining the degree of convexity required. This must, however, be tried here. It is well known, that at first, while as yet scarcely any disturbance has manifested itself, glasses of about 1/60 are usually sufficient, and also that, in proportion as the time of life advances and the range of accommodation diminishes, stronger and stronger glasses are required. It was therefore natural to arrange convex glasses according to the time of life at which they become necessary. This old custom has been ridiculed, and in some degree with justice. It is true that eyes differ too much, to make age alone the criterion in the choice of spectacles. But, on the other hand, the regular diminution of the range of accommodation, already pointed out shows, that, in the case of emmetropic eyes, the time of life may in general be taken as a guide. Only, the many circumstances which modify the indication furnished by the time of life, are not to be neglected. Besides ametropia, which occupies the first place, diminished acuteness of vision is to be noted, while, moreover, the nature of the work to be performed has some influence. . . . But, in order to fulfil a practical object, we shall premise the empirical result: what glasses are required at different ages in emmetropia, with normal acuteness of vision and accommodation, for writing, and for reading ordinary type.

a	Glasses required		*d*	*e*	
Age	*b* In present E	*c* In original E	Distance of distinct vision	R_2	P_2
48	1/60	1/60	14″	60″	10″
50	1/40	1/40	14″	40″	12″
55	1/30	1/28	14″	30″	12″
58	1/22	1/20	13″	22″	12″
60	1/18	1/16	13″	18″	12″
62	1/14	1/12	13″	14″	12″
65	1/13	1/10	12″	13″	11″
70	1/10	1/7·5	10″	10″	10″
75	1/9	1/6·5	9″	9″	9″
78	1/8	1/3·5	8″	8″	8″
80	1/7	1/4·5	7″	7″	7″

This table needs, perhaps, some explanation. Column *b* gives the glasses required for E, proved at the moment; *c* for E in youth, and therefore for H acquisita at the time of observation; in both cases the diminished acuteness of vision belonging to the time of life is taken into account; *d* indicates the distance which is preferred for vision with these glasses; *e*, finally, the space through which they admit of acute vision, that is, from R_2 with the least, to P_2 with the greatest convergence

$$\left(\frac{1}{A_2} = \frac{1}{P_2} - \frac{1}{R_2}\right).$$

In general it should be observed, that it is desirable to ascend but slowly with the numbers, to use the first spectacles in the beginning, only in the evening, and to keep these for day spectacles, so soon as stronger glasses are required for the evening. . . . finally, that, while stronger glasses are necessary for reading, the weaker are often sufficient for writing, and are to be preferred, since the person wearing them, being enabled to see at a greater distance, can avoid the bent position, which is so injurious to the eyes.

The above table holds good for emmetropic individuals. If ametropia be present, it must be taken into account. Therefore always, without exception, we should begin by determining the refraction, and at the same time S, according to the method described above. With sufficient practice, this requires only a couple of minutes. The result obtained supplies the preliminary indication, which must then always be subjected to the control test. If the eye be emmetropic, the control is effected with the glasses mentioned in column *b*; we ascertain, at what distance 2 and 2 1/2 are easily and by preference read, and we determine the space of 1 : A_2 by causing the patient to read 1 or 1 1/2 as close as possible, and larger type as far as possible. If we now obtain about the results to be found under *d* and *e* of the table, the glasses will usually answer. If the distance be too short, the margin for distinct vision too small and brought too near the eye, we must try weaker, and in the opposite case, somewhat stronger glasses.

. . . .

It will be easily understood that the rule here given for hypermetropic individuals, is applicable only to older hypermetropics, that is to those who, when the H is neutralised, are presbyopic.

. . . .

How far Pr is compatible with M, we have seen above

. . . .

Generally speaking, I have found that myopics require convex glasses at a still later period than the degree of M should have led me to expect.

. . . .

The reason is, that, on the one hand, in persons looked upon as emmetropic, a trace of latent H easily occurs, while, on the other, the limited distance (for example, 20 feet, representing 1/240), at which the determination of M takes place, may make it appear somewhat too slight.

We have now to estimate the circumstances, which, both in ametropic and in emmetropic persons, may modify the degree of the glasses required. As such we mentioned

a. A range of accommodation not corresponding to the time of life. Those who are occupied almost the whole day in reading, writing, or other close work, usually accompany their demand for spectacles with the observation that their eyes have certainly suffered much, but that they have also exacted a great deal from them. I hasten to set such people right. Comparative observation has shown me that much close work does not essentially injure the eyes, at least those which are emmetropic, and that the range of accommodation diminishes scarcely, if at all, more rapidly under such circumstances, than it does in agriculturists, sailors, and others, who for the most part look to distant objects. It is true that eyes predisposed to M, are, by much reading and writing, easily rendered more myopic, but these occupations have no influence on the range of accommodation. The same is true of the frequent use of the microscope, or of a magnifying glass, as is required in the work of engravers and watchmakers: the regular course of 1 : A is maintained despite of much or little tension. But there are morbid conditions which cause the range of accommodation, and sometimes also the amount of refraction, to diminish more rapidly than usual. In the first place, general debility, the result of exhausting diseases, is to be noted. Premature old age, in general also deserves to be mentioned. Of the influence of glaumoca I have already spoken. If a person has quickly and repeatedly to strengthen his glasses, we should suspect the existence of glaucoma simplex, and accurately examine the tension of the eyeball and other points connected with this affection. The commencement of cataract also appears to hasten presbyopia, probably through more rapid hardening of the crystalline lens. . . . Emmetropic persons are then apt to complain that they can no longer accurately distinguish near objects, which is to be attributed partly to diminished S, partly to more rapidly lessening 1 : A, and they seek the aid of spectacles. The morbid condition, which especially interferes prematurely with the vision of near objects, is paresis and paralysis of accommodation. This is not the place to enlarge upon this subject, the last chapter of this work shall be devoted to it. Let it at present suffice to observe, that ordinary paralysis may occur at any time of life, but more particularly in youth, that it usually sets in suddenly, and that it is further characterised by a tolerably wide, immovable, or scarcely movable pupil: it is, therefore, hardly conceivable that it could be confounded with true presbyopia.

Now where, from whatever cause, 1 : A is abnormally diminished, stronger glasses are required than where 1 : A is normal.

. . . .

It is another question, whether these may be used. To this we can in general only answer, that the sole difficulty is when the morbid condition is such as to prevent tension of vision. In incipient senile cataract there is usually no difficulty; in paresis of accommodation, tension of accommodation is, when the acute period is past, even desirable, and this is very much promoted by glasses, whereby the distance of distinct vision remains somewhat greater than the patient would wish; but in threatening glaucoma, prudence requires us to avoid tension of the eyes, and we are therefore recommended not to permit, unless exceptionally, the use of spectacles with which the patient can read or work at near objects.

b. Diminished acuteness of vision. — The distance of distinct vision at different periods of life, estimated to be necessary, and therefore to be obtained by means of convex glasses, is in close connexion with S. Consequently with the increase of years, to which diminution of S is related, we find this distance lessen. Where *morbidly* diminished S is concerned, we can take this also into account in the determination of the glasses: we can cause the retinal images to become greater about in the same proportion as the acuteness of vision diminishes. This is to be attained simply by means of stronger glasses. Not only do these bring the distance of distinct vision nearer to the eye, but they also make the angle, under which the object is seen, increase in a still greater ratio than the distance diminishes (compare p. 61). They can thus render ordinary close work still possible with diminished S. The question however, is: may this means be employed? We must admit that its application is liable to great restrictions. In the first place, in acute diseases of the eye, with diminished S, all tension is injurious, and the eyes may, in the hope of improvement, be allowed to rest. And, as to chronic diseases and defects, even in these diminished S cannot unconditionally be compensated by stronger glasses. In general it is to be considered that the limits, within which compensation is possible, are rapidly attained through too great proximity.

. . . .

Moreover the bent position acts injuriously, which, if the distance of distinct vision is very short, cannot well be avoided.

. . . .

All this, finally, renders the cases rather rare, in which the annoyance of diminished S can be met by the use of stronger glasses. . . . It is connected with the least inconvenience in chronic opacity of the cornea, in uncomplicated incipient cataract, in congenital amblyopia from unknown causes, and finally in disproportionately rapidly diminishing acuteness of vision in advanced years—senile amblyopia. We should, under these circumstances, recommend the use of large type, and in general, occupation with coarser work; but if fine work cannot be avoided, the glasses required should be strengthened so far, that the desirable degree of distinct vision should, without too much effort, be obtained. That we must sometimes at a very short distance, for the sake of binocular vision, have to contend with the difficulties of convergence, will immediately more fully appear.

c. The nature of the work to be performed. Two points are here to be distinguished. In the first place, the minuteness of the objects, which renders it necessary that the work should be performed close to the eye, and therefore with relatively stronger glasses. For some work even the young normal eye is insufficient. Minute drawing, engraving, watch-making, and some anatomical operations, require the constant use of the magnifying glass. In other work the eye must at least, with normal S, be still accommodated for the distance of from 4″ to 6″. Hence convex glasses are even early necessary to render permanent accommodation for that distance possible. But, apart from its minuteness, the nature of the work sometimes requires a definite distance: in writing in large registers, in reading in the pulpit, in the use of certain musical instruments, it is often desirable that spectacles should bring the distance of distinct vision to one and a-half or two feet, and therefore weaker glasses are necessary than are given for writing, and particularly for reading. Guided by sound principles, we very soon find practically what glasses fulfil the object: an insuperable difficulty springs only from diminished S; with this, as shall herafter appear, we have to contend most in the case of M.

I have thus, I think, laid down the principal points which must guide us in the choice of spectacles for presbyopic persons. Some observations on the form of these auxiliary glasses may here not be out of place. In general, oval glasses in a frame, with wings resting on the ears, placed at a certain inclination, so that in work the axes of the glasses coincide nearly with the axes of vision, are to be preferred. The nasal portion should have such a form, that in looking at a distance, in the horizontal direction, the person wearing the spectacles should be able to look over the glasses; and if this should be attended with any difficulty, the rings might be flattened above (the pantoscopic spectacles of Smee). Some men, from habit, wish for round glasses, which we may safely allow: they are usually old, quiet men, who, when they desire to look at distant objects, simply take off their spectacles. Others are not at all content with looking, thus unaided, at distant objects over their spectacles; they prefer, as hypermetropics, wearing spectacles insufficient to read with, and they do not see accurately over their reading-glasses; or they have at the same time M and Pr, and desire with rapid alternation to read through their spectacles, and to see distant objects, whether in their office, or as teachers in a school, or in the theatre, or elsewhere. This wish may be gratified by means of glasses *à double foyer*. With these some express themselves satisfied; in the case of others, rays fall at the same time through both surfaces of curvature upon the eye, and these give them up again. I found these glasses most satisfactory for presbyopic painters, who require to look through the upper half, at a certain distance, at persons or at nature, while the lower half is to bring the distance of distinct vision on the canvass or on the paper. White Cooper states, that Sir Joshua Reynolds was much in the habit of using such glasses when painting his inimitable portraits.

The stronger the glasses are, the more attention must be paid to their mutual distance. Great accuracy is seldom required either in Pr . . . or in youthful range of accommodation. . . . Therefore, it is usually sufficient to mention to the optician only when either a particularly great or a particularly short distance of the glass-bearing rings is necessary, and in the absence of such direction to let the medium be used; in giving directions, let it be borne in mind that the less the distance for which the glasses are to be used, the closer they must be to one another. But, so soon as insufficiency of the internal or external recti muscles in binocular vision threatens to give rise to muscular asthenopia, it is of importance that the mutual distance of the glasses should not aggravate this, but should rather counteract it. Now, less convergence of the visual lines is required when convex glasses are placed nearer to one another, and concave further from one another, and *vice-versa*. If, therefore, the internal recti muscles are insufficient, we should take care that the axes of the convex glasses are closer to one another than the visual lines; in this manner we can, where strongly convex glasses are necessary, very much assist the internal muscles, and the images obtained are not perceptibly worse than those we get with a similar effect through prismatic glasses.

. . . .

Nearly always, where strongly convex glasses are required to make binocular vision possible at a short distance, it is desirable, by placing the glasses comparatively near one another, to assist the internal recti muscles of the eye. Where very short distances are concerned, the *dissecting spectacles*, constructed and recommended by Bruecke with convex prismatic glasses, come into operation.

Besides the spectacles, two kinds of *lorgnettes* are in use. Those ordinarily employed by ladies, where the glasses are at a fixed distance, are attended with no inconvenience when it is necessary to look for a short time, or to do anything for which both hands are not required, for one is occupied in holding the glass. But, for constant use, we should at the same time give a pair of spectacles. The glasses of the *lorgnette* may be somewhat stronger: during the short time they are used, no injury is experienced, and the advantage is gained of being able, when necessary, to distinguish smaller things. In the so-called nipping spectacles, used particularly by gentlemen, the distance of the glasses, determined by the thickness of the nose, is usually too short. Therefore, if the glasses are strong, the person wearing them sees with too slight convergence, unless the short distance of the rings be compensated by the axes being placed to the outside of the centre.

Reading-glasses, which magnify the visual angle, and are thus in some cases useful, give to the rays proceeding from a point a direction, as if they proceeded from a more remote point. . . . The recession of the objects increases with the increase of the distance between object and glass. So soon as the distance is equal to the focal distance of the glass, the rays proceed in a parallel direction, and the object appears to be at an infinite distance. Thus far therefore emmetropics can, provided the accommodation be totally relaxed, see through the reading-glass, and thus attain the highest degree of magnifying power; simple presbyopics, who put their accommodation little upon the stretch, always keep the glass nearly at this distance, because they soon see less accurately when the glass approaches the object. At what distance the eye is from the glass, is of little consequence: only the field of vision becomes less, in proportion as the eye removes. If the distance between the object and the reading-glass becomes greater than the focal distance of this last, the rays fall convergingly into the eye, and it is in this manner that hypermetropics, and especially hypermetropic presbyopics, make use with much advantage of a reading-glass, and by its means obtain a high magnifying power.

In the use of reading-glasses binocular vision is usually sacrificed: the one eye looks through, the other close to the reading-glass, best with nearly parallel visual lines; on account of their indistinctness the images have no disturbing influence on the second eye, and the spectator even fancies that he sees binocularly.

If no great magnifying power be desired, we can also see binocularly through one glass, for which purpose the latter must then be held closer to the object. In doing so less convergence of the visual lines, and at the same time less tension of accommodation, is required, than in looking at the same object without the intervention af a reading-glass, and the object therefore appears, according to the laws of sterescopy, to lie further off. However, even in the commencement of presbyopia, the tension of accommodation required is, in reference to the necessary convergence, quite too great, so that binocular vision through the same glass is possible only for young persons, and for older individuals, who are somewhat myopic. It is best attained, even in incipient presbyopia, when we begin by holding the glass at first near the object, and then gradually remove it. In general, however, it must be stated, that binocular vision through a reading-glass is possible to presbyopics only when they are, in addition, aided by weak convex spectacles. Consequently these glasses in general serve only for monocular vision, and they are especially to be recommended for the purpose of magnifying minute objects of art. For reading their use is seldom advisable. They come, however, under notice where diminished S renders a magnifying power necessary, which is obtainable by means of spectacles only for a short distance from the eye. For the special purpose of reading, broad glasses, ground above and below, are the most suitable, and in particular bicylindrical convex glasses, with intersecting axes, deserve to be recommended: the dioptric action of these glasses (compare *Astigmatism*) is nearly equal to that of spherical glasses; but they are distinguished by the fact that they have the greatest field of distinct vision in the direction perpendicular to the axis of the surface turned towards the eye, so that by turning the surface with vertical axis towards the eye, we possess in reading the advantage of having a good image over an extensive field in the horizontal direction.

. . . .

In using optical instruments with one eye, we generally lay it down as a rule, that in order to avoid injuring the organ, it must be relaxed to its farthest point. I have for many years kept this in view in employing the microscope and in the use of magnifying glasses. However, the idea of the proximity of the object easily produces a slight convergence; and if I have, avoiding all tension of accommodation, continued this for some time, I experience difficulty, on discontinuing it, in accommodating for the point of convergence: this difficulty continues longer, the longer I had, at a certain convergence, relaxed my power of accommodation as much as possible. I cannot, therefore, recommend to the emmetropic to totally relax his accommodation in using the microscope, the less so, because by doing this, he will soon find difficulty in applying, in measuring, the method *à double vue*, which in so many respects commends itself to our adoption.

Essential injuries to sight, which are often, with so much exaggeration, predicted, I have never seen arise, even from an undue use of convex glasses. On the contrary, as will appear in the Chapter on M, an inconsiderate use of concave glasses may be very dangerous.

Note to § 18

I have thought it well to exemplify the application of the precepts I have laid down respecting the use of convex glasses, by some cases taken from life. The reader will excuse me if this, for him, is quite superfluous.

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4. *Commencement of presbyopia, with myopia.* Prof. S., aged 56, cannot sufficiently praise the excellence of his sight. 'I see admirably at a distance, read, write, and draw without difficulty, even in the evening'. 'Go on', is my answer. Prof. S., aged 62: 'I still usually see very well, but the work is sometimes difficult to me in the evening. Should I also need spectacles?' He reads 1 1/2 by preference at 14″, deciphers it still at 18″, and therefore has S=about 1·5/1·5; on the contrary, without spectacles, only 16/30, and with — 1/40, to his amazement, 18/20. 'Was I then really myopic?' Het gets 1/60, with a recommendation to use them in the evening. 'These glasses magnify, and at a moderate distance, for example 2′, I see by no means so well with as without glasses.' I answer: 'That is unavoidable, at 60 years of age we can with glasses in the world see both distant and near objects, but set the spectacles somewhat lower, so that at pleasure you can see over them, or use rings flattened above'.

5. *Slight H, requiring convex glasses before the usual age.* Madame v.L complains: 'I have done much work, and spoiled my eyes; I am only 36 years of age, and I can no longer see anything in the evening.' 'Not read?' 'O yes, but I can do no fine work, and reading also tires me; I get terrible neuralgic headach, for which my doctor, and also Dr. K., the homœopath, have given me all sorts of things in vain.' She has S=20/20, with 1/36 more easily still S =20/20, and therefore Hm=1/36. She will derive benefit from glasses of 1/36. 'Must I then use spectacles?' 'It is desirable, indeed necessary, even by day, particularly if you wish to be free from your nervous headach. Besides, by the proper use of spectacles, when you are alone, you avoid fatigue, and you will now and then be able in company to work at intervals without glasses'. 'Is it not the case that I have spoiled my eyes?' 'Not in the least; the form of your eye is the original cause of your requiring spectacles at a comparatively eaıly age. Perhaps other instances of the same are to be met with in your family?' 'It is possible, but I had always such good eyes, and can see so far. Can I do nothing to strengthen them?' 'Often rest is the chief thing. Cool them now and then. Rub, if you choose, a little eau de Cologne over the eyebrows, but put nothing into the eyes, and depend upon it, the spectacles will cure your nervous headache'.

Pr, with M; reading at more than the usual distance. Madame U., aged 65, can in clear daylight still easily read good print. M is suspected and found =1/32, S=18/20. She has spectacles of 1/24, but these tire her, and the letters are not black. R_2 is at the same time=13″, P_2 not much less. Somewhat surprised at her statement, I request her to hold the book in her usual way. She lays if flat on the table, holds herself quite straight on her chair, and is thus at a distance of nearly 16″. Evidently für such use the spectacles were too strong; she required 1/36, which gave her a space of from 17″ to 15″. For very small type she would do well to use the stronger glasses. 'I never read small print', was her answer.

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CHAPTER VI

Hypermetropia. H.

§ 19. *Dioptric Definition of the different Degrees and Forms of Hypermetropia* The refracting system of the emmetropic eye has, as we have seen, in the state of rest of accommodation, its focus on the layer of rods and bulbs of the retina. . . . The farthest point of distinct vision *r* therefore lies at an infinite distance, that is, at the limit of our necessities.

From this ideal state the eye may deviate in two respects and become *ametropic*. The focus of the dioptric system may be situated *in front of*, or *behind* the layer of rods and bulbs. In the first case the eye is *myopic*, in the latter it is *hypermetropic*.

Myopia is a condition which has been long observed, and has been much studied. Hypermetropia, generally as it occurs, was, on the contrary, until quite recently (though mentioned by Ware), almost entirely overlooked, at least its nature and its results were not recognised. But once discovered and understood, it speedily revealed all its mysteries, and gave us the key to a number of phenomena, whose origin had, until then, continued enigmatical: thus the source of asthenopia and of strabismus convergens was found in this anomaly. We have, in the first place, here to treat of it in this section, particularly from the dioptric point of view. From this point of view the definition of H was given. . . . Parallel rays unite not on the retina, but behind the retina. In order to unite in the retina, the rays falling upon the cornea must already have a converging direction. . . . The point which has its image on the retina, is therefore not a true point, but an ideal or virtual point, situated behind the retina. Such points we do not see in nature. From each point of an object the rays always proceed in a diverging, or at most in a parallel direction (. . .) *never* in a converging direction. The eye therefore has no need to be able to adapt itself for converging rays. All requirements are fulfilled, when it can bring tolerable diverging rays to a focus on the retina, and at the same time can relax itself to accommodation for parallel rays. If it can go farther then this, it oversteps the measure, and is hypermetropic. It possesses something useless, and has thereby lost on the other side in what is useful. In order to see remote objects, it must be actively accommodated; and in bringing to a focus it yields, for equal range of accommodation, to the emmetropic eye.

The degree of H is easily expressed. It is equal to the quantity, by which the relaxation of the eye can overstep the measure, and this is found in the strongest positive glass, with which infinitely remote objects can be accurately seen. If this glass amounts to 1/20, 1/10, 1/8, H is also 1/20, 1/10, 1/8, or, more exactly still, 1/19, 1/9, 1/7, since the glass was removed 1″ from the nodal point.

H may be divided into *acquired* and *original*. Of the acquired we have spoken so far (§ 17) as it is developed by the senile changes, in the emmetropic eye. As in the latter, it begins after the 50th year, the original hypermetropia must also, after that period, gradually increase; but only in the same slight degree in which it occurs in the emmetropic eye. Under the head of 'acquired H', we must here provisionally include aphakia.

. . . .

Original H we divide into *manifest* Hm, and *latent* Hl. In my first investigations respecting H, I encountered the difficulty of accurately determining the degree of this anomaly. Thus an eye sometimes at first refused every glass stronger than 1/12, while it soon afterwards gave the preference to 1/8, and subsequently again chose 1/10 or even 1/14. . . . Therefore, from the strongest glasses, with which the eye had, in different trials, still seen accurately at a distance, the degree of H was deduced. . . . But when shortly afterwards, still stronger glasses were sometimes found adapted to the same persons, I discovered my error, and comprehended that those first given had not completely neutralised the H, but that in using them the accommodation to a certain degree continued in operation. This led me to inquire, what the refractive condition of such hypermetropic eyes should be, when by the instillation of a solution of sulphate of atropia, the power of accommodation should be paralysed; and to my surprise, it appeared that not unfrequently in the trials with glasses, the greater part of the H had been suppressed. In slightly myopic, and equally in truly emmetropic eyes, on the contrary, R continues, after artificial mydriasis, nearly unaltered: the power of accommodation here becomes, when the eye is accommodated for *r*, actually almost wholly relaxed; at most only 1/40 remains. Evidently, therefore, it is a peculiarity of H, that with the act of vision tension of accommodation is associated, and thus the H is in part concealed. Hence it appeared that in H a manifest and a latent part are often to be distinguished. But it was then also to be suspected, that slight degrees of H, might be wholly suppressed, and in confirmation of this suspicion, experience showed me that where H was with some reason suspected, without being capable of immediate demonstration, a not inconsiderable degree almost always in fact appeared, on paralysing the accommodation.

The conclusion is: that H may be wholly latent, =Hl, and that, where it occurs in the manifest form, as Hm, a latent par Hl may still be supposed to exist. Therefore H=Hm+Hl, and if Hm=0, then Hl=H. Now, is it also possible that Hl=0. This is actually the case, when in advanced age the power of accommodation is wholly absent. But even already, while it diminishes, Hm must increase in reference to Hl, and experience actually shows, that even in the 40th year Hl, in reference to Hm, is very slight, and that in the 55th, it may be wholly neglected.

. . . .

At twenty years of age about one-half, at forty more than three-fourths will have become manifest, and at seventy we have to expect simple Hm, in a still higher degree (on account of the supervening diminution of refraction, as H acquisita) than H was originally present.

A further division of Hm is that into *absolute*, *relative*, and *facultative*.

. . . .

If with the most powerful tension, $\varphi_{''}$ remains behind the retina, Hm is *absolute*; if $\varphi_{''}$ can reach the retina only with convergence of the visual lines, Hm is *relative*; it is, on the contrary, *facultative*, when also with parallel visual lines $\varphi_{''}$ can be brought into the retina. The definitions give accurate boundaries. In reference to vision the distinction has, too, its important aspect, for with absolute Hm vision can never be acute; with relative only monocular vision can be so (and indeed exceptionally); with facultative, on the contrary, binocular vision may also be acute. But the distinction loses much of its importance, inasmuch as in fatigue and weakness, and also regularly with the increase of years, the facultative passes into relative, and the latter into absolute H.

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§ 20. *Form, Position, and Movements of the Hypermetropic eye. Apparent Strabismus*

In the preceding section we defined H, from the dioptric point of view. The question now is, on what anatomical deviation this refractive anomaly depends.

A great variety of circumstances may, exceptionally, in this respect, come into play. In the first place, absence of the crystalline lens (aphakia), by whatever cause produced—an important condition, to which we shall devote a separate section. Moreover, diseases of the cornea, attended with flattening, whether of the cornea at large, or of its central portion. Thus, I have sometimes found, with central ulcer of the cornea, a high degree of H, which gave way to E, or even to M, combined with irregular astigmatism, when by mydriasis the lateral parts of the cornea also came into play in direct vision.

. . . .

Finally, protrusion of the retina through firm chorioideal exudation, may give rise to some H, and by detachment of the retina it may produce even a high degree of the same, which, in that case, soon gives way to blindness.

The rule is, however, that H depends on a peculiar typical structure of the eye, which may be called the *hypermetropic structure*. The hypermetropically-formed eye is a *small eye*; in all its dimensions less than the emmetropic, but especially in that of the visual axis. Immediately around the cornea, the sclerotic has a flat, slightly-curved appearance; at the equator, on the contrary, the curvature is much greater. A section through the visual axis has the form of an ellipse, of which the

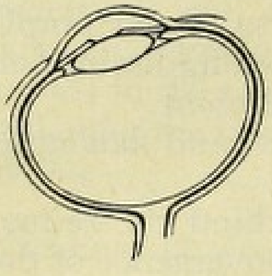

Fig. 34.

visual axis is the short axis (fig. 34) . . . The hypermetropic eye is in general an *imperfectly developed eye.* If the dimensions of all the axes are less, the expansion of the retina also is less, to which, moreover, a slighter optic nerve, and a less number of its fibres correspond. Further, the asymmetry in the several meridians (astigmatism) is, in this eye, on an average, greater than in the emmetropic. Both these circumstances explain the fact, that in high degrees of H the acuteness of vision is usually below the normal. If, in addition, the development of the cornea has been imperfect, which is comparatively rare, the hypermetropic structure passes into true microphthalmos.—The hypermetropic structure is *hereditary*: if one of the parents suffers from H, we find the same anomaly usually in one or more of the children; sometimes, too, several brothers and sisters are hypermetropic, without the anomaly being observable in either of the parents. How far the structure in question is also *congenital*, I have not inquired. According to Von Jaeger's ophthalmoscopic investigations, the eyes of most newly-born children are, on paralysis of accommodation, moderately myopic; but soon, on further developement, these lose M, and in the first years of life mostly become emmetropic.

. . . .

I have in the fifth and sixth, and sometimes even in the fourth year, demonstrated considerably degrees of H, and have never seen these disappear at a later period.

The shorter visual axis of the hypermetropically-formed eye, which is demonstrable even in life, satisfactorily explains . . . the existence of H. . . . *A priori* it might be supposed, that less convexity of the cornea and of the crystalline lens is peculiar to the hypermetropic eye. So far as the cornea is concerned, I am justified by the results of numerous accurate determinations, in denying the assertion. Even in high degrees of H, the radius is nearly equal to that in the emmetropic eye, and in the highest degrees, when the circumference of the cornea is somewhat less than usual, I found the radius even less. . . . However, it has really the appearance as if the cornea of the hypermetropic eye were less convex, which, just as in presbyopia, is to be ascribed solely to the diminished depth of the anterior chamber of the eye, and to the relative smallness of the pupil: a more anterior position of the iris and crystalline lens is part of the peculiarity of the hypermetropic structure.

Whether a flatter crystalline lens belongs to the hypermetropic structure of the eye, is quite unknown. It is true that in some eyes the lens is thicker, in others thinner; but, . . . we have no right to place this difference in connexion with H.

. . . .

I have endeavoured to measure the length of the visual axis of superficially-situated hypermetropic eyes, turned strongly inwards, and thence, in connexion with the simultaneously determined radius of the cornea and the degree of hypermetropia, to calculate the focal distance of the lens. But the measurement of the visual axis appeared to be not sufficiently accurate.

Now, in the absence of decisive determinations, we assume that the cardinal points of the dioptric system in the hypermetropic eye have the same position as in the emmetropic. That the crystalline lens in the hypermetropic eye is placed somewhat more anteriorly, we leave out of account. . . . Now, the position of the cardinal points being the same, we can apply those of the reduced eye, in order to calculate what degrees of H are connected with a given diminution in length of the visual axis. Thus we find:

With a diminution in length of 0·5 mm., H = 1 : 21·43.
,, ,, 1 mm., H = 1 : 10·34.
,, ,, 1·5 mm., H = 1 : 6·649.
,, ,, 2 mm., H = 1 : 4·302.
,, ,, 3 mm., H = 1 : 2.955.

. . . .

Our judgment respecting the position of the eyes is determined by the direction of the axes of the cornea, and these are, with a parallel position of the visual lines, in hypermetropics more diverging than in emmetropics; in myopics on the contrary they are less diverging or even converging. If we consider that between the angle of the axes of the cornea, with parallel visual lines, in the most extreme cases of M and H, a difference of 25° may exist, we shall conceive that this angle is very characteristic of the physiognomy of myopics and hypermetropics, and may indeed suggest the idea of strabismus. We shall hereafter see what an important part apparent strabismus plays in the production of the true, how the apparent diverging promotes the development of true converging strabismus, and *vice versa*; and the importance of the angle α will thus become still more evident. Here it remains only to treat of the question, on what the different values of this angle depend. Fig. 35 distinctly shows, that in the first place the position of the yellow spot l in reference to the axis of the cornea determines this angle. But in the second place, the distance $k\ g$, from the nodal point to the retina, is to be taken into account. It is evident that, in the hypermetropic eye, where this distance is particularly short, . . . the angle α, becomes greater. In this, therefore, really lies in part the cause of the greater value of α in hypermetropic eyes; but for the most part this greater value must still be explained by the more external position of the yellow spot. This position is connected with the arrested development,

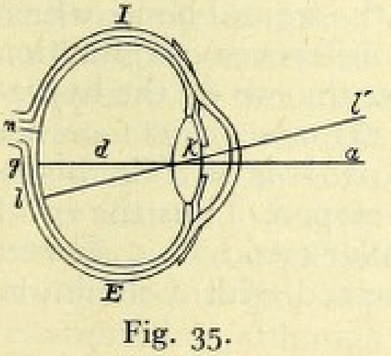

Fig. 35.

especially of the external portion of the hypermetropic eye. It is, on the other hand, as shall further appear, precisely the extraordinary development and morbid distention of the outer parts in myopics, which make the yellow spot in them approach the axis of the cornea, and sometimes even to pass it.

§ 21. *Phenomena. Diagnosis. The Vision of Hypermetropes*

The diagnosis of H is attended with little difficulty. I have already laid it down as our duty, systematically to examine the refractive condition of every ophthalmic patient, and no case of H will easily escape him who does so. But before this examination has been begun, before we have even tested the power of vision, the external appearance will often have made us already suspect the presence of H. In the first place, we find an indication in the anatomical peculiarities, spoken of in the preceding section. The flat anterior surface of the sclerotic, the strong curvation of its meridians in the region of the equator, the shallow position of the iris, the relatively small pupil, the apparent diverging strabismus, all these give a peculiar physiognomy to the eye. But there is still more. In the form of the face, too, the existence of H is not unfrequently expressed. If I am not mistaken, the peculiarity which here prevails, depends chiefly on the shallowness of the orbit. The margins of the sockets are flatter, less curved, the whole face is flattened, with little relief; there is little rounding in the cheeks, because the anterior surface of the face quickly passes into the lateral flatness. Often, too, the nose is but slightly prominent, and the upper part of is dorsum is so little marked that it can scarcely give support to ordinary spectacles. The eyelids are flat and broad, the eyes are far from one another; the same is true of the orbits, at least of their outer margins, whose mutual distance is easily measured. Otherwise, so far as the position of the hypermetropic eyes is concerned, it is sometimes very deep, sometimes superficial, so that nothing is to be inferred from it.

It must be observed, however, that the form here described is far from being constant. But that a connexion does exist between the refraction of the eye and the form of the face, appears most distinctly from the asymmetry of the bones of the latter, including the frontal bone, which almost without exception accompanies a great difference of refraction in the two eyes. In general, we find in such cases the eye on the hypermetropic side placed farther from the root of the nose, and together with the whole side of the face sloping backward. It is as if the bones of the face on this side are in general less developed. Thus the orbit also is less deep, and to this corresponds a smaller eye, with a shorter axis of vision, which again in its turn is connected with a shallower socket. . . .

If we find the physiognomy here described in a young person, who presents himself as a patient, without the external appearance of the eyes betraying any disease, we may with the greatest probability infer the existence of hypermetropia. To the question: 'Can you continue to work long?' we obtain almost without exception a negative answer. This rapidly supervening fatigue, the most usual phenomenon of certain degrees of H, we shall study more fully, in the following Section, under the name of *asthenopia*.

We have now in these cases, as well as in those where all indication is wanting, with the aid of glasses to ascertain more exactly the true state of things. It has already been stated that hypermetropia is perfectly characterised, when with the aid of positive glasses the vision of distant objects is acute; the strongest glasses, with which the acuteness of vision still continues perfect, show us . . . the degree of the hypermetropia. Nevertheless, even with such assistance we are still liable to error. In the first place, as has already been stated, the hypermetropia may be *latent*.

. . . .

I have found that young patients sometimes involuntarily suppress even the hypermetropia increased by the negative glass, and that they have such a fancy for the smaller forms of letters and of other objects, that they imagine that they distinguish them as well, if not better, than with the naked eye. That they are mistaken in this, is evident, but it is not always easy to prove this; for hypermetropic persons, with good accommodating power, lose very little with negative glasses, at all events very much less than myopic individuals gain by them. If the phenomena in other respects justify us in suspecting the presence of hypermetropia, but do not fully demonstrate it, we must have recourse to a mydriatic, whereby the power of accommodation is paralysed, and the hypermetropia, so far as it exists, is rendered entirely manifest. Sometimes examination with the ophthalmoscope is sufficient . . . to establish the existence of hypermetropia. In the passive condition of the eye thus examined, in fact, the power of accommodation not unfrequently becomes more relaxed. . . .

In the second place, we must be especially upon our guard, if the acuteness of vision S is very much diminished. In this case the recognition of objects depends less on the sharpness of the retinal images, . . . than on the magnitude of the images. We may imagine the retina in amblyopic persons to be a very coarse canvass, on which very small objects, even though accurately drawn, are not so well distinguished as larger objects, though bounded by less sharply-defined contours. Or we may suppose very small images to be less accurately drawn on a finer texture, whereby the advantage obtained by increased magnitude readily counterbalances the disturbance, caused by a further loss of sharpness, in like manner as the strongest eye-pieces in microscopic examination, although they render the images more diffuse, often place us in a position to recognise with greater certainty the form of the smallest visible objects, than was possible with weaker eye-pieces. We thus readily understand why amblyopic patients, even when they are not hypermetropic, often choose positive glasses: the greater size of the images is particularly serviceable to them. Where there is any doubt ophthalmoscopic examination seldom fails us. In mydriasis, too, positive glasses, on account of the now so much more rapid increase in magnitude of the circles of diffusion, will not readily be chosen, unless hypermetropia actually exists. . . . I have seen some instances of extraordinarily small pupils, which, connected with a certain degree of amblyopia, on account of the improved power of vision at a distance caused by strong positive glasses, incorrectly led the observer to infer the existence of a high degree of hypermetropia. In very rare cases, too, diseases of the cornea may lead us into error. A slight flattening . . . opposite the pupil, . . . renders the person hypermetropic, which altered refraction is removed on dilatation of the pupil. Lastly, I must caution the reader against making an examination with dirty or dull glasses. . . . If we doubt whether this influence is in operation, we should hold glasses of equal negative focal distance before the positive glasses placed in the frame, in which case the patient ought to see as well as without glasses. If care has been taken to have the glasses clean, this method is very much to be recommended, if we obtain confused answers, especially if we think the credibility of the patient is to be doubted.

As to the functions of the hypermetropic eye, we often find the acuteness of vision diminished. In the slight degrees there is in this respect seldom any difference to be observed, but in high degrees it is almost exceptional to find $S = 1$. It is evident that with glasses which neutrlise the hypermetropia, the acuteness of vision becomes greater: in fact by the use of these, the nodal point is moved forwards . . ., and the retinal images therefore become greater. Even then, however, in high degrees of H, S often remains below the normal. The cause of this diminished acuteness of vision is to be explained partly from the structure of the eye. On account of the shorter distance between the nodal point and the retina, the retinal images are smaller than in the emmetropic eye, and this will in general continue also with the use of convex glasses, unless strong glasses are required and these are held comparatively far from the eye.

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Moreover, as I have already remarked, the hypermetropic eye is, more than other eyes, liable to asymmetry. In the Chapter on Astigmatism, it will be more fully explained in what manner the acuteness of vision diminishes in consequence thereof. Here I shall remark only, that even after the correction of the astigmatism and of the hypermetropia, the acuteness of vision usually remains rather considerably below the normal. . . . The cause of this we know not. Probably an accurate microscopical examination of the yellow spot would enable us to account for it.

In addition to this diminution of the acuteness of vision depending on congenital deviation, an acquired one frequently occurs in hypermetropia. Thus when only one of the eyes is in a high degree hypermetropic, this eye is usually but little used, and this exclusion, with psychical suppression of the images, leads to amblyopia. Chiefly, however, when strabismus is developed in one eye, to which precisely in hypermetropia a special tendency exists, the acuteness of vision rapidly diminishes considerably, and indeed particularly in the region of the yellow spot. In this last case, when the eye, moreover, on closing the other, no longer fixes, no improvement of the acuteness of vision is to be expected. But if there be no strabismus, or if the deviated eye, on closing the other, still looks at least by preference directly, that is with the yellowspot, systematic practice with a strong positive glass is almost always capable of considerably improving the sight. It is then sufficient to practise the weak eye for eight or ten minutes three times a-day, while the other eye is closed, and with the aid of the glass just mentioned, in deciphering or reading a large type. A great number of cases justifies me in asserting that the practitioner will seldom find this plan to disappoint him.

What properly characterises the vision of hypermetropics, is not the diminished S, but the abnormal refractive condition, which requires excessive use of the power of accommodation. . . . The emmetropic relaxes that power as much as possible, and then sees acutely at an infinite distance. . . . On the contrary, the hypermetropic individual, in order to see at a distance, must already bring his power of accommodation into action: that is his *deficit.* Commencing with this, he has still for each convergence to add as much range of accommodation as the emmetropic person. It is true we may say, that his accommodation adapts itself to the refractive condition: he learns, forced by necessity to practise, with relatively little convergence to bring a relatively great part of his accommodation into action, and can, finally, even no longer omit the increased tension; but constantly, at each convergence, he finds himself still nearer to the maximum of the corresponding possible tension, and both his absolute and his binocular nearest point lie farther from the eye than they do in the emmetropic subject. Moreover all this holds good for the facultative hypermetropia in youth. . . . But with the advance of years, while the absolute range of accommodation diminishes, the relative, for a definite convergence, falls too short: fatigue now rapidly supervenes, and thus even in the slightest degrees of hypermetropia premature presbyopia occurs, which has more of the character of asthenopia. . . . The case is much worse in relative hypermetropia. In it, as we have seen, there may still be accommodation for parallel and even for diverging rays, but only on condition that the eyes converge to a point, situated nearer than that from which the rays proceed. Binocular vision and acute vision thereby exclude each other. With one eye, under excessive convergence, there might be acute vision; but generally speaking, no use is made thereof, and if this takes place, there is periodical, to be followed by persistent, strabismus. In very young subjects relative hypermetropia is rather unusual. . . . But at a somewhat more advanced time of life, even so early as in the twenty-fifth year, many cases of H already belong to this category. Vision is in these cases unfortunately circumstanced. Properly speaking it is never accurate either for distant or for near objects, and every effort to distinguish anything, to which is united great knitting of the brow, is rapidly followed by fatigue. Persons with such hypermetropia are always seeking the distance at which they distinguish relatively well. They hold the book now farther off, then again closer, sometimes at only two or three inches, from the eye: but even if the print is large and distinct, they quickly end by throwing the volume away. Very bright light is a great advantage to them, because with a small pupil the circles of diffusion become less. They therefore endeavour, although less generally than myopic persons, to diminish the latter by other means, for example, by narrowing the space between the eyelids. I have seen a boy of eight years, very weak and delicate, with amblyopia of the left eye, and with $H=1/7$, and very little range of accommodation of the right eye. . . . When he wished to distinguish anything, particularly in looking at a distance, he turned his head to the right, and looked with the right eye directly along the nose, which thus covered a portion of the pupil. How inconceivably happy we make such persons with proper spectacles, which are a natural complement of their eyes, I need not say. Absolute hypermetropia we scarcely ever find with the normal accommodating power of youth.

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The cases of absolute, as well as those of the higher degrees of relative H, present almost exactly the image of myopia, complicated with amblyopia, with which they are therefore confounded. Small print such hypermetropics cannot read—they appear, therefore, to be amblyopic,—and larger type they can read only when it is very close to the eye—just like myopic persons. From the latter they are distinguished by the fact, that at a greater distance they see objects comparatively as well, as near ones; and morevover by this, that with positive spectaçles they can read the same print at a greater distance than without spectacles. The enigma, why, while the eye is hypermetropic, small objects are distinguished near the eye more easily than at some distance, for example, at that of one foot, has been partly solved by Von Graefe by a simple calculation, whence it appears, that in such eyes, on the approach of the object, the retinal image increases more in magnitude than the circles of diffusion. . . . Of the correctness of this, we can easily be satisfied, by making ourselves strongly hypermetropic with negative glasses, and then, without altering the accommodation, bringing large letters at different distances before the eye. We shall thus distinguish more easily near the eye, than at the distance, for example, of one foot.

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§ 22. *Asthenopia*

A peculiar morbid condition of the eyes has long attracted the attention of ophthalmologists. The phenomena of which it is composed are highly characteristic. The eye has a perfectly normal appearance, its movements are undisturbed, the convergence of the visual lines presents no difficulty, the power of vision is usually acute,—and nevertheless in reading, writing, and other close work, especially by artificial light, or in a gloomy place, the objects, after a short time, become indistinct and confused, and a feeling of fatigue and tension comes on in, and especially above, the eyes, necessitating a suspension of work. The person so affected now often involuntarily closes his eyes, and rubs his hand over the forehead and eyelids. After some moments' rest, he once more sees distinctly, but the same phenomena are again developed more rapidly than before. The longer the rest has lasted, the longer can he now continue his work. Thus, after the rest of Sunday, he begins the new week with fresh ardour and fresh power, followed, however, by new disappointment. If he is not occupied with looking at near objects, the power of vision appears to be normal, and every unpleasant feeling is entirely absent. If, on the contrary, he endeavours, notwithstanding the inconvenience which arises, by powerful exertion to continue close work, the symptoms progressively increase: the tension above the eyes gives place to actual pain, sometimes even slight redness and a flow of tears ensue, everything is diffused before the eyes, and the patient now no longer sees at first well, even at a distance. After too long-continued tension, he is obliged to refrain for a long time from any close work. It is remarkable that pain in the eyes themselves, even after continued exertion, is of rare occurrence.

At first this condition was considered as a sort of amblyopia. It was called *hebetudo visus*, *amblyopie presbytique*, or *amblyopie par presbytie*. By degrees the cause was sought more and more in the organs of accommodation, at first in the action of the external muscles, subsequently in that of the internal muscular elements; and in the same measure was the importance of the retina thrown into the shade. Excessive tension of accommodation was looked upon as a satisfactory cause of the troublesome symptoms which, it was hoped, might be overcome by rest.

Evidently, however, when it was supposed that the origin of asthenopia was thus explained, the facts were overlooked that thousands in like manner, sometimes in a still higher degree, put their power of vision upon the stretch, without being visited by the troublesome phenomena of asthenopia or impaired vision, and that, on the other hand, these phenomena not unfrequently occur in men, nay, even in children, who had exacted but little from their power of vision.

Since the same cause does not produce in every one the same deviation, writers are accustomed to take refuge in a *peculiar predisposition*. But if the foundation of this peculiar predisposition be dark and obscure, pathogeny has gained but little from the adoption of this course. I therefore felt called upon to propose to myself the question, on what the so-called predisposition to *asthenopia* (so the condition was now more generally called) might depend, and I soon became convinced, that . . . a moderate degree of hypermetropia, is at the bottom of it. The hypermetropia is here, however, more than predisposition. The asthenopia . . . is already wholly included therein. Every hypermetropia which, with reference to the range of accommodation, has attained a certain degree, is at the same time asthenopia. If the symptoms sometimes do not manifest themselves until twenty-five years of age, or even later, this is to be ascribed merely to the fact, that previously the range of accommodation was sufficiently great, easily to overcome the existing degree of hypermetropia.

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I readily admit, that many different conditions were included under the name of hebetudo or asthenopia. When inconvenience was felt on continued exertion, this appeared to some sufficient to justify the inference that asthenopia existed. On this account different forms of irritation, congestion in myopic eyes, hyperæsthesia of the eye, with increasing pain on exertion, different affections of the retina and of the choroid, nay even the beginning of trachoma, and foreign bodies in the sac of the conjunctiva, might all be united under one denomination. But I cannot concur in the adoption of such a primitive semeiotic method. . . . When I asserted that asthenopia is the result of the hypermetropic structure of the eye, I was thinking, not of a symptom, but of a portrait of disease, such as has been drawn above, and in this sense I can fully maintain my assertion. In general, if the portrait be faithfully and perfectly copied from nature, we run little risk of findmore than one condition, to which it applies.

Now that it has actually been shown, that asthenopia depends on H, it appears to be so natural a result of the latter, that the inference evidently suggested itself *à priori*.

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The diminution of the range of accommodation with the time of life explains it satisfactorily. The asthenopia gradually sets in, at first only under less favourable conditions of illumination, and extraordinary exertion or headache, subsequently on all occasions and without exception when close work is performed even for only a comparatively short time. In general the symptoms of asthenopia show themselves the earlier, the higher the degree of H is, on which they depend. I found the year of life at which the asthenopia begins to be about equal to the denominator of the fraction by which the degree of H is expressed: with $H = 1/10$ we may expect the commencement of asthenopia in the tenth year, with $H = 1/25$ not until the 25th year. With $H = 1/40$ it in the fortieth year nearly coalesces with the presbyopia, and the symptoms are then less characteristic. Finally where H is absent, presbyopia is developed, as we have above seen not with the complaint of fatigue, but with that of defective vision for near objects.

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While, even at the commencement of the exertion, the presbyopic eye sees distinctly only at a greater distance, the need of spectacles, to make vision at a *shorter* distance *possible*, is evident. In the hypermetropic eye, on the contrary, there may at first be very acute vision for near objects: the need of spectacles, which would in this case serve to make vision at *any* distance *easier*, was therefore often overlooked.

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The condition for the occurrence of asthenopia may now be still more generally formulized: it is the presence of a rather considerable, but at the same time insufficient, range of accommodation. Now in general this insufficiency is attributable to H, as has been fully explained. But it may proceed also from want of energy. This last occurs exceptionally, especially in general weakness, from loss of blood or otherwise, and in paresis. In both these conditions there is this peculiarity, that a brief but rather powerful muscular exertion is possible, but that the energy employed is almost immediately lost. We observe this in all muscles, and it is true also of those of the eye. A half-paralyzed arm is still raised with force, but it immediately falls powerless: a single almost spasmodic contraction has, as it were, exhausted the muscular power. In like manner the eye is accommodated, for a moment, to a rather near point, but relaxation forthwith ensues, and persistent tension is impossible. . . . These phenomena occur with especial rapidity and characteristically, when a slight degree of H exists, which on an energetic accommodation was hitherto still easily overcome. The same is true of paresis of accommodation, as will hereafter be explained. If in these cases the H be entirely absent, the condition is distinguished, among other things, from ordinary asthenopia, by the fact that, now at least vision at a distance is possible, without tension of accommodation, and therefore persistently. In H this is not the case. Of course, the phenomena are developed the more rapidly, the closer to the eye the objects must be seen, (. . .) but even in looking at a distance, the phenomena of asthenopia would in the hypermetropic not be absent, if there were necessity to accommodate accurately for a long time uninterruptedly for distant objects. I am convinced that the asthenopic person, who states that he experiences no trouble in ordinary life, and that he sees well at a distance, in turns relaxes his accommodation, and is only thus preserved from fatigue.

There are still other morbid states, whose symptoms have some resemblance to those of asthenopia. To these belong especially insufficiency of the internal recti muscles, which Von Graefe has studied with such excellent results. . . . This form was distinguished by Von Graefe, under the name of asthenopia muscularis, from that here described, which may be called the accommodative asthenopia.—In astigmatism too, we shall find phenomena, resembling those of asthenopia. I shall endeavour, in the proper place, to examine how far special peculiarities characterise each of these morbid forms.

An emmetropic person can easily form an idea of the vision of the hypermetropic, and of the conditions and phenomena of asthenopia, by making his own eyes hypermetropic by means of the negative glasses required for that purpose. The only condition necessary is, that he have a tolerably good accommodating power.

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It will have been evident to the reader, that the phenomena of asthenopia proceed from nothing else than from fatigue of the muscular system of accommodation. In what this fatigue consists deserves to be more closely examined.

In my investigations respecting the elasticity of muscles (1859), I have distinguished two forms of fatigue.

One form proceeds from the actual energy, produced by the muscle. The work consists in the moving of a load. The load may be the body itself or some part of the body, which is moved, or, in addition thereto, an object external to the body.

Distinguished from this is the fatigue, which is the result of the simple extension of an elastic muscle in a state of contraction. This takes place when a burden is held, without being moved, as, for example, when, with the arm bent at a right angle at the elbowjoint, the hand is loaded with a weight: the arm and the weight remain in the same place, and yet fatigue soon occurs. At the moment when the weight was placed in the hand, some actual energy was indeed required to make the arm continue in the same position: the muscles (mm. biceps et brachialis internus) had to contract more strongly, in order in the state of extension induced by the weight, to remain as short as before, and the actual energy was thus converted into a potential energy (elastic tension). Moreover, the muscular contraction gradually increases as much as the greater extensibility, accompanying the increasing fatigue of the muscles, requires. It has, in fact, been proved that, accordingly as the muscle becomes more fatigued, its extensibility increases, and this increasing extensibility gradually requires augmenting contraction, in order, . . . to keep the muscle as short as it was. This is evident from the fact, that on the unexpected removal of the load, the arm bends involuntarily, . . . the more strongly, the longer the weight has rested on the hand; and in that involuntary motion of the arm the potential energy of the extended muscle again becomes actual.

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But that energy, in its different modes, seems to be very small in comparison to the often repeated lifting of the same weight. I therefore think the fatigue proceeding from the performance of labour, must be distinguished from that arising from simple extension. According to the law of the conservation of energy, we may, in the first case, expect more metamorphosis of matter in the organism. The acceleration of the heart's action appeared to me to be the measure thereof. I found, in fact, that when a weight is held during some minutes resting on the hand of the bent arm, the pulsation of the heart is much less accelerated than when, during an equal space of time, the weight is alternately taken off by another, and with extended arm placed again upon the hand, and now by flexion raised once more to the original height. The feeling of fatigue in the muscle is, however, in the latter case not greater than in the former.

In explanation of the fatigue, which is the result of the performance of labour, we may take refuge in an accumulation of products of metamorphosis of matter in the muscular tissue, which really goes hand-in-hand with it. The fatigue, proceeding from extension, under the influence of a load not further moved, may, partly at least, have another source. . . . Probably it depends partly on an increase of the products of the metamorphosis of matter in the muscular tissue, produced not so much by an accelerated formation, as by retarded elimination. Indeed, in uninterrupted contraction the vessels are compressed and the circulation is impeded, while in motion from muscular action the latter is excited and accelerated. That accumulation of products of metamorphosis is co-operative, is admissible, because in both cases the coefficient of elasticity of the muscle decreases,—which coefficient may, I think, be connected with the presence of some products of metamorphosis in the nutritive fluid of the muscle. But this is not the place to enter more fully into this question. It is sufficient to have directed attention to the distinction to be made.

Now, to which form of fatigue does that belong, which arises from persistent accommodation for accurate vision in the hypermetropic eye?

Evidently we have here to do with persistent extension of the muscle in a state of contraction.

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This permanent contraction causes fatigue, and the fatigue, promoted by extension, increases, as was above remarked, the extensibility: in consequence of this law, the contraction must be always increasing, in order to keep the muscle equally short and to make it permanently exercise the same force in equilibrium with the resistance. Sooner or later therefore the fatigue must pass into powerlessness. A moderate contraction, such as is required in the normal eye, may be kept up without fatigue for almost an entire day. . . . This applies particularly to involuntary muscles, consisting of fibre-cells, to which (at least in mammalia) the internal muscles of the eye belong. But where hypermetropia exists, such a degree of contraction is required, that increasing fatigue, at length proceeding to complete loss of energy, cannot long be absent. Thus all the phenomena of asthenopia are readily explained. It seems to me that there is therefore no reason for resorting in addition either to the condition and the function of the retina, or to pressure of the fluids, or to obstruction to the circulation.

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What are the results of continued excessive tension of accommodation in asthenopia?

In former years, especially, the most fearful consequences were predicted from it. Asthenopia was considered to be the first stage of, or at least to be intimately related to, amblyopia, and the latter, it was supposed, threatened the destruction of the asthenopic eye, if it was not condemned to almost absolute rest. Precisely the mode of treatment of oculists, in giving asthenopics no spectacles or insufficient spectacles, has placed me fairly in a position to satisfy myself of the unfounded nature of their fears. I have seen hundreds of asthenopic patients, who from youth up to their 30th or 40th year, some to an advanced period of life, had every day anew, without spectacles, or with too weak spectacles, obstinately pushed the tension of accommodation to the uttermost, and I have never seen a diminution of the acuteness of vision arise from such a course. It appears also, that in H a certain immunity against many kinds of diseases, which threaten the power of vision, actually exists; it is certain, that by excessive tension of accommodation the retina is not brought into danger.—In rare cases, perhaps in one in a thousand, I have observed that on every effort to see near objects, almost immediately violent pain arose in the eye, evidently connected with the contraction of the muscles of accommodation. This painful spasm made it necessary for the patient directly to refrain from work. Nor did the use of spectacles avail him, for in each case near objects were seen with convergence, and the tension of accommodation connected with this convergence, was sufficient to excite the pains. These remarkable cases, the cure of which was obtained by the regular instillation of sulphate of atropia, which completely excluded the accommodation, while strong glasses meanwhile rendered work possible, I shall have to describe more fully in speaking of the anomalies of accommodation.

An evident proof, that neither the nature nor the causes of the phenomena of asthenopia had been fully ascertained, notwithstanding many endeavours to investigate them, is to be found in the host of names by which this condition has been designated by different writers. They are almost innumerable: *debilitas visus* of Taylor, *amblyopia a topica retinæ atonia* of Plenck, *affaiblissement de la vue* of Wenzel, *Gesichtsschwäche* or *hebetudo visus* of Jüngken, *dulness of sight* of Stevenson, *debollezza di vista per stanchezza di nervi* of Scarpa, *dimness of vision* of Middlemore, *visus evanides* of Walther, *impaired vision* of Tyrrel, *amaurosis muscularis* of J. J. Adams; *affection of the retina from excessive employment* of Lawrence, *lassitudo ocularis* or *disposition à la fatigue des yeux* of Bonnet, *kopiopie* or *ophthalmokopie* of Pétrequin, *Schwäche der Augen* of Chelius, *amblyopie par presbytie ou presbytique* of Sichel, *languor oculi* of Arlt, *slowly adjusting sight* of Smee, *impaired vision from overwork* of Cooper, and perhaps many others still.

. . . It is evident that in a condition such as this, constituting a part of the floating idea of weaknes of vision, occurring with many complications, and presenting numerous varieties, according to the time of life and the use made of the eyes, there was great difficulty in sketching a typical picture, so lang os the cause of the leading feature of the affection, and therefore its nature, were unknown.

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Scarpa (1816) sees in the affection fatigue of the nerves, especially of those which have direct reference to vision; . . . . Without determining the nature of the affection, Lawrence (1841) states, that this is to be sought in the retina, perhaps primarily in the chorioidea, but still he clearly shows that, while the acuteness of vision is perfect, it has been incorrectly classed together with amblyopia, and Tyrrel endeavours, rather by number than by force of arguments, to prove that a preceding congestion of the chorioidea is the primary cause of asthenopia, which congestion might even pass into chorioiditis.

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It is by Bonnet (1841), and particularly by Pétrequin (1841 and 1842), that we first find the retina excluded, and the primary cause of asthenopia sought in the muscular organs of the eye, especially in those of accommodation. The external muscles were by them put most prominently forward, and being too much preoccupied with the idea of tenotomy, in order to cure the asthenopia, they thought more of an injurious pressure of the muscles than of fatigue. Mackenzie thought he had observed, that myopics also are subject to asthenopia, and that convex glasses do not protect the wearer against attacks of that affection.

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It hence appeared perfectly logical, not to seek the seat of the affection simply in the accommodation. The observation, was however, incorrect. The difficulties which myopics sometimes experience, represent another form of disease, and moreover we have reason to believe that Mackenzie has incorrectly supposed the existence of myopia in some of his patients. As to the attacks during the use of convex glasses, we shall see that Mackenzie was too timid to give glasses of sufficient strength, and asthenopia is, of course, not to be removed by the use of too weak glasses, and lastly, asthenopics really see, when they are tired, comparatively well and easily through a small opening.

From this time we find fatigue of accommodation mentioned by different writers, as at least a coöperative cause of asthenopia. Sichel (1848) had not yet a just idea of accommodation, but he had nevertheless arrived at the conviction that his *amaurose presbytique*, which he indentified with asthenopia, occurred only in presbyopic eyes, and this point he correctly maintains against Mackenzie. But, on the other hand, he keeps up the connexion with amblyopia, and still thinks that this affection may very easily pass into incurable amaurosis.

With good result, the implication of the retina in asthenopia was by Böhm set still further aside. He shows especially, that nerves of motion are much more liable to be affected with fatigue than nerves of sense, and he consequently seeks the primary cause of the affection in the motor nerves of the eye. It is true that Böhm's theory remains somewhat obscure and indefinite, in consequence of the part he ascribes to the external muscles of the eye, and of his not very clear ideas of near- and farsightedness; but in non-squinting asthenopics he recognises as the cause of the affection, the want of permanent power of accommodation for near objects, and with great satisfaction he mentions that he has, by means of convex glasses, delivered many asthenopic patients from their troubles. Böhm is, in truth, the first who unconditionally recommended the use of convex glasses in asthenopia. As, however, he did not hit upon the principle for the determination of the required strength of these glasses, those he prescribed were in general far too weak (1/80 to 1/40), from which, indeed, much could not be expected, and, moreover, supposing that he had to do with an anomaly of accommodation, he still adhered to the hope of being able to cure the asthenopia.

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Others have been less circumspect in the assumption of exciting causes. The majority of these observers believed the causes they assigned to be alone sufficient to produce asthenopia.

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By Carron du Villards we find asthenopia described as a *peculiar* form of disease, from which the embroiderers of Nancy were said to have particularly suffered, and soon after the same affection was found among the lacemakers of Brussels. . . . Thus the circumstance under which the existing anomaly might manifest itself by peculiar morbid phenomena, was considered to be the cause of the anomaly itself. This cannot cause surprise. Up to the 16th, the 20th, nay, even to the 25th year, the power of vision had continued normal; no complaints were made; but gradually precisely in persons who were almost incessantly occupied with close work, the continuance of the latter had become more and more difficult, and if the work was for some time suspended, improvement took place.

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At this time the source of the power of accommodation had not yet been discovered, much less had its mechanism been demonstrated. There was almost as much reason to assign the principal part in that function to the external muscles of the eye, as to the muscular system situated in the eye. This led to the supposition that asthenopia was to be sought in a spasmodic contraction of some external muscles of the eye, and there were practitioners who had the courage to cut through these muscles. This is a melancholy page in the history of operative ophthalmic surgery. It is the more sad, because thereby in general ignorance is exposed, so great, that myopia, presbyopia, and asthenopia were not even distinguished, and because, on the other hand, we find results communicated to which, to use no harder expression, we will, with Mackenzie, apply only the words of Scarpa: 'Istorie di guarigioni sorprendenti, e poco dissimili dai prodigi'.

Much may, however, be alleged in exculpation. In the first place, history shows that every discovery, and certainly also every new operation, usually leads to exaggeration. This is the result of an enthusiasm deeply rooted in human nature, and which has also its goods side. Without it truth appears to gain no victory in the domain of science. Moreover, in the operation for strabismus, improvement of the power of vision was actually obtained, and many now thought that this improvement was the result of a change of refraction. . . . Besides, it is easy to understand, that when the musculus rectus internus was cut through, stronger tension of accommodation, with convergence of the visual lines to a certain point, became possible, just as may be effected by means of a prismatic glass with the refracting angle directed inwards. In any case, we will not judge harshly of the operators of that season of rage for operating. It is enough that for a time the cause of asthenopia was sought in the external muscles of the eye, and that the results obtained on division of the latter were supposed to furnish a fresh proof of the correctness of the views of those who referred it to them.

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Von Graefe puts the question on as broad a basis as possible, by here assigning to asthenopia only a symptomatic signification. Thus he demonstrates the existence of asthenopia muscularis, proceeding from insufficiency of the musculi recti interni. Moreover, he brings asthenopia into connexion with slight degrees of presbyopia. And when he further sees asthenopia arise, 'where the nearest point is but little removed, but where still the *region of permanent accommodation* lies considerably farther from the eye than is normally the case', he seems really on the point of thinking of hypermetropia. In other respects, Von Graefe attaches more importance to the influence of the retina than I think ought to be assigned to it. Finally, he observed asthenopia in consequence of 'actual paresis of accommodation,' and in truth the description of the latter may almost completely apply to asthenopia, the result of hypermetropia.

Our knowledge had reached this point, when I (1858) discovered the cause of asthenopia in the hypermetropic structure of the eye. The supposed anomaly of accommodation then became an anomaly of refraction, the connexion of asthenopia with the circumstances under which fatigue is manifested was made most clear, the necessity of complete relief by spectacles was proven, while at the same time the hope of a radical cure of asthenopia was extinguished for ever.

§ 23. *Treatment of Hypermetropia, with Special Reference to Asthenopia*

The treatment of asthenopia has always been called 'rational'. I remember the time when this quailification was considered to be an honour, and when he who in medicine stood upon mere empirical ground, was regarded with disdain. Fortunately, a change has taken place in this respect. It has become more and more evident that, even with perfect knowledge of the nature of an anomaly, the final decision must remain with empiricism, and that, with our defective and imperfect notions, science can, with respect to therapeutics, at the most, occasionally suggest what deserves, by preference, to be submitted to investigation, and that her further duty is to endeavour to explain what has been ascertained.

Asthenopia has been looked upon as the result of an enfeebled power of accommodation. Hence its 'rational' treatment was directed against the causes of debility, and demanded, above all things, rest of accommodation. With this view, Tyrrell prescribed a systematic treatment. Now, rest was certainly most perfectly attainable by avoiding all work in which looking at near objects was necessary, and where the latter could not be wholly dispensed with, it was thought that the same object might be attained by the use of convex glasses, although, on account of the tension of accommodation connected with convergence, this plan would necessarily be less successful. This constituted the first period of treatment, in which the organs of accommodation should by rest be relieved from their morbid state. Again on rational grounds, the second period must follow—that of practice: the spectacles were gradually weakened, and close work was permitted for longer and longer intervals, though with the strict injunction to suspend the work on the occurrence of the least fatigue. Thus it was hoped that the asthenopia might be permanently overcome.

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On the supposition that the retina was in some measure implicated in the affection, Böhm and Ruete thought it 'rational' to recommend that the convex glasses should be blue. And, indeed, this might, if, as usual, the glasses allowed were too weak, on account of the greater refrangibility of the blue rays, even if the retina was not over-sensitive, be attended with some advantage. . . .

All ophthalmologists did not, however, boast so much of the excellence of their results. 'In many cases,' says Mackenzie, treating of the prognosis of asthenopia, 'it is our duty to declare the disease incurable. If the patient is a young lad, bound apprentice to a sedentary trade, and the disease, . . . not likely to yield to treatment, we may advise him to turn shopkeeper, to apply himself to country work, or to go to sea: if a female, occupied constantly in sewing, to engage in household affairs, or any other healthy, active employment. Many a poor man have I told to give up his sedentary trade, and drive a horse and cart; while to those in better circumstances, and not far advanced in life, I have recommended emigration, telling them that though they never could employ their eyes advantageously where much reading or writing was required, they might see sufficiently to follow the pastoral pursuits of an Australian colonist.'

What is the reason that, before taking so decided a step in the destination for life of a man, it has not been without prejudice investigated, what the effect would be of the constant use of stronger convex glasses? Is it prejudice, in general, against the use of the latter by young persons? Or had the old apprehension that asthenopia might lead to amblyopia found fresh support in the experience that, after the use of sufficient convex glasses, the eyes (. . .) soon act in close work still less perfectly than before? Certainly the prejudice must be deeply rooted; for there lay a very significant hint in the observation drawn by Mackenzie from life:

'A child, the subject of asthenopia, engaged in learning his lesson, complains he cannot see, and repeats the complaint so frequently, especially by candlelight, that his father or grandfather at last says, "Try my glasses". *The child now sees perfectly*, and night after night the loan of the glasses is required before his task can be finished'. And yet he adds, 'It would have been better had glasses been selected of the longest focus, which would have enabled the child to read, or, better still, he had been put to bed, and the lesson left till daylight'.

There is no doubt that Mackenzie gave far too weak glasses, and therefore he concludes with the unsatisfactory words: 'In some instances the state of asthenopia is so very easily excited, that the patient is never able to apply himself to any trade requiring the ordinary use of sight. These facts are sufficient to show the serious nature of asthenopia. It is an infirmity much more to be dreaded than many disorders of the eye which, to superficial observation, present a far more formidable appearance'.

It is a great satisfaction to be able to say that asthenopia need now no longer be an inconvenience to any one. In this we have an example, by what trifling means science sometimes obtains a triumph, blessing thousands in its results.

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In the establishment of the rules to which experience led me, I must distinguish between two series of cases: *a*, those which, with normal range of accommodation, are exclusively dependent on H; *b*, those where diminution of the range of accommodation, or want of energy, plays a more or less important part.

The great majority of the cases belong to the *first* category: hypermetropia is the cause, and, indeed, the only cause, why close vision cannot be maintained. It is self-evident that this form occurs only in youth. . . . Indeed, as I have already explained, a certain range of accommodation belongs to the conditions of asthenopia. Many announce themselves as asthenopics at from the eighteenth to the twenty-sixth year of life. . . . The majority of these are females. The cause of this appears to me to consist exclusively in the occupation. . . . Now, in most female occupations, continued close vision is undoubtedly more required than in those of males; and in certain ranks of society, where the man is almost wholly exempt from special tension of accommodation, sewing and darning in the evening, and often by bad light, fall, in addition to her household work, to the lot of the woman. In this alone, and by no means in the more frequent occurrence of H, I think we must seek the cause why the complaint of asthenopia is oftener heard from women than from men.

The first thing we have to do in asthenopia is to determine the degree of the manifest hypermetropia—in other words, to examine what is the strongest convex glass with which the vision of distant objects becomes acute. This glass is, however, seldom sufficient completely to guard against fatigue in close work. The patient may, nevertheless, be allowed to read with it at our consultation; but it is only when he can do this without any inconvenience, and when, moreover, with these glasses the binocular nearest point p_2 lies but a little farther from the eye than in the emmetropic organ at the same age, we can determine in favour of commencing their use. But we often find immediate indication to give him somewhat stronger glasses, for example, of 1/16 with Hm = 1/20; in very young persons, in whom we may expect much Hl, and, moreover, in those who are somewhat more advanced, for example, at thirty years of age, when the range of accommodation has undergone much diminution, glasses which correct only the Hm are scarcely ever sufficient. If the patient can easily return, the glasses thought suitable are given him, without any further direction than never to work without the spectacles, every half hour to interrupt his work for some minutes, to avoid excessive fatigue, and in about eight days to bring a report of how he finds him self. Almost invariably he returns with expressions of satisfaction and gratitude. He now obtains permission to use his eyes at his own discretion, and is requested to return, if he feels any inconvenience—in any case after the lapse of a year or two, when probably the Hm shall have somewhat increased, and the use of stronger spectacles shall have become advisable.

But it may also appear that the glasses were either too weak or too strong. If too weak, the asthenopia has not been entirely removed; and we now often find, . . . a rather higher degree of Hm than before; . . . —of course, we must then go up, often even above the Hm, and bring the p_2 nearly to the normal distance. If the glasses were too strong, the work had to be held too near the eye; acute vision was, indeed, thus attained, but a peculiar sensation of fatigue ensued (muscular asthenopia). This complaint, although rare, occurs sometimes, even when only the Hm has been neutralised: the explanation of this is found in the too powerful tension of accommodation,... and depening upon habit, precisely at a convergence of from 10" to 14". Under such circumstances, we must really begin with weaker glasses, and pass over to stronger ones in proportion as the extraordinary tension ceases.... I very seldom find it necessary in asthenopia to have recourse to the employment of mydriatics for the determination of H. It is only in those cases where the asthenopia justifies us in supposing the existence of H, and where, nevertheless, no Hm is observed, not even on moderate fatigue,—further, when the spectacles fixed on and modified on good principles, do not answer,—perhaps, also, when we can see the patient only once, that the employment of a mydriatic is required in the interest of the patient. But it is, however, perfectly justifiable for the sake of the more accurate study of the connexion between Hm and Hl, the more so because, during mydriasis, if necessary, close work may be very well performed with stronger spectacles. If we now know Hm and Hl, we give glasses which neutralise Hm and about 1/4 of Hl: in general they will answer the purpose either immediately, or after a few weeks.

Hitherto, as we have seen, ophthalmologists endeavoured, by the use of progressively weaker glasses to obtain a radical cure of asthenopia. With the knowledge of the cause of asthenopia this endeavour is completely reversed. We wish gradually to give stronger glasses, and therefore we investigate from time to time in our asthenopic patients, the position of the relative region of accommodation, or perhaps only the Hm, and if the latter appears to be increased, we give according to the rules laid down, other and stronger glasses. It is not until the H has almost completely given way to Hm, and the relative region of accommodation has on the whole acquired a normal position, that we have, in the use of the glasses so indicated, a decided guarantee against the return of the asthenopia, and in young persons the same glasses are now adapted for distance and for near objects. With this strengthening of the glasses laymen have sometimes made known their fears to me that at last, no spectacles should be found strong enough to accommodate their eyes. To persons in their situation this fear would certainly appear to be justified. We may,however, quite set them at ease on this point. I usually take the trouble to explain to them, that if once the deficient power of the eye shall be entirely made good, the limit for the strength of the glasses is provisionally attained, and that what the senile changes at a more advanced period of life in general demand, can still very easily be added.

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It is now an important question, whether asthenopics should also in ordinary life wear glasses for distant objects. On a superficial view there appears to be no objection to such a plan. . . . Undoubtedly, if we could make the glass an integral part of the eye, we should have no reason to hesitate. . . . But this is not the case: the glasses do not stand *in* the eye, but *before* the eye, and are sometimes not even at hand. Hence it is of great consequence, that the patient should be able to distinguish tolerably well also without glasses, and it is certain that if the hypermetropic individual accustoms himself to wear correcting spectacles, he will gradually lose the power of distinguishing without glasses. That is the unfavourable side of the question of wearing spectacles. . . . With repeated strong tension of accommodation the power of vision, as have seen, remains undisturbed in hypermetropic individuals. From the tension necessary to see distinctly without spectacles at a distance, which is each time required only as for a moment, no injurious effect is certainly to be expected. Therefore this may safely be required of the accommodation. Consequently, when H is still wholly facultative, when the persons can even say to us: 'in ordinary life, I have no inconvenience, and at a distance I see excellently',—we should not press spectacles on them to be worn constantly. At most we may say to them, that, when they have become somewhat older they will derive great advantage from the use of spectacles for distance also; they can then apply to the oculist, so soon as they observe that they no longer distinguish satisfactorily at a distance.

Last year I had the good fortune to meet an English gentleman, eminent in the scientific world. I observed that he saw with spectacles of 1/8 at 11″ distance, and concluded therefore that he was hypermetropic. 'You do not see well at a distance,' I remarked to him. 'O no!' replied the able and vigorous veteran. 'I no longer recognise the characters of minerals, as I formerly did, at a great distance, and if I wish to look at them before my feet through my spectacles, I stumble over them'. 'Go', I rejoined, 'and ask the optician for glasses of 1/30.' On the following day he wrote to me: 'I cannot tell you how grateful I am for the *new* sense you have given me. I now see the eyes of the handsome girls, and the wrinkles of the old ladies as well as when I was a young soldier.'

But it is quite another matter, when, relative or absolute H exists; then, . . . distant vision is not acute, and we need not now hesitate to assist it with glasses. The best result attainable, under such circumstances, consists in this: that the same spectacles, which are not too strong for distance, should be sufficient for ordinary close work.

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With respect to the second category of asthenopia, I have here but little to say. The cases contained in it are characterised by the fact, that the accommodation itself is disturbed or morbidly diminished, and the proper place to consider them is therefore where in the Second Part I shall have to speak of the anomalies of accommodation.

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If general weakness is exclusively the cause, recovery from the asthenopia is to be expected, if we succeed in restoring the strength. If paresis of accommodation exists, without H, the asthenopia of course gives way when the paresis is removed. In either case convex glasses are meanwhile useful. Where painful accommodation exists a special treatment is required.

What I have to say with respect to the treatment of H in general, apart from asthenopia, is included in the foregoing. As to the slightest degrees of H, which scarcely produce asthenopia, they require merely, as has been mentioned while on the subject of presbyopia, that the use of spectacles be permitted some years earlier than usual.

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For ordinary wear the glasses must completely neutralise Hm. In reading . . . frequently the same glasses are sufficient for that purpose; if they are not, we give some a little stronger, so that p_2 comes to lie within the desired distance of distinct vision. . . . Where complication with presbyopia exists, the use of two pairs of spectacles, one to wear generally, the other for close work, is indispensable. When strong glasses are necessary, the preference is to be given, among other reasons, for the more advantageous position of the principal points, to periscopic glasses, whose concave surface must be turned towards the eye.

Are we in H to hope for a radical cure? The answer must be in the negative. *A priori*, we should think, that, as the emmetropic eye may become myopic, and as myopia may be progressive, H might give place to E and even to M. In fact it appears possible that H of the as yet undeveloped eye might disappear during the year of development. But if the development have once taken place, I have never seen H give way . . .: this occurs only where there is increasing convexity from disease of the cornea. On superficial examination one may be deceived in this respect.

A gentleman, aged 54, had been obliged to use convex glasses so early as in his 36th year, and now he preferred working without spectacles. With $S = 1$ he had $M = 1/15$. Had H in this case not given way to M?, I found that his power of accommodation was completely paralysed, and that it had been so from his 36th year, and ophthalmoscopic investigation indicated progressive M. It therefore readily suggested itself that at the age of 36 the paralysis of accommodation, with $M = 1/20$ or $1/30$, had rendered convex glasses necessary, which through the progress of M had become superfluous, and indeed inapplicable. Hence it is evident that the eye, when of hypermetropic structure, has no tendency to M.

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Some cases, which I shall now in conclusion relate, will afford me the opportunity of introducing a few additional practical hints.

H does not always cause disturbance, and correction is then unnecessary.

I. An elegant lady, aged 22, is under treatment for slight granulations. At a distance her vision is acute, with negative glasses it is not so good, with 1/40 and indeed with 1/24, it is as acute as without glasses, but unpleasantly large: 'men are like giants'. There was consequently Hm=1/24, and we may probably infer Ht=1/14. Nevertheless she had experienced no kind of inconvenience. But read 'she did not much, and of work she 'did nothing'.... She had a horror of spectacles. Perhaps, being well able to comprehend this, I ought not to have predicted, that with her 30th year she would have need of them; the recommendation to call in advice, whenever she should not see near objects well, would have been sufficient. Indeed for the moment there was no indication for spectacles, which would only have produced an, as yet, undesirable displacement of the relative range of accommodation. On account of the existing H, stricter rest had to be enjoined, so long as the granulations lasted, than is otherwise necessary.

We learn to distinguish, at first sight, an ordinary case of asthenopia, the result of H.

II. Miss H., aged 19, is announced. She has a florid look, has clear eyes, without a trace of disease, blue iris, mobile pupil, not a very deep globe, flat margins to the socket, the visual axes appear to diverge. I suspect asthenopia. I make her read and bring the book to 6": reading becomes difficult; at 5" it is impossible. There is either H or diminished 1 : A. My eye falls on those about her, I see a brother with converging strabismus. This was decisive in favour of H. 'You cannot persevere with your work'. She answers: 'No'. 'On exertion you get a feeling of tension over the eyes, press upon the part with the hand, rub over the closed eyes, and then it passes off, but only for a short time?' 'Precisely', is the answer. Confidence is gained. 'You have no pain in the eyes?' 'At a distance you see well?' 'Yes'. 'After a long rest you can continue your work better?' 'Yes, yes'. With 1/18 she distinguishes well at a distance, and moving the glasses at the first moment not so well; with 1/16 not so acutely as with 1/18, with 1/24 not more acutely; between the two eyes there is little difference. Ophthalmoscopically all is well. I learn further, that for some years the inconvenience felt in working has been always increasing; that formerly when weakened by fever, she could for a time neither read nor sew; that she once tried a pair of spectacles, but was strongly cautioned against wearing them, &c., &c. She gets spectacles of 1/16 to work with, with a recommendation now and then to pause for a little, and at first not to do much in the evening. At the end of a week she has forgotten her ailment. She now works too with less trouble occasionally for a short time without spectacles, which I advise her to do, though with the recommendation to return to the use of the spectacles on the least trace, or rather before the occurrence of fatigue.

Asthenopics have sometimes a sad past, and live in a gloomy future.

III. The Rev. G. D., aged 52, looks dejected. 'My good Professor', he says, 'I come to you, for I feel that I am getting blind!' For the last twenty years he has thought that within a year he should be blind; and, singularly enough, although he still sees, he continues to look upon every year as the last! Such is the man! His life has been a struggle with his eyes. Even as a child he read with difficulty. When a student, the least exertion fatigued him, and he was compelled to learn more by hearing than by his own study. As a preacher, he has been obliged to write his sermons in a rather large hand, and still to get them off by heart. And, what was the worst part of it, he never read nor worked without the idea that he was thus hastening his blindness—interfering with the concentration of his mind upon any definite object. The same fear of blindness had restrained him from a matrimonial alliance with which he believed his happiness for life to be connected. He trusted in art. He had faith in a person he consulted in Germany; and if the optician had sometimes given him spectacles which had brought him relief, these were mercilessly taken from him again by the oculist on the first consultation, as a treacherous instrument which must, in the end, inflict upon him the total loss of his sight. At last he had in his fortieth year, got convex glasses of 1/40, and he now uses 1/20. 'Do you see with these spectacles at a distance?' was my first inquiry. 'Something better', he replied, 'but still very imperfectly'. I tried 1/10: 'Much better' was his verdict;—subsequently I gave him 1/8: 'Still better'. In a word, there was $H = 1/7$ with $S = 17/20$, and, with his slight range of accommodation, he needed glasses of 1/5·5, in order to make reading at the distance of a foot easy. He got 1/7 to wear. The man was grateful as a child. He left me as one saved from destruction.—Such victims of the prejudice against the use of convex glasses are not uncommon.

Where H exists, paralysis of accommodation may give rise to disquieting symptoms.

IV. E. K., a boy of ten years, son of Dr. K., remarks in the morning that he is not in a condition to read. His father sees that the pupils are rather large and are immovable. Paralysis of accommodation occurs to him; but at a distance also, the boy cannot properly distinguish objects: 'there must consequently be a lurking affection of the optic nerve of the brain'. He brings his son to me. I establish the fact of paralysis of the sphincter of the pupil in both eyes. Neither on convergence, nor on the incidence of strong light, does contraction of the pupil arise: accommodative and reflex movements are both absent. The inference that there is paralysis of accommodation is thus justified.

Why cannot the boy see even at a distance? A glance with the ophthalmoscope clears all up: it appears I must accommodate about 1/12 in order to see in the uninverted image the fundus oculi; and, as I am emmetropic, our boy has therefore H of about 1/12. With 1/12 he then saw admirably at a distance; with 1/6 he read at the distance of a foot. All fear of an affection of the system of the optic nerve was gone. In speaking of the anomalies of accommodation, I shall revert to such cases. Here it may suffice to observe that within four weeks the paralysis had given way, the H had again gradually become for the most part latent, and that in what the boy had to do or to read, he now no longer complained even of fatigue. In a few years asthenopia may be expected, and the use of the convex spectacles while working will then be indicated.

Paresis of accommodation in young persons is scarcely distinguishable from asthenopia through H

v. H. J., a boy aged 14, is brought to me, complaining that for some time he has been unable to read. He looks pale and weakly. I suspect asthenopia, whether in consequence of a slight degree of H, or in consequence of paresis of accommodation. The pupils move well. 'Do you feel weak?' 'Yes, I have not yet recovered my strength after an attack of sore-throat'. The articulation of words is imperfect, he speaks through his nose, and the soft explosive consonants (*b*, *d*, and *g*) are, especially at the end of the words, pronounced as corresponding nasals (*m*, *n*, *ng*) (paresis of the palate). These symptoms are characteristic as the result of angina *diphtheritica* (better, *diphtherina*). I therefore infer the existence of paresis, notwithstanding the movable pupils. At a distance S is $=1$, and neither convex nor concave glasses are borne: consequently we have to deal with E. The nearest point lies, instead of at 3″, at 9″, and can be maintained there only for a moment, as by spasmodic tension. . . . From ordinary asthenopia, in consequence of H, the condition is distinguished by its rapid appearance (N.B., about a fortnight after the symptoms of angina had given way), by the easy *permanent* vision at a distance (. . .) and by the almost immediate occurrence of fatigue and of absolute impossibility of seeing near objects.

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Strong H in a child has hitherto been almost invariably regarded as M.

vii. A girl, aged six years, is said to have very weak eyes. If she wishes to see anything, she runs to a bright light, and holds the object directly before her eyes. Her anxious parents had taken much advice respecting her; the child was generally considered to be near-sighted. The fact that she so particularly looks for bright light, in order to see anything well, makes me doubt the correctness of this opinion: in that case considerable amblyopia would necessarily be combined with the myopia.

From the external appearance, I had scarcely a doubt of the existence of H. At the distance of 3″ the child saw, with her head aslant and her eyelids nearly closed, No. III of Snellen; smaller letters she did not see; with 1/6 on the contrary, she saw II at 8″: so the proof was supplied. S was $=1/2$. Probably astigmatism exists, to be more fully investigated at a somewhat later period, when the patient shall be able to give a more accurate account of herself. Meanwhile, she may provisionally use 1/6 in learning,—if she chooses she may also wear them habitually. 'This she would rather not do'.

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§ 24. *Strabismus convergens, the Result of H*

Strabismus is a deviation in the direction of the eyes, in consequence of which the two yellow spots receive images from different objects. In strabismus the visual lines do not cross one another in the point it is desired to observe; only one of the two, that of the undeviating eye, is directed to that point. Under this deviation not only does the expression of the face suffer from the want of symmetry in its most eloquent parts, but the power of vision, at least in one of the eyes, is usually disturbed, and the squinter always loses the advantage of binocular vision.

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We now know that by far the greater number of cases of strabismus are connected with anomalies of refraction.

According to the direction of the deviation, two forms of oblique vision are specially to be distinguished: strabismus convergens and strabismus divergens. The main result of our investigation may be expressed in these two propositions.

1. *Strabismus convergens almost always depends upon hypermetropia.*
2. *Strabismus divergens is usually the result of myopia.*

We have here to treat only of strabismus convergens.

Experience, in the first place, shows, that strabismus convergens is, in the great majority of cases, combined with H. In 172 cases investigated by us, H was 133 times proved to exist in the undeviated eye. . . . In thirteen cases difference of refraction of the two eyes was recorded; . . . at least five times paralysis had gone before; three times there was complication with congenital cataract, twice with nystagmus.—It is evident how greatly H preponderates: it occurs in about 77 per cent. of the cases. And yet I am convinced, that if we could investigate without distinction all cases of strabismus convergens which occur in a given population, H would be met with relatively still more frequently. In the first place, ordinary cases of strabismus convergens are seldom brought to the oculist, and these are precisely the cases in which H is the only cause: if inflammation, paralysis, or any special complications be present, the patients do not dealy to call in help; and thus, in proportion to the whole, a greater number of these exceptional cases comes to be seen.

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I therefore do not hesitate to declare, that it is exceptional, to find strabismus convergens without hypermetropia.

In general, it is not the highest degrees of H with which strabismus is combined. Often even, at least in young persons, the hypermetropia is completely latent. . . . Where it was manifest, it amounted to from 1/30 to 1/10, rarely to 1/7 or more. The total hypermetropia was, usually not examined, but of course attained, especially in young subjects, a considerably higher degree. With 1/30 manifest H more than 1/15 total H may in general be assumed. . . .

Since in strabismus convergens H in general exists, no other connexion is conceivable than that H is the cause of the deviation. H is, indeed, the primary anomaly, to be sought in the structure of the eye, and originally proper to the organ; strabismus is the secondary condition, which does not arise until some years after birth. In the first period, in the commencement of the so-called periodical oblique vision, it can be proved that H already exists: unquestionably, therefore, it precedes the squinting. And if we add, that the incipient strabismus again gives way, when the hypermetropia is neutralised by a convex glass, we readily infer that H may produce strabismus. The only question, therefore, is, how it can do this, and the answer is evident.

The hypermetropic individual must, in order to see distinctly, accommodate comparatively strongly. This holds good for all distances.

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Now, as we have seen, there exists a certain connexion between accommodation and convergence of the visual lines: the more strongly we converge, the more powerfully can we bring our faculty of accommodation into action. A certain tendency to increased convergence, so soon as a person wishes to put his power of accommodation upon the stretch, is therefore unavoidable. This tendency exists in every hypermetropic person. An emmetropic person may also convince himself of this by holding negative glasses before his eyes, and thus bringing the latter temporarily into a condition of hypermetropia. He will distinctly remark, that on the endeavour to see accurately, double images every time threaten to appear as the result of increased convergence, and that he soon has a choice only between indistinct vision and squint. Probably this conflict exists unconsciously in the case of all hypermetropic persons.

Hypermetropia is a very widely spread anomaly. I am convinced that it occurs still more frequently than myopia. Now, if strabismus convergens is in general the result of hypermetropia, the latter evidently is very often met with without strabismus; we may even say, that only in a comparatively small number of cases of hypermetropia is strabismus developed. This, however, need not by any means surprise us. In general , in fact, the necessity of seeing an object *single* with both eyes together, is deeply felt. The direction of the visual lines is thereby forcibly determined. Of this I convinced myself, many years ago (1845), in my experiments on the action on prismatic glasses. If we bring a weakly prismatic glass, with the refracting edge turned inwards, before one of the eyes, the fixed object is directly seen double, but increased convergence is immediately involuntarily produced, which makes the double images coalesce; and if, some moments later, we again remove the glass, double images for an instant reappear, which, however, equally rapidly disappear, in consequence of lessening the convergence. Now, it is as if the double images, of their own accord, again coalesce: the movement made takes place so spontaneously, that the person is not even conscious of it. This abhorrence of double images, or rather the instinctive adherence to binocular vision, preserves most hypermetropic individuals from strabismus. They sacrifice the advantage of seeing accurately, rather than to allow that on the two yellow spots different objects should form their images. In this, therefore, we find the reason, why not nearly all hypermetropics squint. If one eye be covered with the hand, while it, as well as the other, is open, the visual line will, in *most* hypermetropics, rapidly deviate inwards. The same thing takes place when an emmetropic person holds a negative glass before the uncovered eye.

The question which now suggest itself is: What circumstances must coöperate to give rise to strabismus in hypermetropic individuals?

These circumstances are of a twofold nature: *a*, those which diminish the value of the binocular vision; *b*, those which render the convergence easier.

To the first class belong:

1°. *Congenital difference in the accuracy of vision, or in the refractive condition of the two eyes.* In hypermetropia the accuracy of vision is often imperfect, whether in one or in both eyes. This is in part attributable to astigmatism, in part to a still unknown imperfection of the retina. If the diminished accuracy of vision affects only *one* eye, then, on too great convergence, the image of this eye will not so much disturb vision. The same is the case when the degree of H in the deviating eye is greater, and the image in this eye is therefore less accurate. In either case, consequently, strabismus will more easily arise. But the tendency doubly increases when both circumstances, a higher degree of H and diminished accuracy of vision, as is often the case, occur combined in the same eye. If the eye has long been deviated, there arises a secondary diminution of the accuracy of vision, as a result of strabismus, to which I shall subsequently revert. . . .

2°. *Spots on the cornea.* It is often remarked, that in oblique vision the deviated eye, or, indeed, both eyes, exhibit opacity, or spots on the cornea. Pagenstecher and Saemish have recently called attention to the frequent occurrence of corneal spots in strabismus. It does not appear to me, however, that spots on the cornea should, in themselves, be capable of exciting strabismus.

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But it is quite a different question whether, where hypermetropia exists, specks on the cornea and other obscurities might not increase the tendency to strabismus; whether the less accurate image might not make the image less disturbing, and diminish the abhorrence of an accessory second image. I am very much inclined to assume this. At least, I find specks on the cornea much more common in hypermetropia with strabismus, than in hypermetropia without strabismus.

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In the second place, as I have remarked, the origin of strabismus is promoted by circumstances which render convergence easier. Under this head are to be noted:

1°. *Peculiar structure or innervation of the muscles*; *easy mobility of the eyeballs inwards.* . . . It may readily be assumed that . . ., in fact, some eyes converge without any particular tension up to 3″, nay, even up to 2″, and less, from the eye.

. . . .

When it is stated that such voluntary squinting, often produced for the sake of imitation, or of mockery, has, with some, given rise to permanent strabismus, I readily admit it, but on condition that hypermetropia at the same time existed. Moreover, I have not been able to satisfy myself that a special tendency to strabismus may be hereditary. Let me be understood. In a very high degree hypermetropia is hereditary. It is a rare thing, with hypermetropic structure of the eyes in one of the parents, not to find hypermetropia also in some of the children. But whether this hypermetropia in the parents was combined with strabismus or not, has, if any, certainly only slight influence in the development of strabismus in the hypermetropic children born of them. If in a family one or two labour under strabismus convergens, we may be nearly sure that in some other members hypermetropia will occur; but that in the same family most of the hypermetropics should be affected with strabismus, has very rarely occurred to me.

2°. *Relation between the visual line and the axis of the cornea.* We have above seen that in general in hypermetropic individuals, in order to give a parallel direction to the visual lines, a more than ordinary divergence of the visual axes is required. Thence we have in so many hypermetropic persons apparent strabismus divergens. On the other hand, we know that most eyes can with difficulty be brought to a state of divergence: a weak prism, with the refracting edge held outwards before the eye, produces double images, which most people are not able to overcome. . . . It is therefore natural to assume, that when for single vision more than ordinary divergence of the corneal or visual axes is required, the divergence may very easily be insufficient, and that, accordingly, as a matter of course, for seeing at a shorter distance also, there may readily be too great convergence. . . . Now, if, in looking at a distance, the requisite divergence of the axes of the cornea easily falls short, the convergence will likewise, under the influence of the hypermetropia, in looking at near objects, be relatively too great. The condition for the development of strabismus is thus given. In fact, it often seemed to me that in squinters, after tenotomy, a considerable degree of divergence of the axes of the cornea was required to make the visual lines assume a parallel position;—often the eyes are apparently quite properly directed, and yet when, on fixing a remote point, one and the other eye are alternately covered with the hand, we observe that the eye just opened has each time to make an extensive movement outwards, to fix the remote point. . . . This leads me to suspect that while in general the great angle α promotes the occurrence of strabismus convergens with H, an extraordinary magnitude of this angle predisposes more particularly to this form of strabismus. In order to test this suspicion, the angle α was measured in ten cases of strabismus convergens. The measurements were in great part made by Mr. Hamer, now house-surgeon in our Ophthalmic Hospital, according to the method already described, with his usual accuracy.

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As an average we obtained $\alpha = 7°.63$. This but slightly exceeds $\alpha = 7°.3$, previously found as the average in non-squinting hypermetropics. . . . In order to have a better ground of comparison, the angle α was determined in some cases of H, in degree about equal to H of squinters.

Now, in the first place, we find among these non-squinting hypermetropics *a* on an average $= 6°.56$, that is, $1°.07$ less than in squinters. In the second place, it appears further, that the degree of H . . . keeps about equal pace with *a*. . . . The result, therefore is, that, with equal degrees of H, high values of *a* especially predispose to strabismus convergens. To this result I attach the more importance, because it *in general* proves, that the greater angle *a*, proper to H, is not indifferent in its bearing on the connexion between H and strabismus convergens.

In the highest degrees of H, strabismus is rarely observed. This need not surprise us. In such cases the power of accommodation is, even under abnormally increased convergence, not sufficient to produce accurate images, and such hypermetropics are thus led rather to the practice of forming correct ideas from imperfect retinal images than of, by a maximum of tension, improving the retinal images as much as possible.

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As to *external causes*, we often find mention made of the fixing of near, and particularly of laterally placed objects, as a feather of the cap, the flame of a candle, a toy or such like. From what has been said, it will have been seen that I attach but little influence to these things. At least, I am convinced that the *emmetropic* eye will not in this way be led to squint.

. . . .

Converging strabismus, in consequence of H, *we see* to arise mostly mostly about the 5th year, probably because the effort to see accurately then begins to be developed; the range of accommodation is now also sufficiently great, by means of somewhat increased convergence, easily to overcome the H. To *reports* of its occurrence at, or shortly after birth, in consequence of convulsions or of other diseases, no credit is in general to be given. Exceptionally it commences after the 7th, extremely rarely so late as the 18th year, unless special accessory causes exist. At first the deviation is transient, connected with fixing, that is with an effort to see accurately, sometimes only with the fixing of near objects: it passes off again when the fixing ceases or the eyes are closed. This is the socalled periodical squint, by some described as a distinct period. Even in this period, and when the strabismus is developed first in the 16th or 18th year, we very rarely hear a complaint of double vision. This is explained, in my opinion, by the fact, that the deviation arises only on the effort to see a given object accurately. On that object the attention is fastened. To it the one visual line remains directed. Now the double image of it lies in the deviating eye at some distance from the yellow spot, and must therefore appear indistinct, so that beside the direct fixed one, it is not easily seen as a second image. And on the yellow spot appears the image of a wholly different object, with which the observer is in general not occupied, and from which it is therefore easy to abstract. But when the deviation, before S is much diminished, occurs involuntarily, without a special effort to see accurately, there is occasionally some transient double vision. The periodical form of squint on looking at near objects, just described, sometimes continues as such. . . . In most cases, however, the squint soon becomes constant. The rule is, that invariably one and the same eye deviates (strabismus simplex); this held good even when the squint was still transient. . . . The squint is usually concomitant; the movements are free; the excursion normal although with excessive mobility inwards, limited outwards, *in both eyes*, even when the one constantly deviates, the other being steadily properly directed; this is found also to be the case when the squint is still periodical. Both the internal muscles of the eye are therefore to be considered as shortened. The shortening, at first dynamical, has in the constant strabismus become organic: it is the result of excessive action, with relaxation of the antogonistic muscles; morbid structural change does not exist. That both internal muscles are shortened, depends upon the habit of keeping the fixed object to the side of the deviated eye, so that even in the non-deviated eye the musculus rectus internus is brought into relatively strong contraction. In this position the H of the non-deviated eye is best overcome. Also when the strabismus has become constant, a comparatively stronger tension of the internal recti muscles is connected with the fixing of an object, . . . after tenotomy the increase of the convergence often again appears very well marked in these cases on fixing an object.

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In strabismus simplex the acuteness of vision suffers more and more in the deviated eye. At first, on bringing the hand before the fixing eye, the deviated eye directs itself properly to the object; even when the hand is taken away, the originally deviated eye may continue to fix, soon, however, usually when movement is required or even on the first winking of the lids, giving way to the other. The acuteness of vision in the deviated eye has then already diminished, but it continues still for a considerable time satisfactory, may be recovered by practice, and improves almost always immediately after tenotomy. After some time, however, on closing the fixing eye, the deviated eye usually directs its visual line no longer to the object. . . . When this takes place, we may infer, that . . . the acuteness of vision of the deviated eye is much diminished, while, on the contrary, that of the indirect vision, on the innermost part of the retina, in so far as it perceives objects, which are not represented on the retina of the other eye, has continued undiminished. It is again Von Graefe, who has first accurately investigated this loss of physiological sensibility through psychical exclusion. And this is indeed a remarkable phenomenon! That through attention we can sharpen our senses, is an admitted fact. How rapidly, on the other hand, a nerve may become blunted, from whose impressions we wish mentally to abstract ourselves, the case here described supplies an example important for physiology at large. Although no organic changes of the retina are to be observed, no improvement of any importance is to be obtained, if fixing no longer occurs under any circumstances, either by practice or by tenotomy.

But we must not too rapidly decide this point. There is a period in which the deviated eye will not see large objects otherwise than indirectly, and nevertheless, on using a convex glass, it will quickly look directly. . . . In this period we may by practice and by tenotomy sometimes still attain a brilliant success.

A word still as to the practical application of what has been said. I have alreday above stated, that so long as strabismus occurs only intermittingly with fixing of an object, its development may be prevented by wearing convex glasses, which neutralise the exising H. This I first observed in a young man, who in his 18th year began for the first time to squint in fixing. He had Hm = 1/20. After he had worn glasses of 1/20 for two days, he began to be no longer able, to make one eye deviate. . . . By continuing to wear the spectacles, the squint ceased to be produced, and the tendency to it was completely lost.

If the squint sets in very early in life, wearing spectacles is of course attended with difficulties, and particularly when the patients are of the female sex, they are unwilling to be condemned to wear glasses during their whole life. In such cases I generally confine myself to advising them to look twice daily for some minutes, with the deviating eye alone*, which practice is sufficient to prevent the diminution of the acuteness and the limitation of the field of vision: at a later period, when the strabismus is confirmed, the operation of tenotomy is performed. Where the patient preferred obviating the strabismus by wearing spectacles, I willingly consented to it, and almost invariably the object was thus attained. Mooren (1863), too, has recently stated that, where a tolerably high degree of Hm existed, he has, in he first stage of strabismus, with good result prescribed the use of convex glasses. In comparatively great degrees of H the prevention of strabismus is, in fact, more particularly desirable, because subsequently, even after full tenotomy, the tendency ot strabismus continues, and, in order to prevent a relapse, the use of convex glasses, at least for close work, is still necessary. Moreover, I have observed, that when hypermetropics with already confirmed strabismus, especially after insufficient tenotomy, regular wear convex glasses, the degree of strabismus often diminishes so much, that the deformity is almost entirely removed.

If we now inquire whether the cause of strabismus was ever before sought in hypermetropia, this question may be answered in the negative. Indeed, this could scarcely be otherwise. It is only a few years since hypermetropia was properly understood; and the forms which are wholly or in great part latent, were overlooked, until I satisfied myself of their existence, and immediately began to perceive their relation to strabismus. But to this conclusion, what had been observed and recorded by my predecessors, in a certain degree contributed.

. . . .

So I wished to take it up somewhat more fully, and to inquire in general, with what anomalies of the eye the different forms of strabismus are connected. It occurred to me, that such an investigation might tend to clear up the pathogeny of strabismus. The investigation required the statistical method. In a great number of squinters, therefore, everything was determined for both eyes, which appeared possibly to be the cause or the result of this anomaly, or to be capable of in any way explaining its origin: sex, age, and ordinary occupation were noted; of each eye in particular were determined the refractive condition, the range of accommodation, the acuteness of vision, the extent of the movements, these last in connexion with the variable or unvariable angle of squinting; to these points were added the time and mode of origin, the hereditary causes; finally, complications of various kinds and peculiar disturbances in vision (limitation of the field of vision, double vision, etc.). In this inquiry, several of my pupils, and in particular Dr. Haffmans, ably and zealously assisted me. The registers relating to this subject embrace 280 cases. It is true that in very many instances not all the determinations just mentioned were made, and the accuracy of other cases leaves something to be desired: he who knows by experience, how much time and trouble are necessary, especially in children, or in unintelligent persons, satisfactorily to investigate both eyes with respect to their function, will very easily understand this. But this will not prevent many a question respecting strabismus from finding its answer in the facts collected. Here I have been obliged to confine myself chiefly to the pathogeny, and indeed, in particular to that of strabismus convergens.

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*Mydriasis by atropia, of the eye which is usually properly directed immediately causes the other to be used, and is therefore sometimes recommended in the case of young squinting children, on whom it is undesirable as yet to operate.

§ 25. *Aphakia*

The absence of the lens in the dioptric system of the eye is in many respects an important condition. It must, therefore, be considered strange, that writers had neglected to give it a name. I have proposed to designate it by the term aphakia, and this word is beginning gradually to find acceptance.

Aphakia may be produced by different causes. It occurs most frequently as the result of operation for cataract or of a wound, which has given rise to gradual solution of the lens. When the lens has by luxation or depression of cataract disappeared from the plane of the pupil, though it may still be present in the eye, it no longer belongs to the dioptric system, and we are therefore most fully justified, in speaking of anomalies of refraction, in calling the condition, in this case also, by the name aphakia. Luxation of the lens is usually the result of a wound. Very remarkable cases of spontaneous luxation of the lens are communicated by Bowman. In the writings of Von Graefe I have seen it mentioned that he has observed congenital aphakia in many members of the same family. Such cases have not occurred to me. Partial luxation of the lens, causing the equator of the lens to correspond to the plane of the pupil, is, on the contrary, very frequently met with, and is not uncommonly found in several children of the same parents. This state cannot, however, be considered as aphakia; it belongs rather to irregular astigmatism.

In the condition of aphakia the eye is the simplest imaginable dioptric system. In consequence of the slight thickness, in fact, and the nearly equally curved surfaces of the cornea, we may safely neglect the slight difference in the coefficient of refraction between the cornea and the aqueous humour, and therefore suppose that the aqueous humour extends to the anterior surface of the cornea; and as, moreover, the coefficients of refraction of the vitreous and aqueous humours are equal, we have in the aphakial eye only one refracting surface to take into account, namely, the anterior surface of the cornea. The cornea is not spherical, but somewhat ellipsoidal, and, in fact, with such eccentricity, that the spherical aberration is partially removed. In the calculation the radius in the apex must form the basis. In order to find the cardinal points, we need know only the radius of the cornea and the coefficient of refraction of the aqueous humour. Now as the coefficient we have, with Helmholtz, assumed 1·3365; as the radius of curvature, in the apex of the cornea, we may, according to our measurements, take as the average 7·7 mm. We thus obtain the subjoined system.

$F' = h\varphi'$ $(= 7{\cdot}7 : (1{\cdot}3365 - 1) = 22{\cdot}88$.

$F'' = h\varphi''$ $(= 7{\cdot}7 \times 1{\cdot}3365 : (1{\cdot}3365 - 1) = 30{\cdot}58$.

$h\,k' = F'' - F' = 7{\cdot}7$.

. . . .

Experience has shown, that in the majority of cases glasses are required of from 1 : 3 to 1 : 3·5, placed at 6‴ from the eye. This corresponds to a length of the visual axis of from 22·9 to 23·9. This length coincides nearly with that of the emmetropic eye. But if the eye was myopic before the development of cataract, weaker glasses are, after the operation, sufficient. A case even occurred to me, in which the accuracy of vision of distant objects was incapable of improvement by either positive or negative glasses. In this instance the visual axis of the eye, emmetropic with aphakia, had actually a length of rather more than 30 mm., and we may assume that so long as the crystalline lens was still present, myopia of about 1/3 had existed. In a second case, ... in a man, aged 73, glasses of 1/8 were sufficient. In this instance there must have existed, before the occurrence of the cataract, a myopia of rather more than 1/5, which had now given way to H = 1 : 7·5. The patient now declares that he can see without spectacles better at a distance than he could in his youth before the occurrence of the cataract; as the pupil is now smaller than it formerly was, this is not surprising.

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It is a very common case, that for seeing at a distance in aphakia, glasses of 1/6 or 1/5 are sufficient, which, when the form of the cornea is normal, proves that the visual axis is longer than usual. Now, in all these cases myopia has previously existed, and the connexion between M and length of the visual axis is thus in aphakia most clearly brought to light. Especially in cases of congenital cataract have I been able to satisfy myself of this. It has appeared to me that this condition is usually connected with a myopic structure of the eye. We know that under these circumstances not the entire crystalline lens is obscured, or rather, that ordinarily only some laminæ are obscured, while the nucleus, and especially the peripheric layers, are transparent. Now, if the transparency of these last is tolerably perfect, vision often becomes pretty good on artificial mydriasis. It is then only rarely that positive glasses are required for reading, etc., notwithstanding that the power of accommodation is removed. The degree of the myopia is now also still easily determined. In connexion with this M we shall find, that when the operation has become necessary, and the lens is removed, glasses of from 1/4 to 1/6 are in these cases usually sufficient for seeing at a distance. Sometimes I have had the opportunity of determining, in the same eye, the degree of M before, and that of H after the operation.

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That from the above observations the focal distance of the original crystalline lens, in a given position, may be calculated, the reader will, no doubt, have already understood. I hope to do this hereafter for a greater number of cases.

Original H, too, makes its influence felt where aphakia has supervened. In one case even of congenital cataract, H was found after operation in the right eye = 1 : 2·44, in the left 1 : 2·43. These eyes were evidently rather small (approaching to microphthalmos), without particularly marked curvature of the cornea, and the hypermetropic structure was in them not to be mistaken. Moreover it is in general rare in aphakia to find $H > 1 : 2{\cdot}5$. Where I met with $H = 1 : 2{\cdot}4$ or $1 = 2{\cdot}3$, I could during life, the eye being strongly turned inwards, very well satisfy myself that the visual axis was shorter than normal, and calculation, after measuring the radius of curvature of the cornea, gave the same result.

The existence of aphakia is, at the first glance, not very easily recognised. Often the anterior chamber of the eye is deep, and we find a certain degree of iridodenosis: but none of these phenomena are characteristic. The search for the reflected images of Purkinje is decisive: the two reflected images of the lens are absent. Moreover, the sectors and the direction of the fibres of the crystalline lens are easily seen on lateral illumination with light concentrated by a lens, particularly with the aid of a magnifying glass, as Helmholtz first remarked: where these are wanting, we may infer the existence of aphakia. Finally, the degree of H, whether established by experiments with convex glasses, or by ophthalmoscopy, in connexion with the form of the eye, cannot deceive us. When after a blow or knock upon the eye the power of vision has suddenly diminished, without very manifest disturbances in the organ, we should specially bear in mind the possibility of the lens having disappeared from the plane of the pupil, in consequence of luxation, and we should satisfy ourselves upon this point in the manner above described.

The acuteness of vision is in aphakia usually imperfect. The cause of this is almost always to be sought in turbidity of the surface of the pupil. Even after the most successful operations for cataract, where on inspection the pupil appears completely black, we shall, on examination with the ophthalmoscope, and especially with concentrated incident light, usually find some turbidity, depending chiefly on a slight deposit on the inner surface of the capsule of the lens. In consequence of this a portion of the light becomes diffused, and diminishes the sharpness of the retinal images. Slight as this turbidity may be, it has great influence, as appears from the fact that when even only a small part of the plane of the pupil is perfectly clear, vision immediately becomes comparatively very good.

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A change in the curvature of the cornea, which gives rise to tolerable regular astigmatism, is, after extraction, not unfrequently the cause of diminished S. This may, as will hereafter appear, be in great part corrected by a certain inclination of the glasses.

That, on account of the high degree of H, without convex glasses the power of vision in aphakia leaves much to be desired, needs no proof. Vision will be the more imperfect, the larger the pupil is. . . . But even with the use of glasses a large pupil has considerable disadvantages. The power of accommodation is, in fact, in aphakia completely removed, and a glass, therefore, gives a distinct image only for a definite distance. All points, which are either more or less remote from the eye, are now of course seen with circles of diffusion which are larger, the larger the pupil is. With a narrow pupil the smallness of the circles of diffusion even of objects, for whose distance the eye is not accommodated, might lead one to suppose, as has often happened, that the power of accommodation in aphakia is not removed. It is on account of the great advantages for vision of a small pupil in aphakia, that we cannot consider the performance of iridectomy, especially inferiorly, in the operation for cataract, as an indifferent matter. . . . That iridectomy . . . much diminishes the dangers of the operation, is fully established. For many years I have observed this. For this reason I have, when there is a tendency to prolapse, or when a portion of the iris has suffered much, advised the performance of iridectomy. . . . But this iridectomy is performed superiorly. In this case the part which has suffered excision is almost completely covered by the upper eyelid, and the circles of diffusion therefore do not become greater.

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In order to prescribe the most suitable glasses in aphakia, we begin by determining what glasses are required for distance: the best object for this purpose is a point of light. We now easily calculate from the result obtained, what focal distance is necessary for near objects.

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But the question is then, whether we shall have at our command a lens of the calculated focal distance. The object may, however, in case of any difficulty upon that point, be attained, as shall hereafter appear, by modifying the distance of the lens from the eye.

With respect to the choice of glasses in aphakia, we should not forget, that, especially in old people, completely as the operation may have succeeded, the power, of vision is seldom perfectly acute, and that, consequently, in order to read, the point of distinct vision must be brought rather near the eye. Not unfrequently this distance may amount to not more than 6″.

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In the above theory and calculation, we have assumed that in aphakia the power of accommodation does not exist. It is an important question whether we are justified in doing so. For if it can be proved that in aphakia no trace of accommodative power remains, the inference would seem to be legitimate that this power depends exclusively upon a change of form in the lens. Hitherto this question has not been rigidly investigated. It is true that Thomas Young had already in some cases of aphakia examined the eye with reference to its accommodative power; but the eyes at his disposal were not particularly well adapted for the purpose, and he moreover thought the result only tolerably satisfactory in proving the absence of the accommodating power. Von Graefe, on the contrary, found that some accommodating power remained. He remarks, however, that those who made the most accurate, and, on repeated investigation, the most uniform, statements, had the least range. Whatever else we find here and there noted respecting the occurrence of considerable range of accommodation in aphakia, proves only that the writers had no idea of the degree of distinctness of vision, even in imperfect accommodation.

My investigations have led me to the conviction, that in aphakia not the slightest trace of accommodative power remains.

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A young person, of perfect, indeed of extraordinary, acuteness of vision, who was himself interested in the investigation, had suffered from congenital cataract, and had been operated on by me in both eyes with the most complete success. With glasses of 1/3, placed at 5‴ from the eye, he saw, at a great distance, a point of light sufficiently round and perfectly defined. A sight was placed in the direction between one of the eyes and the point of light, and when he now looked with converging visual lines towards the sight, the point of light remained unchanged or became somewhat smaller and sharper, without changing its form. If the lens was removed only 1/4‴ more or less from the eye, the distant point of light had ceased to be a defined, round point, and was elongated in one direction, to the form of a line; now even with the most powerful exertion, and convergence in the point of the sight, the line of light became only somewhat shorter, without however, a point making its appearance. This shortening, as well as the diminution of the acutely seen point, depended upon narrowing of the pupil, which was, indeed, directly observed. The experiment was repeated separately for each eye, with a like result. Behind the black plate, which in the trial was placed before the one eye, the turning of this eye, in looking towards the sight and towards the remote point of light, could be observed. The force of the experiment, therefore, leaves nothing to be desired. No accommodation whatever existed. Nevertheless in this case also a small margin of distinct vision was, on examination with the optometer, observed,—a proof that we cannot thence infer the existence of accommodative power.

In a second similar case, that of an intelligent young man, the total absence of accommodative power was in like manner proved. In this instance it was, moreover, established, that when a point of light was acutely seen at a distance, through a given lens, the addition of a lens of . . .1/300 or of — 1/300 (a combination of 1/50 with — 1/60 of or 1/60 with — 1/50) produced an evident change of form in the image of light, while on varying the convergence and endeavouring to accommodate, no change whatever took place. The range of accommodation therefore amounts, in aphakia certainly to less than 1/300, and may therefore be considerd = 0. It may well surprise us, that v. Jaeger, who is aware of these investigations, still speaks of accommodation in aphakia.

The complete want of accommodative power may readily mislead to the idea, that in aphakia glasses of different focus are necessary for each distance. Fortunately this is not the case. An accommodative power remains, the mechanism of which is extremely simple. The drawback is, that the hand must in it perform the active part. The power of accommodation to which I have alluded, consists in the alteration of the distance between the glass and the eye.

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I teach all sufferers from aphakia to accommodate in this manner.

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If glasses of 1 : 3, placed at half-an-inch from the eye, are necessary for distant vision, then, on removing the glasses to 1″, the point of distinct vision lies at 22″, on removing them to 1½″ it lies at 13½″, and some people then read exceedingly well.

Notwithstanding this artificial power of accommodation, it is in general advisable in aphakia to give two spectacles, one for distant, the other for close vision. Each pair of spectacles can then take on itself a part of the desired region of accommodation, and the necessary displacement may now be very slight. . . .

If, with good power of vision, aphakia exists in both eyes, we must carefully attend to the mutual distance of the axes of the two glasses. The greatest care is then required, in order, under different circumstances, to guard against double vision.

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Finally, in altered curvature of the cornea, which is seen especially after prolapsus iridis in extraction, an oblique position of the glass is required, of which I shall speak more fully in treating of astigmatism.

A word, in conclusion, on examination with the ophthalmoscope in aphakia. . . . If the rays, in order to come to a focus on the retina, must converge in a point situated 3″ behind the cornea, the rays proceeding in a diverging direction from the retina will appear, after having been refracted on the anterior surface of the cornea, to proceed from a point situated 3″ behind the cornea. With myopia of nearly 1 : 3, therefore, the observer can still examine the retina in the unreversed image. We understand, moreover, that in order to see the fundus accurately in aphakia in an ordinary eye, an emmetropic eye must either remove, or accommodate strongly for near objects, or make use of positive glasses.

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Note to Chapter VI

In the writings of the eighteenth century I have sought in vain for proofs that H was observed and recognised as such, or that the existence of this anomaly of refraction was even suspected. It is not until 1811 that we find a case communicated by Wells

It relates to his own eyes. At the age of 55 he remarked, that his presbyopia was attributable to loss (diminution) of accommodation, and that he required even glasses of 36 inches positive focal distance, in order to see acutely *at a distance*. This observation did not escape the learned Mackenzie (1830). 'Although the eye', we read, 'after middle life, loses the power of distinguishing near objects with correctness, it generally retains the sight of those that are distant. Instances, however, are not wanting of persons of advanced age requiring the aid of convex glasses to enable them to see distant, as well as near objects'. As he, in addition, quotes the case of Wells, it follows from the above, that he considers the occurrence of the condition in question at a more advanced period of life as not unusual, and Wells himself was of the same opinion.

The cases here spoken of have, however, reference only to hypermetropia acquisita. If no other form occurred, hypermetropia would not be of any great importance. It would then really be coextensive with presbyopia, and we should have been able to concur in the use of the term *hyperpresbyopia*, which Stellwag von Carion, starting from such cases, has given in general to those eyes in which the focus lies behind the retina.

On the 19th November, 1812, James Ware read before the Royal Society his *Observations relative to the near and distant sight of different persons*. After having spoken of the senile changes of the eye, and having, in conclusion, quoted Wells' case of relative hypermetropia acquisita, he adds the following remarkable words: 'There are also instances of young persons, who have so disproportionate a convexity of the cornea or crystalline, or of both, to the distance of these parts from the retina, that a glass of considerable convexity is required to enable them to see distinctly, not only near objects, but also those that are distant; and it is remarkable, that the same glass will enable many such persons to see both near and distant objects; thus proving that the defect in their sight is occasioned solely by too small a convexity in one of the parts above-mentioned, and that it does not influence the power by which their eyes are adapted to see at distances variously remote. In this respect such persons differ from those who had the crystalline humour removed by an operation; sinde the latter always require a glass to enable them to discern distant objects, different from that which they use to see those that are near'. In these few words James Ware entitles himself to be called the discoverer of hypermetropia. . . . But not perceiving the great bearing of his discovery, Ware confines himself to this brief communication, which was either overlooked or not comprehended. Even Mackenzie speaking of it in connexion with presbyopia can say only: 'The cases related by Mr. Ware, as occurring in young persons, seem to partake more of the character of asthenopia than of presbyopia'. . . .

With Ware our knowledge of H was lost. We next meet with Sichel, whose doctrines have long exercised a great influence. Cases of an anomaly of such general occurrence could not escape so excellent an observer. As 'une espèce d'amblyopie congénitale compliquée de presbytie et prise d'ordinaire pour un très-haut degré de myopie', to which he gives the name of *amblyopie presbytique congénitale*, he sketches a distinct picture of high degrees of hypermetropia. The nature of the affection he did not, however, comprehend. He states, indeed, that . . ., improvement is obtained by convex glasses,. . . but he was far from believing that they really required these. 'Il serait dangereux toutefois', he says, 'de les leur accorder trop tôt, ou de permettre qu' ils usent des verres trop puissants: *mieux vaut les en priver le plus longtemps possible*'.—If hypermetropics, who had already worn convex spectacles, resorted to him, he did not hesitate to declare that the use of the glasses was the cause why they could not distinguish without such assistance, and already saw a dangerous amblyopia looming in the distance. He therefore unconditionally forbad the use of positive glasses for remote objects. This he did even in the case of old persons. Nay, he blames Mackenzie in this respect, who nevertheless certainly did not go too far. In this singular prejudice against the use of positive glasses is contained the proof, that the nature of the deviation remained a mystery to Sichel.

. . . .

He who knows by experience how commonly H occurs, how necessary a knowledge of it is to the correct diagnosis of the various defects of the eye, and how deeply it affects the whole treatment of the oculist, will come to the sad conviction that an incredible number of patients have been tormented with all sorts of remedies, and have been given over to painful anxiety, who would have found immediate relief and deliverance in suitable spectacles. We may therefore look upon it as truly fortunate, that many had recourse simply to ordinary empirics, so-called opticians, who endeavour to give men those spectacles which render their vision persistently easier. Sichel's lamentation over the number of patients who had got convex spectacles for distant vision, satisfactorily proves that the opticians knew very well, that in some eyes distant vision is improved by convex glasses. And still every day almost the same thing occurs.

. . . .

At length in 1853, we find hypermetropia, for the first time, described in a scientific manual. Ruete, *Lehrbuch der Ophthalmologie für Aerzte und Studierende*) in the following words, under the name of *oversightedness* (*Uebersichtigkeit*): 'Oversightedness is the condition in which, on account of a peculiar, and as yet not sufficiently investigated, construction of the refracting media of the eye, neither near nor distant objects are distinctly seen. The eye appears in it to suffer from a total want of accommodating power, and to possess but a very slight refractive power. This defect of sight is in general congenital, or is at least developed in very early youth. Vision is considerably improved by the use of convex spectacles, whose focal distance must, however, vary according to the distance of the objects, so that those suffering from this defect are able even to read'. The description still leaves much to be desired. . . ; moreover, it is incorrectly supposed, that the power of accommodation is in these eyes almost wholly wanting. But still in these few words lies the germ of further investigation, and we thus see here also, as in many other points in ophthalmology, the impulse given by Ruete to our knowledge.

Two years later, namely on the 12th of April, 1855, Dr. Carl Stellwag von Carion laid before the Imperial Academy of Sciences at Vienna, a detailed essay entitled: *die Accommodationsfehler des Auges*. In it we find a correct definition in the following words: 'the optical essence of oversightedness lies in this, that the focal range of the dioptric apparatus in perfect rest of the accommodating muscle is greater, than the distance of the layer of rods and bulbs from the optical centre of the refracting media.' Stellwag too has the merit of having satisfactorily indicated the method of determining r in cases of H. Slight degrees of H he appears, however, scarcely to have recognised, the latent not at all; and on the whole, as the very name of hyperpresbyopia used by him shows, he has not strictly enough distinguished hypermetropia from presbyopia.

Only a few months after Stellwag von Carion had brought forward his investigations on defects of accommodation of the eye, we find in the *Archiv für Ophthalmologie* a paper by Von Graefe, under the title of 'Ueber Myopia in distans, nebst Betrachtungen über das Sehen jenseits der Grenzen unserer Accommodation', in which occurs a masterly description of the highest degrees of hypermetropia. Stellwag von Carion had observed, that 'the oversighted person' , in order to recognise an object, brings it very close to the eye, and singularly enough, he seems to imagine that it then appears more illuminated. Von Graefe has remarked the same, but has also, in part at least, indicated the cause, by proving mathematically, that in the hypermetropic eye, on approaching the objects, the angle under which they appear increases more rapidly than the circles of diffusion, and by imitating the effect on the eye made hypermetropic by negative glasses. He shows further, that this hypermetropic eye is clearly distinguishable in structure from the myopic eye, by the flatness of its anterior chamber and by the narrowness of the pupil; but he has not, any more than Stellwag von Carion, properly recognised and appreciated the slight and moderate degrees of hypermetropia.

In my first communication (1858), and likewise in the dissertation by MacGillavry (1858), soon after written under my superintendence, the condition under consideration was indeed accurately distinguished from presbyopia, but the division into anomalies of refraction and of accommodation, and the opposition of myopia and hypermetropia, were not yet apparent. It was at the meeting held at Heidelberg in 1859, that I first showed, among other things, that presbyopia and the so-called hyperpresbyopia are, both in essence and in symptoms wholly different conditions, that the latter alone is opposed to M, that an eye may be even very hyperpresbyopic without being in the least affected with presbyopia etc., I argued that, consequently, the name of hyperpresbyopia must be set aside, and Helmholtz, who was at the meeting, immediately proposed the term hyperopia. This coincided with the word 'oversightedness' (*Uebersichtigkeit*) first used by Ruete, and quickly found acceptance with some. On more fully working out my system, I thought, however, that the term hypermetropia would be more in accordance with the nomenclature I had already employed in the words ametropia and emmetropia, and this name has since that time been most generally adopted.

My investigations respecting H are to be found in *Ametropie en hare gevolgen*, Utrecht, 1860, and in the *Archiv für Ophthalmologie*.

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CHAPTER VII

Myopia. M.

§ 26. *Dioptric Determination, Diagnosis, Degrees, Occurrence, Hereditariness, Development with Advancing Age*

Myopia we have already considered as the condition opposed to H. In the latter, the focus of the dioptric system lies behind, in M, on the contrary, it lies in front of the retina; in other words parallel rays, derived from infinitely remote objects, unite in the myopic eye in front of the retina in φ', and each infinitely remote point therefore forms upon the retina a circle of diffusion. Hence it follows, that, in order to unite upon the retina rays must proceed from a point *r* situated at a finite distance, and must therefore fall diverging upon the cornea.

The above is true of the eye in a state of rest. By tension of accommodation the emmetropic eye, and usually even the hypermetropic, can bring its focus for parallel rays in front of the retina; but it does not therefore become myopic. Even when by spasm of accommodation relaxation to E is not possible, the eye cannot be said to be myopic. M depends, just like H, on the structure of the eye, irrespectively of accommodation, or rather with actual relaxation.

In general M is easily recognised.

. . . .

Almost always the myopic presents himself before us with the statement, that he can see near objects well, while he with difficulty distinguishes at a distance, and if we then place in his hand a book with small type, . . . the distance which he chooses itself indicates about the farthest point. We now, however, make him remove the book farther off, until he reads less easily and sees even somewhat larger letters less acutely, and we estimate the distance at which this diminution of acuteness commences. If this be 6″, we try at first glasses of — 1/6; if it is 10″, glasses of — 1/10, &c.

. . . .

We now investigate immediately and more accurately the *degree* of M; in other words, we determine R, the distance from *r* to *k*′. This is found by trying, what the *weakest negative glass* is, with which vision is as acute as possible. In order quickly to attain this object, we place the glasses supposed to be suitable in a frame, . . . and now hold, while we raise the frame somewhat with the fingers, glasses before the eye, which are somewhat weaker, and ask whether with them vision is as good or even better: if he answers yes, we then place these in the frame, and compare them, in like manner, again with somewhat weaker glasses, repeating the trial until we receive for answer, that vision is not so acute with the glasses last tried. But we should even still try yet weaker glasses, and not be satisfied until we are told that vision is with them much less acute: experience has in fact taught me, that we cannot be too cautious; for with good accommodation the action of too strong glasses is easily enough overcome, and since with slight differences in strength the sight remains nearly the same, this equality may lead to its being said that the vision is less accurate. Thus I have with $M = 1/16$ seen $-1/8$ preferred to $-1/9$ or $-1/10$, although $-1/16$ finally proved to be sufficient.—Not unfrequently, however, the glasses first tried are too weak, in which case, on comparison, the weaker are immediately rejected. This we find to occur especially with older myopes, who prefer reading at a comparatively great distance; while very young, and still in the possession of a great power of accommodation, they readily bring the object within the distance of their farthest point, and so, on the first trial, they cause a higher degree of M to be suspected. If we have now found that, in order to attain the greater acuteness of vision, a stronger glass is necessary, we go on until further strengthening no longer produces an improvement, and we then try once more, whether a somewhat weaker glass is not equally satisfactory. Thus the object is at length attained.

We have already observed, that the distance at which the glass is held from the eye, has an influence upon its action. While a convex glass, by removal from the eye, acts more and more strongly, the reverse obtains with regard to concave glasses. The thing is plain: parallel rays, refracted by a concave glass, appear to proceed from a point placed as far *before the glass*, as the focal distance amounts to, and that point lies still so much farther from the eye, as the distance between the eye and the glass. Thus a glass of $-1/8$, held an inch farther from the eye, is equal to a glass of $-1/9$, but with this difference, that the images are smaller: therefore $-1/9$, if held an inch closer to the eye, is chosen. Now, of the influence of distance on the action of glasses, we may often advantageously make use, in order to see quickly whether the glass tried is too strong or too weak. If it is too strong, removing it a little is no disadvantage; if it is too weak, the patient will hold it rather directly to the eye. However we must not be too sure on this point. Thus, the myope who has a good accommodating power, will hold even a too strong glass by preference close to the eye, because the retinal images are thus rendered larger. Therefore when vision is equally good or even better on the removal of the glass, we may infer that the latter is too strong, not *vice versâ*. In any case we should never be satisfied, until we have determined what is the weakest glass which, held close before the eye, is quite sufficient. By this the degree of M, and at the same time the acuteness of vision are known. The investigation may in general be undertaken with both eyes at the same time: almost invariably the M is sufficiently nearly equal in the two eyes, and what has been found for both eyes, may in a moment be tested for each eye separately. But if we have reason to suspect, *a priori*, inequality of the M in two eyes, or if we obtain confused answers to the first tests of vision, we may first try the one eye and afterwards compare the other. We should always begin with the eye which the patient himself calls the best, the other should be gently closed with the hand.

Von Graefe has lately (1863) had an optical instrument made, which, by a simple mechanism, can be so modified in its action as to represent lenses of very different focal distances. It may now, held before the eye, be so arranged that the ametropia is precisely corrected, and thus the tedious determination with different glasses may be dispensed with. Von Graefe praises it very much. I am sorry that I have not yet been able to try it. It appears to me that the influence on the magnitude of the images must give rise to some disturbance in the determination. In using this instrument, each eye is separately investigated.

Many will possibly find the above directions tedious and too minute. And yet they are in many respects incomplete; so that, at the risk of incurring the displeasure of my readers, I will take leave to point out some additional sources of error. Let it be borne in mind that an incorrect determination of the degree of M may highly endanger the eyes.

In the first place some think, although they are not nearsighted, that they see distant objects more accurately with concave glasses: the smaller dimensions of letters and of other forms appear to them so flattering and agreeable, that they feel bound to boast of their distinctness. Therefore we should never be content with the declaration: 'I see better'; but we should satisfy ourselves of its correctness, by making the patient name the letters.

In some cases objects are really better distinguished by using concave glasses, although the eye is free from M. We meet with this especially in misty opacities of the cornea, when the narrower pupil, which is the result of the tension of accommodation made necessary by the concave glass, diminishes the diffused light. Particularly when the turbidity is local, and is so situated that it disturbs direct vision only when the pupil is dilated, constricting the pupil by using a concave glass, produces a very considerable improvement of the power of vision. . . .—Further, one should beware of mistaking spasm of the ciliary muscle. . . . for M. In speaking of the disturbances of accommodation, I shall revert to this subject. Here it may suffice to state, that the sudden occurrence of the disturbance, in connexion with other phenomena (especially myosis), will lead us to suspect the existence of spasm, which is easily tested by paralysis by atropia. We shall further see, in the disturbances proceeding from high degrees of M, that a certain measure of spasm is not unfrequently combined therewith, and makes the degree of M be too highly estimated.

On the other hand, *actually existing* M *is not always indicated on ordinary investigation.* This depends upon different causes. In the first place, diminished S is to be noted. If, as we have already seen, without the presence of H, a convex glass is sometimes chosen for distance, because the advantage of magnifying the images may counterbalance the disadvantage of diminished acuteness, a concave glass, which diminishes the size and adds little to the distinctness, will, under similar circumstances, where M exists, be rejected. Always too, in the highest degrees of M, a too weak glass is preferred above a completely compensating one, and often vision is better with it: the cause of this lies partly in the diminished S, partly in the fact, that the circles of diffusion prove particularly small in relation to the degree of the M still remaining with imperfect correction. In the second place, a smaller pupil is to be noted. The smaller the latter is, the less disturbance do the circles of diffusion cause in imperfect accommodation. . . . We should take particular care that in trying the glasses the eyelids be not squeezed together, as myopes are accustomed to do, and the circles of diffusion be so diminished.

Next to the examination with glasses is that with the ophthalmoscope. . . .

It is desirable systematically to carry out the ophthalmoscopic investigation for each eye. The emmetropic individual should combine with this ophthalmoscope a glass of 1/10, should look 10° or 15° to the outside of the visual axis directed on a given point, beginning at the distance of 10″, and should gradually approach, so as consecutively to see the cornea, pupil, lens, and vitreous humour; he should, in the investigation of the lens, especially make the patient look for a moment downwards (where the opacity usually begins); in the examination of the vitreous humour he should make him move the eye in different directions, and then suddenly stop at the originally fixed point (so as to see floating flakes); he should again remove, in order, with the interposition of a convex lens, to look into the inverted image; he should then begin again in the original direction, so as to see the entrance of the optic nerve; subsequently he should make him move slowly in different directions, and should look from different points, in order consecutively to pass through the whole fundus oculi; above all, he should not neglect for a moment to make him fix the light in the mirror (in order to judge of the macula lutea); and finally, he should examine, if there is indication for it or if strong magnifying be desired, with a weak object-lens in the inverted image and with the requisite glasses in the unreversed, or employ the method of Liebreich.

The ophthalmoscopic investigation yields essential service in the determination of the degree of myopia: 1°, when the eye is blind, and the nature of the morbid process may be connected with its structure. Helmholtz (1851) determined the M in such a case; it has often occurred to me to be able to give a favourable prognosis for the second eye, because the ophthalmoscope showed me, that the lost eye had been highly myopic. 2°, when, with diminished S, the ophthalmoscope is first used, which now directly gives us tolerably accurate information respecting the existing ametropia: at the first glance into the eye from a certain distance it is evident in strong M, that the inverted image stands before the eye; 3°, when we wish to determine the degree of M in indirect vision, or to establish the existence of locally exalted M, through locally increased staphylomatous distention: in either case the examination with glasses fails;—4°, where simulated or concealed M is suspected; 5°, in children, from whom correct answers are not to be expected.

The degree of M is, as we have already seen, expressed as M=I : R. R is the distance from the farthest point *r* to the nodal point *k'* in the eye, situated about 1/4″ behind the cornea. The position of *r* is found by determining the glass, which neutralises the M: it lies so far in front of this glass as the focal distance amounts to. If, for example, the required glass is = — 1/12, *r* lies 12″ in front of the glass, and if the glass stands 1/4″ before the eye, and therefore 1/4″ + 1/4″ = 1/2 in front of *k'*, *r* lies 12 1/2″ from *k'*, and consequently R is = 12·5 and M = 1 : 12·5 (compare p. 27). We now understand distinctly, that the distance *r* (that from the glass to *k'*) signifies little when the glass is weak: . . . But 1/2″ difference in distance acquires much importance, when strong glasses are in question; for example, glasses of — 1/2, which may then act as glasses of — 1/2·5.

. . . .

The strongest concave glasses to be met with in spectacle boxes, are of — 1/2. With these we can at most neutralise M = 1 : 2 1/3. Now, not unfrequently, still higher degrees of M occur, and in order to determine these, we must place — 1/2 as spectacles before the eye, and examine what glass must in addition be held in front of them, in order to produce complete neutralisation. Let this second glass = — 1/3, then both combined give — (1/2 + 1/3) = — 1 : 1·2; and to this we have still to add the distance *x* from the strongest glass to *k*, so that, with *x* = 1/2″, M is, in the case supposed = 1 : 1·7. If great accuracy is desired, we must, in the calculation, also take into account the distance between the two glasses, and reckon, for example, — 1/2, placed at 1/4″ before — 1/2, only as 1 : 3 1/4. We may then further, with sufficient precision, measure the distance to *k'*, that is *x*, from the middle of the mass of the biconcave glass — 1/2.

M occurs in the most different degrees from E to M = 1 : 1·3, probably still higher. The highest degrees are, however, the rarest. For many thousand eyes of myopic patients who have consulted me, the degree of M has been noted. The following table thence calculated for one thousand eyes, gives a synoptical view of the relative occurrences of the different degrees.

At first, to begin with the highest degrees, for each 1/24 M less, the number of cases increases. That the increase subsequently becomes slower, and finally even gives place to diminution, depends solely upon the fact that comparatively few of those affected with the slight degrees apply to the oculist. Nevertheless, I have endeavoured, in

Degree of the myopia	Number of cases in 1000
16 : 24 = 1 : 1 1/2	
	3
15 : 24 = 1 : 1 2/3	
	4
14 : 24 = 1 : 1 5/7	
	3
13 : 24 = 1 : 1 11/13	
	5
12 : 24 = 1 : 2	
	13
11 : 24 = 1 : 2 2/11	
	16
10 : 24 = 1 : 2 2/5	
	24
9 : 24 = 1 : 2 2/3	
	47
8 : 24 = 1 : 3	
	49
7 : 24 = 1 : 3 3/7	
	68
6 : 24 = 1 : 4	
	83
5 : 24 = 1 : 4 4/5	
	110
4 : 24 = 1 : 6	
	149
3 : 24 = 1 : 8	
	171
2 : 24 = 1 : 12	
	169
1 : 24 = 1 : 24	
	85
0 : 24 = 1 : ∞	

connexion with other observations, *approximatively* to express the relative occurrence of E and of the different degrees of M and H, among the Dutch population in general (fig. 36). Along the figure are given, from 1 : ∞, above, the degrees of M to M = 1 : 1·3, and beneath those of H to H = 1 : 2 2/5, being the highest degrees observed by me. The lengths of the transverse lines correspond to the frequency of occurrence in the adjoining degrees, with this exception, however, that the lines *a* and *a′* next to 1/∞ must be supposed to be ten times longer.

. . . .

From the figure it now appears, that in the slightest degrees H occurs more frequently than M, while the contrary obtains in the higher degrees: M = 1/24 is already more frequent than H = 1/24. The highest degrees of both are so rare, that they can be expressed only by a point. From this figure it is very clear, that the emmetropic is the normal eye. . . .

On the distribution of M, position in society has a great influence. It is remarkable how much in the registers of my private patients (the more wealthy) the M,—in those of my hospital patients, on the contrary, the H predominates. To be correct, I must say, that among those in easy circumstances not much less H, but much more M occurs. That, moreover, the inhabitants of towns suffer more from M than those of the country is a matter of general observation. Ware (1812), upwards of 50 years ago, directed his attention to this fact.

. . . .

Further, I believe that M is not equally prevalent in all countries. It is certainly more specially proper to cultivated nations. Furnari (1860) tells us that among the Kabyles no myopes occur, and among the States of Europe visited by me, I, both in general life and in the cliniques, nowhere met with relatively so many myopes as in Germany. It would be of great importance, to possess accurate statistics of the ametropia occurring, at a given time, in a particular category of men, especially, for example, among the students of a universtiy, in order

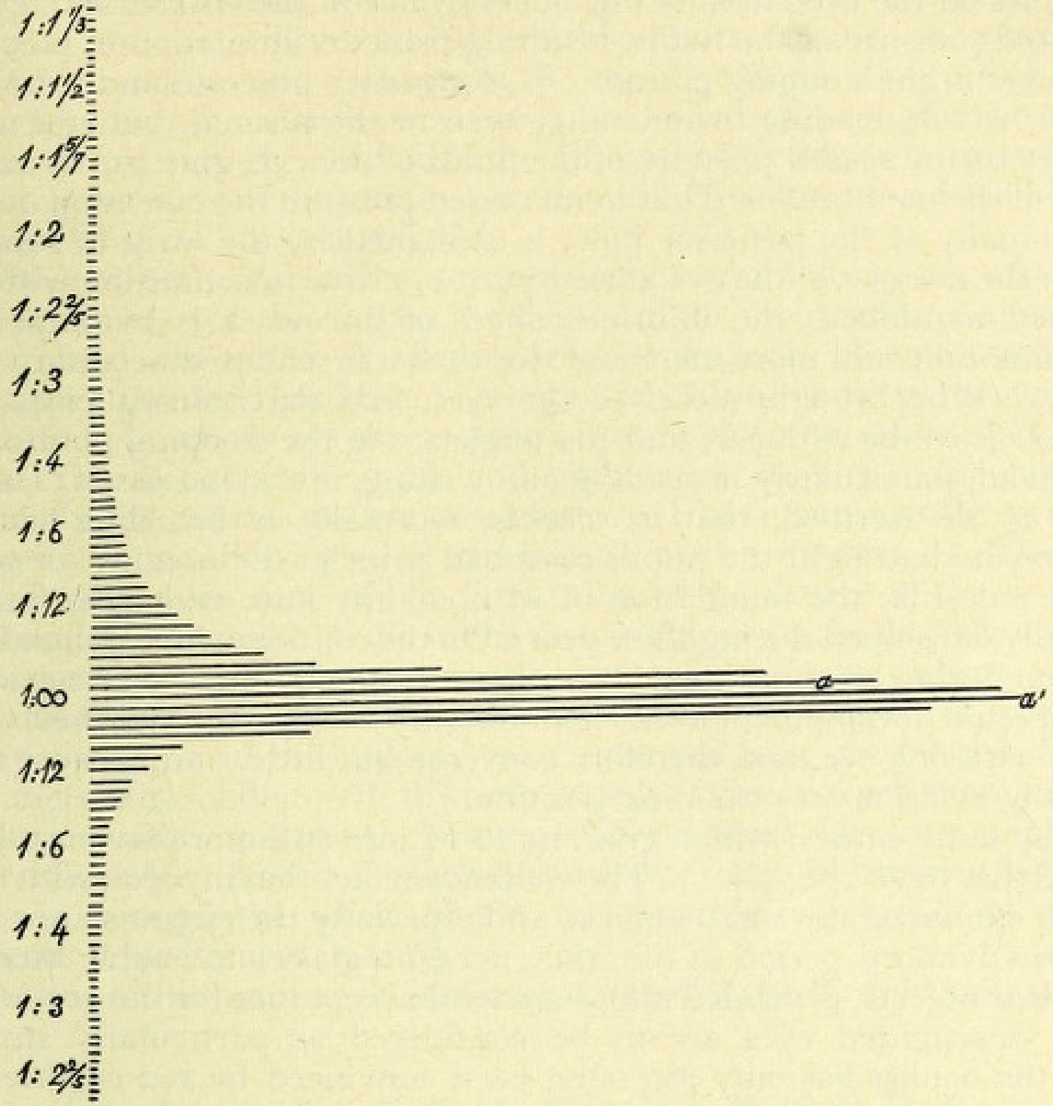

Fig. 36.

to be able to compare them with the results of repeated investigations at subsequent periods. If it were thus found—and I can scarcely doubt that it would be so,—that the M is progressive in cultivated society, this would be a very serious phenomenon, and we should earnestly think of means of arresting this progression. Not only is the myope not in a condition to discharge all civil duties, not only is he limited in the choice of his position in society, but in the higher degrees M leads to disturbance of the power of vision, and threatens its subject with incurable blindness.

The distribution of M, chiefly in the cultivated ranks, points directly to its principal cause: tension of the eyes for near objects. Respecting this fact there can be no doubt. But the explanation of it is not so evident.

. . . .

Three factors may here come under observation: 1°, pressure of the muscles on the eyeball in strong convergence of the visual axes; 2°, increased pressure of the fluids, resulting from accumulation of blood in the eyes in the stooping position; 3°, congestive processes in the fundus oculi, which, leading to softening, even in the normal, but still more under the increased pressure of the fluids of the eye, give rise to extension of the membranes. That in increased pressure the extension occurs principally at the posterior pole, is explained by the want of support from the muscles of the eye at that part. . . . Now in connexion with the causes mentioned, the injurious effect of fine work is by imperfect illumination, still more increased: for thus it is rendered necessary that the work be brought closer to the eyes, and that consequently the convergence be stronger, and the tendency to the stooping position of the head, particularly in reading and writing, is also increased. To this it is to be ascribed, that in schools, especially in boarding-schools, where, by bad light the pupils read bad print in the evening, or write with pale ink, the foundation of M is mainly laid, which, in fact, is usually developed during these years. On the contrary, in watchmakers, although they sit the whole day with a magnifying-glass in one eye, we observe no development of M, undoubtedly because they fix their work only with one eye, and therefore converge but little, and because they usually avoid a very stooping position.

The same causes, which give rise to M, are still more favourable to its further development. . . . The wellknown fact that myopes, with little light, can recognise small objects, and especially the circumstance that at an advanced period of life, they need no glasses to enable them to see near objects, procuded almost general acceptance for the prejudice, that nearsighted eyes are to be considered as particularly strong. But the oculist has only too often been convinced by sad experience, of the contrary. I have no hesitation in saying, that a near-sighted eye is not a sound eye. . . .The characteristic of myopia . . . is a prolongation of the visual axis, and the latter depends upon morbid extension of the membranes. If this extension has attained to a certain degree, the membranes are so attenuated, and the resistance is so diminished, that the extension cannot remain stationary. In this progressive extension progressive myopia is included, which is a true disease of the eye.

From what has here been said, it will easily be understood, that high degrees of myopia are less likely to remain stationary than slight degrees are; at a more advanced time of life they even continue to be developed, with increasing atrophy of the membranes. In youth almost every myopia is progressive; the increase is then often combined with symptoms of irritation. This is the critical period for the myopic eye: if the myopia does not increase too much, it may become stationary, and may even decrease in advanced age; if it is developed in a high degree, it is subsequently difficult to set bounds to it. At this period, therefore, the above-mentioned promoting causes should be especially avoided. On this point I cannot lay sufficient stress. Every progressive myopia is threatening with respect to the future. If it continues progressive, the eye will soon, with troublesome symptoms, become less available, and not unfrequently at the age of 50 or 60, if not much earlier, the power of vision is irrevocably lost, whether through separation of the retina from the choroid, from effusion of blood, or from atrophy and degeneration of the yellow spot. In a subsequent section I shall have to treat of these sad results of M.

The number of myopes most accurately examined by me, amounts to more than 2500. Each time the degree of the myopia was accurately determined and noted. If after months or years the myope consulted me again, the determination was repeated. I thus came to the conviction, that almost always the myopia is somewhat progressive, that such is the rule between the 15th and 25th years, and that the highest degrees often exhibit the greatest increase. I have never in the periods of youth or manhood proved diminution of the myopia, . . . Even at a more advanced time of life diminution of the degree of the myopia seldom occurs. Undoubtedly in the near-sighted eye the dioptric system undergoes the same change as in the normal, but when at the same time the visual axis increases in length, . . . this change is wholly or partially compensated, and the myopia may even continue progressive at an advanced time of life.—All this is the result of direct experience, which, however, with respect to the same persons, extends only over some few years. In order, therefore, to get a satisfactory idea of the course of the myopia through the whole of life, the recorded experience of many patients must be made use of.

When in this manner the ordinary course of the farthest point, that

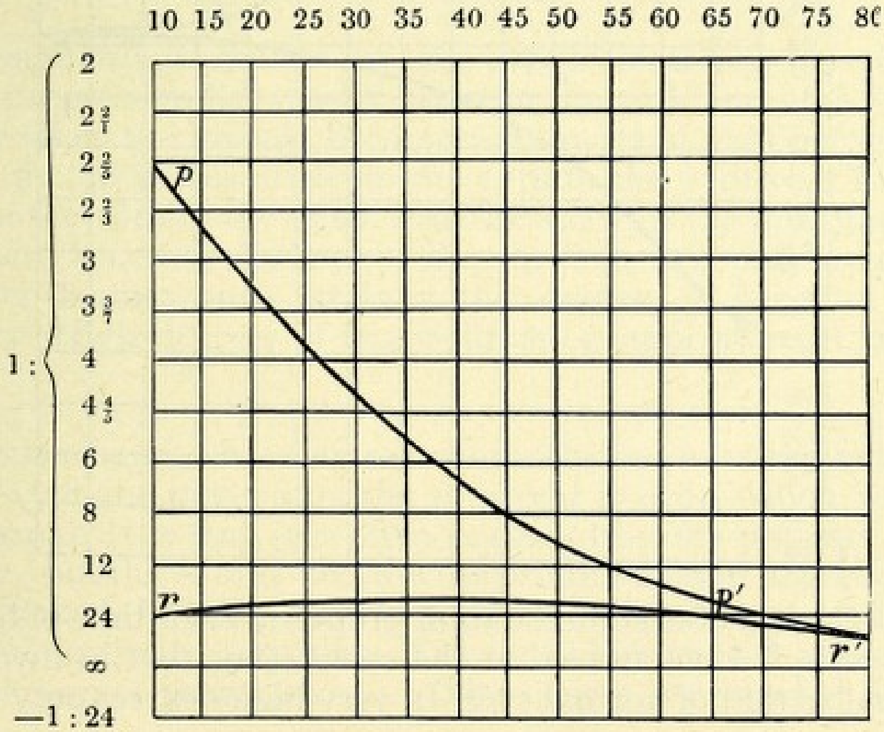

Fig. 37.

is the degree of the myopia through all periods of life, had been ascertained, it was not difficult to infer the course of the nearest point, as has been done in figs. 36, 37 and 38. For this it was only necessary

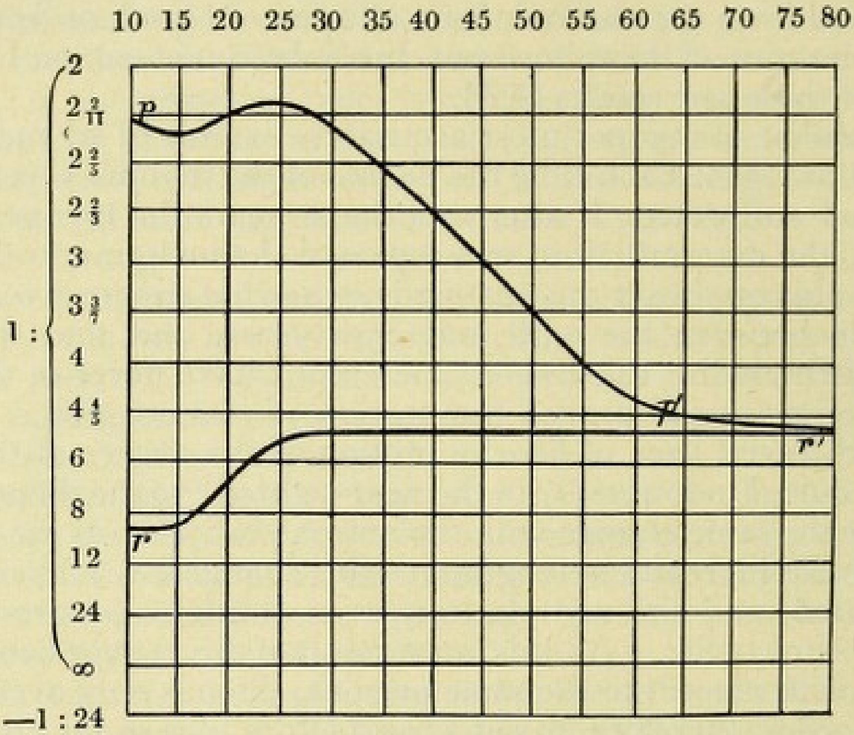

Fig. 38.

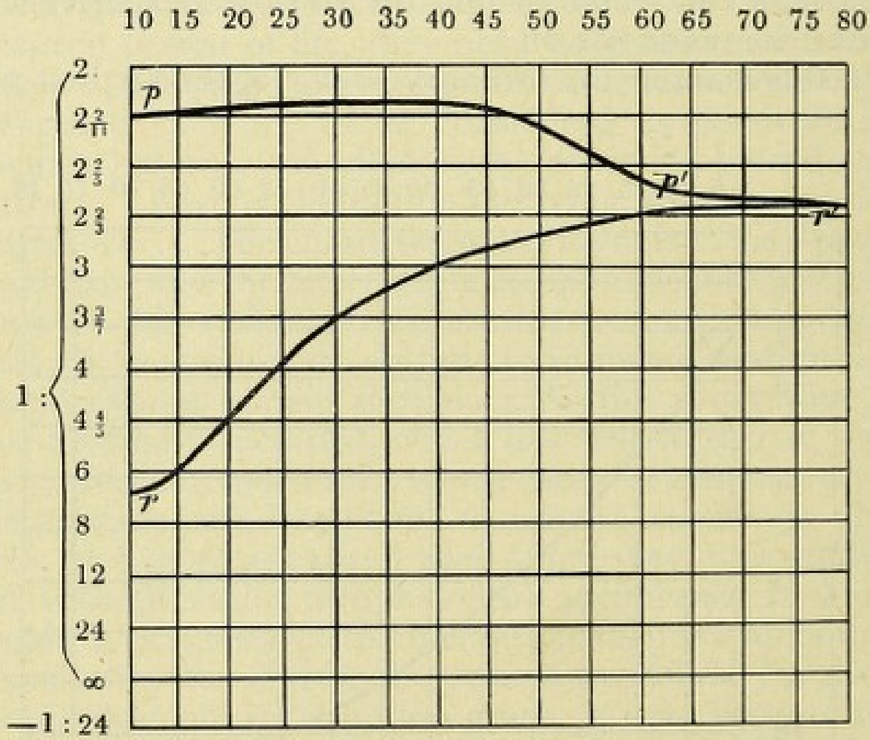

Fig. 39.

to know the range of accommodation proper to each time of life. With respect to this, I have arrived at the conclusion, that in myopes it is about equal to that of normal eyes. In very high degrees only it is less;

and here the whole eye, particularly the anterior part, the m. ciliaris included, is extended, which may be noted as a sufficient cause thereof.

These observations are illustrated in the sketches of figs. 37, 38 and 39, the meaning of which, after what has been said respecting fig. 31, needs no further explanation. They represent three categories of myopia, in its course of development, as it mostly occurs. Fig. 37 is *a stationary*, Fig. 38 a *temporarily progressive*, fig. 39 a *permanently progressive* myopia. The course of the myopia is shown by the line *r r'*, which represents the farthest point. The range of accommodation, proper to each time of life, is expressed by the distance between *r r'* and *p p'*. I must allow myself to make some observations respecting each of these categories.

Fig. 37 is called *stationary myopia*. Yet we see the myopia ascend from 1/24 to 1/16. As I have above remarked, such ascent is, in the years of development, to be considered as the rule. Consequently if the ascent be not more remarkable, the myopia may, in contrast to the progressive, be called stationary. In general the slight degrees belong to this form. For this reason, a myopia of only 1/24 was chosen for Fig. 37.

. . . .

In the most favourable course of the myopia, it remains quite stationary during the period of manhood, and may, on the approach of old age, even diminish a little, as the figure shows. This, however, seems to occur but very rarely. The generally received opinion, that with the increase of years the degree of myopia usually diminishes, is an error, based partly upon the incorrect idea, that the degree of the myopia is determined by the nearest point, partly on the incontestable fact, that vision at a great distance gradually becomes more distinct, which is, however, to be attributed rather to the increasing constriction of the pupil.

The *temporarily progressive* myopia is represented in fig. 38. In this case the progression lies mostly between the 12th and 25th years. It is fortunate when the myopia becomes stationary at least before the 30th year. In fig. 38 it ascends from the 13th to the 35th year from 1/8 to 1/5; from the 18th to the 22nd year the ascent is the most rapid. After that it here becomes stationary. But, in fact, it is only exceptionally that, after having once attained this degree, it becomes perfectly stationary. High degrees of nearsightedness appear never to be congenital.

. . . .

On the other hand, I have extremely rarely seen near-sightedness arise after the 15th and never after the 20th year in eyes, which were previously normal. It is true it is often supposed by the patients that such is the case, but this is only because the primitive slight degree of myopia was overlooked. In this primitive degree, trifling as it was, lay the germ of the affection; the complaints of various kinds are not made until the myopia becomes progressive.... The course represented in fig. 38

is still to be considered comparatively favourable. It seldom becomes in manhood completely stationary. . . . Often it continues to increase, at least in some degree, and thus approaches to the

Permanently progressive myopia, represented in fig. 39. In the majority of cases belonging to this category, the myopia is considerable even at the age of 15 years. Therefore it is here assumed $= 1/6$. It ascends most rapidly to the 25th, indeed even to the 35th year, more slowly at a more advanced period, incessantly, as it appears, but still often in jumps. The line $r\ r'$ gives a view of this. It may ascend to 1 : 2 and more. The worst is then to be feared. It is rare at 60 years of age to find a tolerably useful eye, with myopia of 1 : 2 1/2 or even of 1 : 3. Diminution of such degrees of myopia at an advanced time of life, is not to be thought of: the influence of the increasing distention of the eye in the direction of the visual axis, is never overcome, and is even not compensated by the diminishing refraction of the lens.

From the progression of the M it follows, that the higher degrees occur proportionately most frequently at a more advanced time of life. How far very young children are affected by it, has not been accurately investigated. A commencement in this direction was made by Ed. v. Jaeger, who has also stated his intention of following the course of the refraction in the same persons through their whole life. We wish him for that purpose a long life and faithful patients. He should, however, not have neglected the value of the method, followed by me, of throwing some light on this subject.

. . . .

I cannot, with any accuracy, give the proportion in which hereditary cases occur; but this I may say, that where I found near-sightedness in one or more of the children, and had an opportunity of examining both parents, I only exceptionally saw M wholly wanting in both, while, on the other hand, when one and equally when both parents were myopic, the predisposition almost always passed on, at least to some of the children. . . . Experience shows further, that where only a trace of M is present in youth, it inevitably becomes further developed, and that the greatest care leads to nothing more than limitation of the degree.

. . . .

In some families the M has attained a high degree, and the danger is the greater, because, according to experience, the hereditary tendency manifests itself the more certainly, the more the myopia has already been transmitted through a number of generations, and has assumed a typical character.

. . . .

§ 27. *Results of the Ophthalmoscopic Investigation of the Myopic Eye*

Since the ophthalmoscope has made the fundus oculi accessible to examination during life, our idea of the anatomical basis of M has undergone a complete modification. Ophthalmoscopic investigation has shown that, almost without exception, even in moderate degrees of M, changes, especially in the chorioidea, are to be observed; and it has now further been found, that these changes are the expression of atrophy of the chorioidea, which, combined with atrophy of the sclerotic, is, as well as the latter, dependent on a distention of the posterior part of the eyeball. *Myopia* and *staphyloma posticum* have thus become nearly synonymous.

Thousands of myopic eyes have been examined by me; of not less than 700 do I possess more or less detailed drawings or sketches, of some eyes more than one, with an interval of some years; and in every case sex, age, degree of M, and in many instances accommodation, movements of the eye, acuteness of vision, hereditariness and accessory disturbances have been noted. From these observations . . . the following description are in great part borrowed: much of the same is, however, already to be found in the writings of my predecessors. The principal changes are: *atrophy of the chorioidea, on the outside of the entrance of the optic nerve*, when highly developed, combined with *change of form of the nerve-surface, a straightened course of the vessels of the retina, incomplete diffuse atrophy of the chorioidea in other places*, and *morbid changes in the region of the yellow spot.*

. . . .

Of the changes the atrophic crescent on the outside of the nerve-surface is the most common and the most characteristic. This is, the time of life being equal, in general more fully developed the higher the degree of M is, and for equal degrees of M it is more developed the more advanced the age of the individual is. The subjoined table exhibits the length of the axis of the atrophied part, in relation to the age and the degree of M, deduced from observations on 1400 eyes.

LENGTH OF THE AXIS* OF THE ATROPHIC CRESCENT IN MILLIMETRES WITH

Age in years	M= 1/∞ to 1/12	M= 1/12 to 1/6	M= 1/6 to 1/4	M= 1/4 to 1/3	M= 1/3 to 1/2
10 to 30	0·20 mm	0·43	0·56	0·74	1·25
30 to 50	0·30	0·70	0·97	1·36	1·68
50 to 80	0·71	1·05	1·18	1·80	2·13

* The axis of the atrophic part was determined by measuring the sketches made of 700 cases of myopia. For actual magnitude the nerve-surface was used as a scale, whose diameter was assumed = 1·9 mm. In the annular and in the circular atrophy, the extent on both sides of the nerve-surface was assumed as axis. Imperfect and undefined atrophy are not included.

. . . .

Taking into account that the degree of the myopia also, at least in most cases, increases, we may even infer that the atrophy increases with age still more rapidly than the numbers belonging to the same column indicate. Probably we approach the truth by reading off in the diagonal direction, and thus assuming that, when the axis of the atrophy at twenty years amounts to 0·20 mm., this at 40 years increases to 0·70, and at 65 to 1·18.

After the simple announcement of the facts, I shall now endeavour to give a sketch of the development of the atrophy and of its concomitant phenomena, as the ophthalmoscope reveals them in the myopic eye.

In a very young individual atrophy is, in moderate degrees of M, very rarely to be observed. Hasner (1860) declares, however, that he has seen it remarkably developed at four or five years of age, and Ed. v. Jaeger has, from the examination of children in schools, even come to the conclusion, that a particular form of atrophy, which sometimes led him to recognise one child as brother or sister of the other, differing in each of the two eyes, may be hereditary. Even in nurslings and new-born infants of myopic mothers, he saw the tendency to atrophy of the same form. I too have seen, without particularly looking for them, some cases of distinctly developed atrophy at the ages of five and seven years. . . . There first appears either an irregular, small projection, rich in pigment to the outside of the optic nerve, or a little crescent, distinguished from the adjoining fundus by a brighter red colour, its boundary being somewhat darker at the outside than the contiguous fundus. In the first case the atrophy extends directly from the margin of the nerve-surface, while the pigment, in a certain sense, removes outwards, and a white strongly reflecting line, which soon assumes the crescentic form, appears along the nerve-surface. In the second case . . . further development consist at first rather in the becoming more perfect, than in the extension of the atrophy. Often, however, we now see a second convex line of pigment arise at the outside of the original crescent. While in adolescence myopia is gradually more and more developed, there not unfrequently set in troublesome symptoms of irritation, and on ophthalmoscopic examination we now often find the most external boundary of the atrophy, as well as the nerve-surface itself, in a congestive condition. If the myopia seems likely to attain only a slight degree, there occur in adolescence but the first traces of atrophy . . . But where myopia of 1/6 or 1/5 exists from the sixteenth to the twentieth year, we find, almost without exception, a very decided, almost perfect atrophy accurately defined under the form of a crescent, whence it sometimes appears that precisely this part is more highly concave than the rest of the fundus. The pigment-epithelium has disappeared upon this surface, the chorio-capillaris seems to be no longer present, the greater chorioideal vessels are slender, extended, sometimes they have almost wholly disappeared, while only brownish-grey spots still indicate the intervascular space.

. . . .

Apparently, the boundary of the pigment is thus displaced outwards. In so far as the membranes at the outside of the nerve-surface are extended, this is really the case. But in addition we must, in explanation of the process, assume that in the place where, at the inner boundary of the hyperæmia, in consequence of extension the atrophy begins, the pigment is absorbed, and at the same time is more strongly formed on the hyperæmic line extending outwards. In general the stronger formation of pigment is due to hyperæmia of the chorioidea. Now, if on the one hand, probably through a more rapid course of the atrophy, the absorption of the pigment is imperfect, and if black spots therefore remain in the atrophic part, the hyperæmia on the other, extends in some points more outwards, and here gives rise to increase of pigment. Thus it would appear too, that the spots of pigment existing at both sides of the boundary of the atrophy may be explained. A real displacement of the pigment over the surface of the chorioidea . . . seems here not to be admissible.— . . . We may remark, that in slight degrees the form is never annular, and that the annular and circular forms are to be expected when the crescent rapidly extends far around the nerve-surface, most of all, when also at the opposite inside of the nerve-surface a second smaller crescent is early formed.

The atrophied part is for a long time regular in form, and beyond it scarcely any change is to be seen in the fundus oculi: at most it may be observed, . . . that the chorioideal vessels are more separated, and are in part more slender than usual. But after the five-and-thirtieth, and particularly after the fortieth year, in high degrees of M, . . . the boundary line of the atrophy sometimes describes a more irregular form, or atrophic spots have formed next the original ones, which by the extension of both may subsequently coalesce. The most important change beyond the seat of the original atrophy is the degeneration in the region of the yellow spot, especially when it occupies the fovea centralis. It is true this may occur at any age even in non-myopic eyes, . . . but a particular morbid change, based upon extension and atrophy of the sclerotic and chorioidea, whereby the retina here also becomes secondarily disturbed in its function, is decidedly peculiar to high degrees of myopia. As we know that the yellow spot often corresponds to the apex of the staphyloma posticum, and that in high degrees the atrophy of the sclerotic and chorioidea is here the strongest, this can by no means surprise us. In the first place, there often arises, in $M = 1/4$ or more, in advanced life, imperfect diffuse atrophy of the chorioidea, in a belt passing from the outside of the atrophy through the yellow spot, and recognisable by a disproportionately white or yellow-dotted grey, sometimes strongly reflecting almost glittering appearance, with interspersed pigment; and where this occurs, the region of the yellow spot never altogether escapes; but in addition, at a comparatively less advanced age, the above-described local degeneration of the yellow spot not unfrequently supervenes on the original atrophic crescent, while the part situated between this and the yellow spot still deviates but little from the normal. On one occasion I observed this in a patient aged fifteen; under thirty years of age it is, however, even in the highest degrees of M, still rare; after the thirtieth year it recurs with comparative frequency in myopia of 1/3 or more, and at sixty the yellow spot, and even the fovea centralis, have in M of 1/3, often, and in myopia of 2 1/2 and 1/2, they have, I might almost say, always suffered. This occurs both when the original atrophy is annular or circular, and when it extends only to one side, sometimes even when the axis of the atrophy is still short, and is not directed to the yellow spot.

The above-described changes of the nerve-surface are distinctly seen only in comparatively high degrees of myopia, for example, higher than 1/5, and in these degrees the straightened direction of the retinal vessels, especially at the side of the atrophy, is not to be mistaken.

. . . .

Other deviations, to which highly myopic eyes are liable, as effusion of blood, detachment of the retina, glaucomatous degeneration of the nerve-surface and opacity of the lens, are not constant and not sufficiently peculiar to M, to justify their description here as the simple results of a further development of M. More correctly might chorioiditis disseminata, to be treated of in the following section, be referred to M.

Movable flocculi in the vitreous humour are, on the contrary, but seldom absent in high degrees of M.

We have still, in conclusion, two important questions to treat of: first, how far the atrophy, above described, is constant in myopia; secondly, whether it occurs only in M, and is, therefore, characteristic of the latter?

. . . .

As I have already remarked, slight degrees of myopia may exist in young persons without atrophy, but wether the myopia have remained stationary, or have been further developed, in the fortieth year traces of atrophy are usually no longer absent.

. . . .

We are therefore justified in saying that *myopia depends on a condition in which the development of atrophy is included.* In the following section it will more fully appear that M may also exceptionally be produced by some other changes of form of the eyeball; but, singularly enough, in those cases in which morbidly developed greater convexity of the cornea contributed to the M, the atrophy peculiar to staphyloma posticum is found only extremely rarely entirely absent.

As to the second question, we cannot consider the atrophy described to be completely characteristic of M. We often see, at least in mature age, slight traces of atrophy at the outer margin of the nerve-surface, sometimes even an annular or circular atrophy, without M being present; twice I have observed it even with certain degrees of H. . . . In the second place, a peculiar form of atrophy not unfrequently occurs around the nerve-surface in glaucoma. This is annular, and attains only a moderate magnitude; evidently the chorioidea is here also atrophic, which atrophy appears to me to be connected with the excavation of the nerve-surface: probably in this case inflammation is also in operation.

Note to § 27
The ophthalmoscopic investigation of strongly myopic individuals in the non-inverted image, for which the use of a highly negative eye-piece is necessary, requires a great deal of practice. . . . But for ordinary cases, examination in the inverted image is quite sufficient. Without the use of an object-glass, the inverted image of the fundus oculi stands before the myopic eye, at the distance for which the latter is accommodated. . . . But it is better to add a convex object-glass to the observed eye, whereby the field of vision becomes larger and, by movement of the glass in the vertical plane, extends alternately in different directions. In the choice of this object-glass we find ourselves, however, in a difficult dilemma: if we select one too strong, the image becomes quite too small; if we choose one too weak, we obtain too small a field of vision. The too small image we can partially counteract, by combining a pretty strong eye-piece with the ophthalmoscope, whereby the observer can, without any effort, see the little inverted image very near, and magnified: in general, when the investigator is not myopic, such a convex glass is to be recommended. Therefore a pretty strong object-glass, with which the magnifying is less, but the field of vision is greater, is advantageous, and this is to be combined with a tolerably strong eye-piece.—Liebreich has proposed a particular method of examining very highly myopic eyes. He uses no object-lens, but only a strong eye-piece, and with this approaches the eye so much that the iris lies nearly in the focus of this lens, so that a very large field of vision is obtained. At the same time, the inverted image must come to lie between the eye observed and the lens, in order that it may be seen through the latter . . . Then we have really the advantage of seeing a large field of vision under a strong magnifying power.

. . . .

§ 28. *Anatomy of the Myopic Eye*

In the preceding paragraphs we have seen, that M depends almost exclusively upon the prolongation of the visual axis, connected with staphyloma posticum.

. . . .

If we now endeavour to form an idea of the development of staphyloma posticum, the optic nerve with the membranes of the eye and the nerve-surface itself, will, in the first place, attract our attention. According to ophthalmoscopic examination, we have in these parts to seek the commencement of the affection, and in many instances anatomy at least does not oppose this view. We have then to suppose that in these cases the dispostion consists in this, that the sclerotic near the optic nerve is more extensible, particularly to its outside, and that by this extension the outer sheath of the optic nerve is soon a little removed from the latter, and the sheath of connective tissue is so extended (compare fig. 40 *c'*). So soon as this happens, the thin layer of sclerotic tissue,

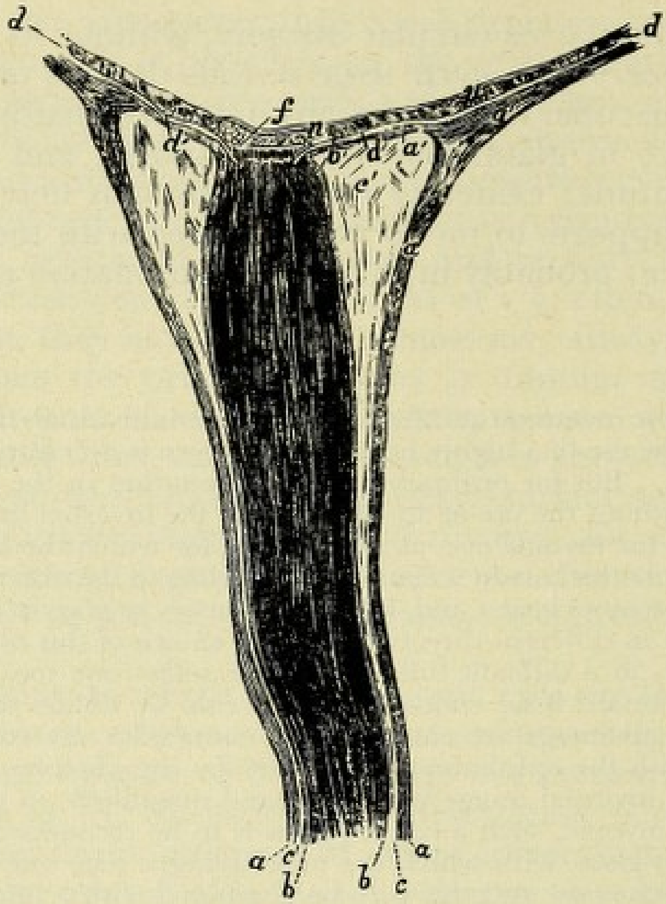

Fig. 40.

b', situated in front of the sheath mentioned, must be very much attenuated, and the same is true of the chorioidea, *d'*, connected therewith, and forming, with the fibrous layer mentioned, the so-called lamina cribrosa, between the nerve-fasciculi. At the side of the nerve-surface, therefore, the retina now rests on an extended and attenuated chorioidea and sclerotic, which posteriorly further lose all support. It is not until we come somewhat more outward that we find the external sheath of the optic nerve, *a*, strengthening the sclerotic. With this extension, in the immediate neighbourhood of the optic nerve, the origin of the atrophic crescent seems to be really connected: the chorioidea, *d'*, is here united with the nerve, both immediately through the fibres, which are continued between the fasciculi of the nerve, and mediately through their connexion with the inner sheath of the nerve. At the borders of this attachment its vessels cease; on any extension, therefore, obstruction to the circulation in the extreme terminations of the choriocapillaris must easily arise, and thus the condition for incipient atrophy is supplied. We find something similar in the origin of emphysema of the lungs from atrophy of the most distended pulmonary vesicles, which thereby also finally lose both their capillary network and their pigment.

. . . .

The extension at the margin of the optic nerve takes place often only at one side, and indeed principally at the outside, with which the atrophic crescent keeps pace at the same side. The number of my observations is not sufficiently great to enable me to form a positive opinion,—but it appears to me very likely that, if the apex of the staphyloma falls nearly in the optic nerve, the outer sheath has given way at all sides of the nerve, and that to this the annular and circular atrophy of the chorioidea then also correspond: in the eye, from which fig. 40 was taken, the atrophy was really circular. If, as is usually the case, the apex of the staphyloma is situated at the outside of the optic nerve, atrophy of the chorioidea is also found especially at this side, and even the fact, that the yellow spot, to which the apex of the staphyloma often corresponds, is situated at the outside of and a little beneath the nerve-surface, and that the axis of the atrophic crescent usually extends in this same direction, indicates most distinctly, that there is a connexion between the apex in question and the direction in which the atrophy of the chorioidea advances.

. . . .

As to the narrowing of the nerve-surface in a direction perpendicular to the axis of the crescent, observed with the ophthalmoscope, I can give no satisfactory explanation.—Now, in the ordinary cases, where the optic nerve does not lie in the apex of the staphyloma, it may be a question, whether the extension does not commence rather in the region of the yellow spot, and only secondarily become communicated to the outside of the optic nerve. This view is the more admissible, not only because by it the position of the optic nerve at the inside of the ellipsoid would be explained, but also because in very young persons, with comparatively high degrees of M, the crescentic atrophy of the chorioidea is still often absent, or at least is very slight. We can also very easily imagine, how extension in the region of the yellow spot gives rise to the atrophy. In the yellow spot the chorioidea, which here abounds in pigment, is more intimately connected with the sclerotic. If the membranes here give way backwards, the extension will be equal on all sides, and the chorioidea will, moreover, the more easily maintain its connexion with the sclerotic, because precisely here it is more intimately connected with it. If now the sclerotic too gradually extends in the direction of the optic nerve, the chorioidea becomes very tense over this part, for we may assume the yellow spot and the outer margin of the optic nerve to be two fixed points: at the attachment, therefore, to the outside of the nerve-surface the chorioidea is particularly strongly drawn, and considering that the chorioideal vessels terminate precisely at this boundary, the production of atrophy by extension cannot surprise us; according to the direction of the tension which takes place it is even easy to understand why the atrophy should assume the crescentic form. The atrophy at this place will now certainly be still promoted, so soon as also in the immediate neighbourhood of the nerve the sclerotic is extended, and thus the outer sheath of the optic nerve gives way outwardly. This giving way can almost without exception be demonstrated, and it is attended with the necessary consequence, that the arterial circle, known even to Zinn, occurring in the sclerotic around the optic nerve, as Jaeger has shown, is removed from the nerve. On the whole, the outer half of the sclerotic is extended in a higher degree than the part situated at the inside of the nerve: there it is consequently also in general thinner. With this is connected the fact that, as we have already seen, the yellow spot removes towards the inside, so that it may even go beyond the axis of the cornea, whereby the visual line cuts the cornea to the outside of its axis. That in this extension atrophy does not occur at the outside of the yellow spot in the anterior part of the chorioidea so readily as at the inside, is easily explained from the great extensibility of the chorioidea in this direction. It appears, moreover, gradually to move a little over the surface of the sclerotic: thus, at least, I think the retrogression of the iris, of the ciliary process and of the chorioidea itself, with the ciliary muscle must be explained, in those cases in which the anterior part of the sclerotic has retained almost its normal thickness. However, there exists everywhere more or less extension of the chorioidea, and that this gives rise to diffuse atrophy and to diminution of the elastic resistance, needs no proof. To the elastic resistance of the chorioidea, I think essential importance must be attached. If the membranes of the normal eye be all cut through together, the chorioidea is seen to retract, leaving the sclerotic bare at the edge. This proves that the chorioidea may be displaced, and moreover, proves its tension. During life, in consequence of the vessels being full, of the tone of the blood-vessels, and of muscular fibres scattered here and there, the tension of the chorioidea is undoubtedly still greater. By virtue of this tension it bears a part of the pressure of the fluids of the eye, which now does not act entirely upon the sclerotic, and it is evident that where an atrophic condition has set in, and the chorioidea has given place to a thin, brittle membrane, the full pressure comes to bear upon the already extended sclerotic. Consequently a tolerably advanced staphyloma does not easily become stationary, the less so because the pressure of the fluids in the myopic eye is in general somewhat increased. Therefore, also, in staphyloma the blood-vessels and the inequalities of the chorioidea, as well as the elongated, but not easily atrophied, ciliary nerves, make deep impressions on the inner surface of the atrophic sclerotic. More than once this has attracted my attention. The extension, and with it the atrophy, is particularly great. On this excessive extension the above-described local changes mainly depend, whereby the function of the retina comes to suffer. It is easy to see, although it has not been proved by accurate microscopic investigation, that under such extension the outermost layer, which consists of radiatingly placed very small bulbs, must suffer; that these bulbs at least must be separated, irregularly distributed and made oblique, and that they must easily be actually destroyed. In other parts, too, of the retina, the rods and bulbs, as we have seen, appeared to be more separated. That, on the contrary, in the fibrous layer little or no disturbance occurs, will not appear strange, when we consider how well the structure and function of nerves in general resist extension by morbid tumours or from other causes. . . . In this respect the retina has a great advantage over the sclerotic.

The changes in the *vitreous humour* may have a different origin. They may depend upon extravasations of blood, which, perfect as the absorption may be, never leave behind them an absolutely clear vitreous humour. Solution of the as yet so badly explained connexion of the vitreous humour, gives rise to turbidity, as is seen in traumatic injuries, and where foreign bodies are present.

. . . .

Now the considerable distention of the vitreous humour in staphyloma posticum probably also causes laceration, at least synchysis, and some turbidity is consequently to be expected. Finally, in some cases, an irritative or inflammatory condition of the retina and chorioidea is also certainly in operation.

We have now approached an important point. The question is, how far staphyloma posticum is connected with inflammation. It is known that Von Graefe at first thought the practical idea of sclerotico-chorioiditis posterior applicable to it: but that he in vain sought, in two eyes which he had the opportunity of examining anatomically, the proofs of preceding inflammation.

. . . .

Thus much is certain, that the staphyloma posticum cannot be considered as a simple result of sclerotico-chorioiditis, and that without the disposition, and that usually of an hereditary nature, it is not easily developed. Moreover, it must be admitted that without symptoms of irritation or inflammation staphyloma posticum may attain a tolerably high degree. But, on the other hand, there is no doubt that the morbid distention very often leads to irritation and inflammation, and finds therein, with softening of the membranes, a condition of rapid development.

. . . .

Von Jaeger's doubt, whether chorioiditis disseminata occurs more frequently in highly myopic eyes than in others, indeed surprises me. In high degrees of M this inflammation is atacertain time of life the rule. In the course of the morbid distention inflammation is readily developed, which cannot be considered as a new condition, but usually makes itself known, at an early period, as more or less distinct irritation. Even in youth, as Hasner also obeserves, symptoms of irritation are usually present even in slight degrees of M, and ophthalmoscopic investigation now reveals to us capillary redness of the nerve-surface, and, what is remarkable, sometimes only over the half of its extent.

Probably there is in this case, in consequence of tension of the chorioideal ring and of the lamina cribrosa, some mechanical irritation, perhaps even pressure on the smal fasciculi of the optic nerve. Subsequently, as the extent becomes greater, and the disproportionate tension is augmented, the phenomena of irritation increase, and at the boundaries of the circumscribed atrophy hyperæmia exists, showing that the chorioidea before atrophying, here also passes through a period of irritation. . . . Even the abundant deposition of pigment on the boundaries of the crescent, again absorbed in the progress of the atrophy, in order to be anew deposited more externally, is in favour of a state of irritation. At a later period the subjective phenomena, also, become more characteristic, and in different parts of the fundus oculi atrophic spots are formed, preceded by inflammatory action: chorioiditis disseminata, I repeat it, is in the highest degrees of M at a more advanced age, connected with its normal development. Our conclusion is, therefore, briefly as follows: that almost without exception the predisposition to the development of staphyloma posticum exists at birth; that it is developed with symptoms of irritation, which in moderate degrees of staphyloma do not attain any great clinical importance; but that in the higher degrees an inflammatory state almost always occurs, at least at a somewhat more advanced time of life, as a result and as a co-operative cause of the further development of the distention of the atrophy.

This conclusion is certainly not inconsistent with the fact, that after death so few products of inflammation are to be met with. For these products pass, as well as the normal tissue, into a state of atrophy. In this way false membranes, as we see in the synechia of the iris, in adhesions between the pleuræ, and in other places, become atrophied and absorbed when extended. Even on the capsule of the lens sometimes nothing else remains of the inflammatory products of iritis than some spots of pigment. In staphyloma posticum the inflammation exists almost as the transition period to atrophy.

. . . .

Another important question is, in what the predisposition to staphyloma posticum may consist. It appears to be as yet not satisfactorily solved; at least I have no decided opinion on the subject.

. . . .

Now, this predispostion has been brought into connexion with the history of the development of the eye. If we look at the drawing given in the *Archiv für Ophthalmologie* by Von Ammon, to the *protuberantia scleralis*, described by him thirty-five years previously, as existing at a certain period of the fœtal eye, which is here reproduced as fig 41, the form of staphyloma posticum is at once suggested to the mind. Von Ammon states, that in an early period of fœtal existence the sclera is still open at the

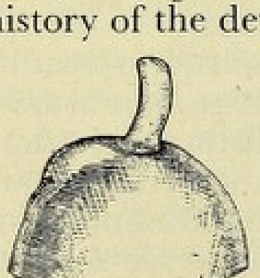

Fig. 41.

cerebral side; that it then has the form of a cup, and is connected by an oval opening with the anterior cerebral cell. This opening is closed by a tissue proceeding from the margins, and as the eye becomes larger, the supplementary tissue forms the protuberance in question, which is, according to Von Ammon, directed at first downwards, but subsequently backwards and outwards, as it is here represented. Von Ammon adds, that the different membranes close the said opening nearly at the same time. In the first place, there is brought into connexion with this mode of development the coloboma chorioideæ, which as a defect of the chorioidea, proceeding from the nerve-surface, extends inferiorly, whether over only a small extent, or over the whole chorioidea, and may now unite even with coloboma iridis. We have here, therefore, an ordinary *arrest of development.* And as such Stellwag von Carion and Ed. von Jaeger also consider the disposition to staphyloma posticum. The arrest of development is here only much less, and might be limited even to a slight remnant of the protuberantia scleralis. The direction of the atrophy, indeed, corresponds to that of the already fully-closed protuberantia scleralis.

As I was already about to observe, I am unable, for want of personal investigation, to give any opinion upon the subject. I, however, feel myself called on to remark, that it appears to be chiefly this idea which has led Stellwag von Carion and Von Jaeger to... the supposition that congenital myopia is in no way connected with the use of the eyes, and that it should be equally distributed among all classes of society.... I cannot avoid observing, that ... this view does not invalidate my statement, that the undue use of the eyes promotes the occurrence of staphyloma posticum. Indeed, it is certain that if, with slight predisposition, the eyes are much used for close work, the staphyloma becomes more fully developed, and direct experience as well as analogy shows, that in such a case the probability of transmission to posterity, even in a higher degree, is greater than when the staphyloma was not brought under promoting circumstances to a state of further development.

§ 29. *The Vision of Myopes*

. . . .

In slight degrees myopia is attended with no inconvenience. Against the disadvantage, that at a great distance vision is not perfectly accurate, is the advantage that, the range of accommodation being equal, very small objects brought closer to the eye, and therefore, under a greater visual angle, can be better distinguished, and that when at a more advanced period of life the range of accommodation is diminished, ordinary work can be still longer performed without spectacles.... In somewhat higher degrees myopes have, at least in youth, with perfect accommodation, a tendency to approach closer than is necessary to the objects, and thus, particularly at sedentary work, to assume a stooping position. If the myopia amounts to 1/10 to 1/8, or more, this occurs without exception; of course, to a greater extent, the higher the degree of the myopia is. With increasing myopia, too, the fancy increases of occupying one's-self with small objects: persons so affected read by preference small print; they accustom themselves to small handwriting, and as much as possible avoid long lines. It is evident that in doing so they are able to see more at once, and, for example, in reading, they need not move the eyes and head so much as when they have broad pages and large letters before them.

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Much greater still, in these high degrees of M, is the inconvenience of indistinct vision at a distance. The emmetrope can form an idea of it by holding before his eye a strongly convex glass, and he will be surprised how quietly myopes usually submit to their fate. But at the same time, many peculiarities developed in myopes, unless they early accustom themselves to the use of spectacles, will no longer be an enigma to him.

The circles of diffusion in vision at a distance are the greater, because in myopes the diameter of the pupil, as even Porterfield and Jurin were aware, is in general larger than in non-myopic persons, and to this magnitude the circles of diffusion are proportionate. . . . With a bright light they see remote objects much more distinctly, and therefore also at a more advanced time of life, the degree of M being unchanged, they distinguish better at a distance, which often makes them incorrectly infer that the degree of the myopia is diminished. Myopes now also distinguish much more accurately beyond their farthest point, when they look through a small opening, and in the highest degrees of myopia, as will hereafter be seen, even practical use may be made of this fact. The Calabar bean, too, which, dropped in solution into the eye has the remarkable property of constricting the pupil, is thus serviceable to them: on very slight action of this agent the pupil becomes narrow, without increasing the myopia, and when the remedy acts more powerfully, the farthest point, which had at first approached the eye, after an hour returns to its normal condition.

Among the early scholars many myopes were to be found. In this number was Dechales, a Jesuit of the seventeenth century, who has with wonderful accuracy described many peculiarities of myopic vision. In church he saw very remote little flames as round circles of diffusion, and thereupon studied his entoptic spectrum, which he perfectly understood. He was also aware . . . that myopes distinguish more accurately through a small opening, and with respect to the influence of the approximation of the eyelids he communicates some particulars, which are not te be met with even in later writers. Thus he observes, that, properly speaking, only the vertical dimension of the circles of diffusion thereby disappears, so that horizontal lines are better seen, but that also the horizontal extension of vertical lines is somewhat divided by the cilia, so that a number of images are seen close to one another, of which one is usually distinguished by particular clearness. Many myopes have so very much accustomed themselves to approximate the eyelids that it actually belongs to their physiognomy, and that they persevere in doing so, even when the use of concave spectacles makes it superfluous: this reminds us of the involuntary tension of accommodation, sometimes even combined with strabismus, of young persons whose H has been corrected by a convex glass. In strong myopia the imperfect vision has, even at a short distance, peculiar results. Those affected with it seldom fix the persons to whom they speak, because they imperfectly distinguish their features; they have in general no correct idea of the impression which their person and their words make upon another, and a peculiar freeness and too great self-confidence, or else, what is rarer, a more than ordinary bashfulness, are thence no unfrequently developed. In their bearing, and often also in their gait, a certain awkwardness is frequently manifested, by which some are recognised at a distance. Finally, much more of what passes in the world escapes them than they themselves are aware of, and with respect to a number of things their knowledge is less correct, because they fill up what is deficient through the operation of a brisk imagination. Cardanus asserts that myopes are particularly amorous, because that not observing defects, they look upon human beings as angles. The starry heavens they also see in extraordinary splendour.

In point of acuteness of vision myopes are in general inferior to emmetropes. In low degrees of M the difference is extremely slight, but in the higher degrees it is, at least in advancing years, considerable, even without the myopia being combined with unusual morbid changes.

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The cause of diminished S in myopes is evident. In M the retinal images, indeed, are larger for equal angles, under which the objects are seen, because the distance from the nodal point to the retina is greater; but, on the other hand, the surface of the retina is also larger, and therefore in a given plane comprises fewer percipient elements. Where there is perfect compensation of these two factors an equal number of percipient elements could now, the visual angles being equal, be impinged upon, and S may thus remain equal. But the extension affects especially the posterior pole, also occupies principally the region of the yellow spot, and for direct vision, therefore, perfect compensation is not to be expected, even when the extension produces no further disturbance in the function of the different elements. We had here in view the determination of the acuteness of vision applied to objects situated within the farthest point of distinct vision. The determination with the aid of objects situated at a greater distance, and seen with correcting glasses, proves still more disadvantageous, because k'' thereby approaches the retina.

With the increase of the myopia, the same objects at an equal distance are undoubtedly seen with a smaller portion of the percipient elements. As this has occurred gradually, the eye has, during its occurrence, accustomed itself to it, and the magnitude of an object is now also correctly estimated, and the finger, when it is wished to touch it, goes right to its boundaries.

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In any case we are justified in coming to the remarkable conclusion, that in consequence of slowly progressive displacement by extension, a point of the retina is projected outwards in a direction different from that originally belonging to it, and we hence infer that the direction of projection is not absolutely congenital, but that it has been developed in connexion with other means of observation.

That myopes are possessed of a normal power of accommodation could be overlooked only by confounding the region and the range of accommodation . . . It is also satisfactorily seen when we neutralise the myopia, whereupon young myopes see near objects perfectly well, distinguish acutely at a few inches from the eye, and are at the same time in a condition to see remote objects accurately. We have, too, already remarked that the range of accommodation of myopes appears to be equal to that of emmetropes; but in the highest degrees, in which the musculus ciliaris and sometimes also the nervi ciliares are atrophied, the power of accommodation diminishes and is at last wholly annihilated: this, however, happens at an age when, moreover, this power has been almost quite lost. We have, too, already calculated what range of accommodation, with difference in length of the visual axis, corresponds to a certain change of the crystalline lens, and we found that myopes, on account of their longer visual axis, are in this respect somewhat in the background. On the other hand, the use of concave glasses has a compensating effect.

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§ 30. *Complaints and Disturbances in Myopia*

Slight degrees of M give rise to no complaints. In youth the inferior acuteness of vision at a distance passes almost unobserved, and at the fiftieth, sometimes at the sixtieth year, when the narrower pupil makes remote objects more distinct, we hear only boasting and praise of the excellent vision for near objects.

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But even in youth many myopes complain of inconvenience from continued tension. There is then a state of irritation which appears to be combined with hyperæmia, both of the external eye and of the internal parts. At a later period, expecially when the eyes are very prominent, and probably, in consequence of tension of the extended muscles, are somewhat harder than is normally the case, such a state of irritation may become habitual, and may even be combined with a troublesome irritation of the eyelids. Especially when the myopia in a certain period rapidly attains a higher degree, pain and fatigue of the eyes, particularly by artificial light, are much complained of.

Where high degrees of M are in question, there is added to this state of irritation a certain spasm of accommodation, so that now a still higher degree of M is met with, which on the yielding of the irritation, especially after a Heurteloupian abstraction of blood, and a stay in the dark, again gives way. . . . In other cases the myopia gradually attains a very high degree, without the occurrence of any other disturbance than imperfect vision at a distance. Indeed, when we consider the changes which the fundus oculi has undergone, we are often surprised at the slight disturbance connected therewith. The explanation of this is to be sought in the fact that when important structural changes of the chorioidea arise slowly, the retina undergoes but little disturbance, and that, moreover, diminished acuteness of sight on indirect vision is not apt to cause much inconvenience. Even with the marbled atrophic white and yellow-speckled appearance, extending in a girdle from the outside of the crescent through the region of the yellow spot, direct vision sometimes still retains its normal acuteness, and the imperfection of indirect vision is scarcely observed. However, in extensive diffuse atrophy beyond the crescent this is exceptional. But the disturbance of vision is much greater when, as is often the case, the existing tension and extension give rise to a state of general irritation of the retina. This is the proper amblyopia of myopes. It sometimes attains in a short time a tolerably high degree, and is again capable of improvement on the employment of suitable treatment. Von Graefe considers the prognosis in this form of amblyopia to be even comparatively very favourable, and I quite agree with him if our object be limited to obtaining a temporary improvement. But in high degrees of myopia, relapse and eventual aggravation of the affection are always to be expected. Besides the diminished S, the rapid supervention of fatigue, a feeling of tension in the eye, sometimes pain on pressure, and moreover photopsia and muscæ volitantes are connected with this condition. These last two phenomena often in myopia constitute a permanent source of complaint, even when no particular state of irritation and no extraordinary diminution of the sharpness of vision exist. Ordinary muscæ volitantes, as I have already explained, are not attended with any essential inconvenience . . . Myopes are, however, troubled with them more than others.

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I have seen instances in which anxiety about muscæ volitantes amounted to true monomania, against which all reasoning and the most direct demonstrations were in vain. This is especially the case when morbid changes in the vitreous humour have supervened. We must admit the existence of morbid changes so soon as we can with the ophthalmoscope perceive turbidities in the vitreous humour. To these a real pathological importance is to be attached. The ordinary corpuscles are too small to be ophthalmoscopically visible, and therefore whenever forms appear, we must admit the existence of abnormal products. . . . In inflammatory irritation they are certainly almost always to be considered as the results of exudation. Such forms, also, arise and disappear, independently of myopia, in consequence of kyklitis and chorioiditis anterior; in myopia they are usually situated more deeply in the vitreous humour, sometimes even in connexion with the surface of the optic nerve, and they scarcely ever disappear. In order to see them, the observed eye should be directed downwards, and suddenly raised to the point at which we again look through the plane of the pupil, in which case we usually observe them rapidly floating past. . . . Usually, they are long and fibrous, or granular, sometimes also perhaps membranous.

The second complaint we mentioned was photopsia. This in general accompanies the more acute amblyopic symptoms of myopes; but sometimes it continues constantly present in high degrees of myopia, and yields to no treatment whatever. Ophthalmoscopically we then usually observe diffuse atrophy, combined with white spots and so-called pigment-maceration, the origin of which is also connected with inflammatory action.—Nervous persons are sometimes very much depressed by the constant phenomena of light, which are still more troublesome in the dark than in the daylight. I believe, too, that they must be looked upon as an unfavourable sign, because they indicate persistent irritation from increasing tension and distention, or from inflammatory action; but still I have found that the power of vision may with them long remain tolerably uniform. The principal point will be, how far the atrophy extends in the region of the yellow spot.

Besides the amblyopia dependent on supervening irritation, the acuteness of vision is in general, as we remarked in the preceding paragraph, diminished in high degrees of myopia; but on this point little complaint is made. As myopes can hold objects so much closer to the eye, and thus look under a greater visual angle, they can still very long sufficiently distinguish them, and from distant vision they have never required much. In general, therefore, they do not apply to the oculist, until a disproportionate disturbance takes place in direct vision. They then complain of obscurity in reading and writing, of a dimness or glimmering which lies over the letters, of truncated letters or of total absence of others; of total inability to see correctly what they fix. Often this is preceded by the curved appearance of lines, which indicates a disproportionate displacement or transposition forwards of a part of the percipient elements. Where these complaints arise in myopes, we always find also one or other of the above-described changes in the yellow spot. In this region there are almost invariably to be seen whitish spots, little accumulations of pigment, and other proofs of atrophic degeneration, even before any complaint is made. Usually the degeneration of the yellow spot sets in much earlier in one than in the other eye; but while we see it tolerably compete in the one, precisely the changes just mentioned appear in the second eye, and foretell but too certainly, that after a few years direct vision will here also be lost. Against the progress of this degeneration we can by hygienic measures do comparatively little, and by proper medical treatment nothing whatever. It is true that even now the acuteness of vision sometimes improves; but in this case we must suppose that the disturbance was dependent rather on irritation of the retina, supervening on the atrophy: the atrophy itself runs regularly through its course, and combating the attendant symptoms of irritation can at most retard this course. The dimness which was complained of, sometimes continues for a long time almost unchanged, until in a few days or weeks reading becomes wholly impossible. This does not always indicate a really quicker development. The latter, indeed, occurs, and sometimes even a local effusion of blood in the yellow spot puts an end at once to direct vision; but in general it is only the extension to the fovea centralis, which so rapidly injures the acuteness of vision. In fact, there have been almost always long before numerous little blind spots scattered here and there in the retina, and particularly around the fovea centralis. They sometimes even extend into a part of the fovea centralis, which in another part still continues available. Peculiar phenomena may be produced by these groups of scotomata: thus I have seen cases in which very small print was more easily and more quickly read than a larger one, because of the latter a whole word was never seen at once, and even larger letters were only partly visible. The glimmering complained of is entirely due to the fact, that in slight movements of the eye the letters form their images alternately on sensitive and insensitive parts, and thus each time come and disappear, sometimes with change of form, according to irregular displacement of the percipient elements. So long as the fovea centralis still fixes, the patients can themselves very well project their scotomata on a surface, for example, on a sheet of paper, and fixing a given point, can circumscribe the boundaries of the blind spots with a strongly-contrasting object. In this manner we can satisfy ourselves as to the existence of these groups of scotomata in the region of the yellow spot, without the fovea centralis being as yet affected and reading having become an impossibility.

The scotomata in question are little interruptions of the field of vision. We should suppose that they must exhibit themselves as black spots. This, however, they do not: almost invariably they are seen only more or less ditinctly as grey spots. They approach in this respect the *undefined non-vision*, the hiatus in the field of vision, which is projected through the nerve-surface, and this is, in fact, to be compared with the portion of space lying beyond our field of vision, for example, behind us; we do not see it black, we see it *not*. . . .

In connexion with scotomata, it seems fit here to state some facts with reference to limitation of the field of vision in general. Even long ago some knowledge existed on this subject. Mariotte discovered the blind spot name after him, which discovery attracted much attention at the time, and gave rise to various theories. Determinations of its magnitude and position might have led to the inference, that it corresponds to the nerve-surface, before I had shown that a little image of a flame, thrown with the ophthalmoscope upon this surface, actually does not become visible to the eye under examination, until it passes the bounds of the nerve-surface. It was known, too, that the field of vision is sometimes partly lost, and hemiopia and visus dimidiatus were spoken of. But I believe I am correct in stating that the systematic investigation of the limits of the field of vision in amblyopia was first introduced into practice by Von Graefe. Dr. Snellen subsequently applied himself to show, that in many cases of amblyopia, . . . particularly where ophthalmoscopic investigation exhibited no morbid changes, direct vision is almost always very much diminished in the whole region of the yellow spot: the boundary where the duller vision begins, is in these cases often tolerably accurately indicated on the projected field of vision.

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As limitations and interruptions peculiar to myopia, we have, in addition to the above-mentioned scotomata, still to mention chiefly those which occur as amplifications of the spot of Mariotte; as well as those which depend on atrophic spots developed with inflammatory symptoms; on detachment of the retina, in consequence of exudation and sometimes of extravasation of blood; on extravasation of blood also in the tissue of the retina; finally, on glaucoma.—As to the spot of Mariotte, Von Graefe states that a magnifying of its surface in the sclerotico-chorioiditis (the staphyloma posticum) of myopes can always be demonstrated. . . . My investigations have shown that with a slight development of the crescent, as we can observe ophthalmoscopically with a little image of light, the perception of light is not deficient there, but that in high degrees with complete atrophy it really wholly, or almost entirely, disappears: sometimes even we find again tolerably accurately in the projected form that of the crescent. It is also in a physiological point of view not unimportant, that even in those cases the conduction of the more peripherically received stimulus of the retina is not deficient over the atrophic crescent,—whence it appears, that the fibrous layer of the retina, through which this conduction must take place, has not essentially suffered. . . .

Detachment of the retina is one of the worst morbid forms, to which the myopic eye is much more liable than any other; it is met with chiefly in the lowermost half, which according to Von Graefe is to be ascribed to the fact, that when it occurs in high parts, it may, by sinking of the fluid be transmitted downwards. Sometimes it is only to a slight extent, and the retina is but little removed from the chorioidea.

In other instances a great part, nay even the whole retina, may be detached and it then, according to the very correct expression of Arlt, assumes the form of a convolvulus-flower, whose stem is the optic nerve. When the detached portion is of moderate size it projects far enough into the vitreous humour to be seen, without a negative glass. We recognize it at once by its grey colour, and by the moveable folds of the membrane, on which the retinal vessels are very distinctly visible, at first even with difference of colour of the arteries and veins. It is remarkable that the perception of light has then not yet ceased, so that we must suppose that the layer of rods has separated with the retina, and may in this state continue sensitive to the impressions of light.

A striking case of this kind occurred to me. A girl, aged fifteen, with M=1:2 1/2 in both eyes, on a sudden cried out with joy that she could see the people at the other side of the street before the window, and could even recognise them. Her joy was, however, of short duration. Three days later the eye was quite blind, and I discovered a detachment of the retina, extending through the yellow spot, whereby the latter was pushed forward almost into the posterior focus of the eye.

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Almost always the fluid situated behind the retina is of a serous nature, more or less turbid, and subject to further metamorphosis. . . . The condition for its formation we know not, but it is certain that when the retina is detached the bulb is usually soft. It is very plausible to assume that the extension which the retina undergoes in staphyloma posticum may cause it to be more easily separated from the chorioidea, and it seems certain that increasing staphyloma must promote its further detachment.

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The circumscribed extravasation of blood, sometimes to be seen in the yellow spot, and in some measure elevating the latter, is certainly derived from effusion from a chorioideal vessel; on the other hand, we not unfrequently see in the retina itself a number of smaller extravasations near the retinal vessels, and apparently derived from the latter. Of some larger retinal sanguineous infiltrations it is also more than probable that they took their origin from retinal vessels. The chief symptom in these cases is the scotoma, or the interruption of the field of vision, which is always more remarked and more troublesome, the closer it is to the yellow spot.

With all these morbid changes in the fundus oculi occur, to a greater than ordinary extent, changes in the vitreous humour, which in general give rise only to flakes floating before the field of vision, but, nevertheless, in some instances, especially when they are of a membranous nature, very essentially interfere with the power of vision; and with these changes of the vitreous humour is combined the disposition to opacity of the lens, which, undoubtedly, is greater in myopes than in emmetropes. It is remarkable that in the commencement of cataract myopes imagine that it is only their myopia which is increasing. As they see objects at a short distance from the eye under great angles, they do not so immediately experience much inconvenience, for example, in reading. Therefore, they remark at most that with respect to distinguishing at a distance they are retrograding, and they are surprised only that their myopia, which ought to improve with years, as it is said, is on the increase.

In connexion, finally, with high degrees of staphyloma posticum, glaucoma is not unfrequently developed, especially at a more advanced period of life; this, however, in its typical form, belongs rather to the emmetropic and to the hypermetropic eye. When combined with high degrees of M, it appears as if it ought, even in its origin, to be considered as a distinct form of disease. . . . It is glaucoma simplex in so far as the ordinary inflammatory symptoms proper to glaucoma are wanting, but beyond this it is distinguished from ordinary glaucoma by less hardness of the eyeball, oblique direction of the excavation, unusual limitation of the field of vision, while, moreover, we cannot in these cases reckon so certainly upon the results to be obtained by iridectomy, as in the ordinary cases of glaucoma.

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§ 31. *Insufficiency of the internal Muscles and Diverging Strabismus, both Results of M.*

Diverging strabismus is in general combined with M. In the commencement of my statistical investigations, I had become aware of the connexion between hypermetropia and strabismus convergens; but I was far from suspecting that myopia stands in almost as close a relation to strabismus divergens. Systematic investigation first brought this to light.

The nature of the connexion is not, however, in each case the same. . . . If strabismus divergens arises, in connexion with myopia, the anomaly of refraction, as such, is not indeed wholly without action, but the anatomical element has the chief causal influence, I mean *the distention and the altered form of the eyeball:* therefore where myopia exceptionally depends on other causes, consequent strabismus is not to be expected. In the ordinary forms of M, . . . it is chiefly the ellipsoidal form, which, in turning round the short axes in a cavity of similar shape, in consequence of the required change of form, gives rise to great resistance. Besides, the centre of motion has removed not only from the anterior but also from the posterior surface of the eye.

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As a result of the greater distance from the centre of motion to the posterior surface of the sclerotic, the excursions are in these cases greater for equal degrees of rotation, and turning is therefore necessarily limited.

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This is true of movement both inwards and outwards. . . . The limited movement outwards has, in the first place, no other result than that the lateral excursions for distant binocular vision are less, and that turning the head more rapidly must supplement it, which besides is necessary in wearing spectacles. But the insufficiency of the turning inwards has other and more important results, which we have consecutively to consider. . . .

Insufficiency of the inward movement we assume, when the visual lines cannot be brought to intersect at a distance of 2″·5, at which they cut one another under an angle of about 51°. In high degrees of myopia this insufficiency exists almost without exception. For this a double cause may be assigned. In the first place, the mobility is, as we have seen, actually diminished by distention and modification of form. . . . But, in the second place, in order to bring the visual lines to intersect at the distance of 2″·5, the angle α being small, the axes of the cornea must be brought under still *stronger* convergence than in emmetropic eyes. . . .

Now the insufficiency of which we are here speaking, leads in some instances to fatigue in vision, when the work requires a certain convergence to be maintained for a long consecutive period (*asthenopia muscularis*).

Cases have occurred to me, in which there was at first vision with both eyes, but where, on fatigue, the one eye gave way, and the work was then attended with less difficulty.

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With this giving way on continued tension *relative diverging strabismus* is already admitted: at a greater distance the visual lines are properly directed; in close work only one eye is used.

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Relative diverging strabismus, in fact, exists, so soon as the proximity required for acute sight excludes binocular vision.

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If now vision once takes place with deviation, there can be little tendency to make the tension required for convergence . . . Precisely when difficulty in convergence begins to be experienced, does the associated tension of accommodation become particularly great.

In progressive myopia we often observe how binocular vision attempts to maintain itself against the relative diverging strabismus. It is, however, usually obliged speedily to give way to the fatigue arising from the tension. Reading, for example, is at first binocular, but after some time one eye yields, involuntarily and unconsciously, so that the complaint is made that one page moves over the other.

. . . .

The greatest difficulty is always experienced when the eyes are directed upwards. . . .

On the boundaries between alternating and confirmed relative diverging strabismus lies a practically important condition. The condition is this: there is still tendency to convergence, this is seen on approximating an object: but even before the distance of distinct vision is attained, or at least soon after, the one eye deviates. If we now give concave spectacles, which bring the binocular farthest point to 8″, 10″, or 12″, vision again takes place with both eyes. Often, however, complaints are now heard of the occurrence of fatigue, and examination shows, that not the tension of accommodation, but the convergence required, slight as it is, is the cause thereof. Consequently, asthenopia muscularis is in operation, so that, in order to make binocular vision possible, a combination of the concave with a prismatic glass is required. In these cases it is especially evident, that the cause of the relative diverging strabismus is to be sought solely in the impeded movement inwards, while the tendency to co-operation of the two retinas for the sake of binocular vision may continue undisturbed. It is only in absolute diverging strabismus that that tendency is, as shall hereafter appear, not unfrequently removed.

We have above seen, how in progressive M binocular vision for near objects usually in vain endeavours to maintain itself. To this there are, however, exceptions.

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Indeed, even in high degrees of M . . . the visual lines may sometimes be properly directed in close vision, and may without effort be kept in that direction. But this in many cases is obtained only at the expense of the mobility outwards. Limitation of the latter is, in such instances, rarely absent, and it may now attain to that degree, that the visual lines cannot in distant vision be brought to parallelism, which constitutes relative converging strabismus. And if with increasing M in these cases the convergence for near objects also becomes insufficient, we have the singular combination of relative diverging strabismus, in vision for near objects, with relative converging strabismus in distant vision, while at a medium distance a certain margin has remained for binocular vision. . . . However, as I have observed, this is all exceptional. The rule is, that the facility of convergence does not keep pace with the development of the myopia, and that the tendency to relative diverging strabismus rapidly becomes remarkable. I satisfied myself by investigation, that in M the mobility inwards is in a great number of cases very soon limited, while that outwards is in no way impeded.

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The *absolute diverging strabismus* is distinguished by divergence of the visual lines in distant vision. . . . In a few cases, however, I observed, that in looking to a great distance divergence existed, but that, on looking to the distance of some feet or some inches, this gave way to *sufficient* convergence, which was then, however, not to be maintained. The fact is remarkable. The explanation may be, that binocular vision is much more important for the estimation of near, than for that of remote, objects.

At first, diverging strabismus exists usually in a slight degree, and only slowly increases. Sometimes it continues in but a slight degree during the whole of life. I have, indeed, found that precisely the highest degrees of diverging strabismus not unfrequently have another origin than simple myopia.

It is commonly the custom to apply the term squint exclusively to the absolute form. In this sense it is less frequent than strabismus convergens. And if, . . . myopia cannot occupy the same prominent position as an etiological element, that hypermetropia does in reference to strabismus convergens; nevertheless, in about two-thirds of the cases of *absolute* diverging strabismus, myopia was met with. But if, on the other hand, we take *relative* diverging strabismus also into account, the diverging form is as frequent, if not more frequent than the converging; and now, moreover, the extraordinary causes, originally proceeding from the muscles or from blindness in one eye, fall into the background: therefore in at least 90 per cent. of the cases of *relative* diverging strabismus we find M.—It is often remarked that while strabismus convergens usually occurs in childhood, strabismus divergens is most frequently not developed until a later period. The observation is correct. The fact is connected with the cause of its occurrence: *progressive myopia*.

Now if, in general, absolute diverging strabismus proceeds from relative, it is far from being the case, that the relative should always be followed by the absolute form. . . . We certainly find many myopes with relative diverging strabismus, without the absolute form being developed from it. Here, therefore, the question also arises: What accessory circumstance causes the true absolute diverging strabismus to occur?

Perhaps we may be able to invert this question, if we first consider why, in general, the relative deviation predisposes to the absolute. The result of this consideration may be thus formulised:

Relative diverging strabismus gives dissimilar images on the two yellow spots, in close vision. The effort at simple binocular vision must, in general, be consequently weakened. A commencement of deviation, having arisen where much advanced convergence was required, immediately attains a tolerably high degree, by simply yielding to the natural tension of the muscles,—partly also, perhaps, in order to make the double images more remote from each other. . . . In general, when, for example, with blindness of one eye, the internal recti muscles are no longer for the sake of binocular vision of near objects stimulated to contraction, they soon, through diminished energy, become ineffectual, and strabismus divergens is the usual result thereof. Relative diverging strabismus now leads to similar inaction, likewise followed by diminished energy. Thus two important factors coincide: slight resistance to double images, and diminished force of the internal muscles. It can, therefore, not be a matter of surprise that, in distant vision also, the action of the latter soon fails. And this must occur the sooner in myopes, because the angle α is particularly small, and therefore distant vision requires a slighter divergence of the corneal axes than in emmetropes.

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Thus, undoubtedly, the origin of absolute diverging strabismus is satisfactorily explained. We must now invert the foregoing question. We ask no longer: What accessory circumstance, where relative diverging strabismus exists, leads to the development of the absolute variety? We rather inquire: What is the reason that not every relative diverging strabismus is followed by the absolute form?

In the first place, I remark that absolute diverging strabismus is, as I find more and more every day, in high degrees of myopia very general, much more general than is supposed. Slight degrees pass unobserved, because, although the visual lines diverge, the corneal axes exhibit no particular divergence, often certainly still less than in non-squinting hypermetropes: it is not until the properly directed eye is covered, that it appears that the visual line of the other was directed too much outwards. But I repeat the question: What is the reason why not *every* relative diverging strabismus is followed by the absolute form?

The cause of this lies partly in the maintenance of binocular vision. Although . . . the attempt to obtain equal impressions on the two yellow spots and on further corresponding points is weakened, it is not extinguished. In many the one eye actually turns outwards behind the hand, to reassume a proper direction when uncoverd. And where this giving way does not take place, it is sufficient to hold a weak prismatic glass, with the refracting angle towards the nose, before the eye, to satisfy ourselves of the attempt at binocular vision: we immediately see a convergence set in, correcting the action of the prism. . . . It thus also appears that acute sight is not an absolute condition for maintaining single vision.

Further, we seek the cause of the absence of absolute strabismus in limited mobility of the eyes. Turning the great ellipsoidal eyeball of myopes is impeded not only inwards, but sometimes also outwards. This obstruction may go so far that, as I have above remarked, relative converging strabismus in distant vision may be combined with relative diverging strabismus in near vision. But even if does not attain this degree, it really hinders an excessive deviation outwards, especially when it is allied to the need of binocular vision.

Thus then, just as in converging strabismus, different impelling and resisting forces contend with one another.

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If the difference of refraction is great, the one eye highly myopic, the other scarcely so or even emmetropic, the rule is perhaps that in distant vision the myopic eye has deviated outwards. These cases furnish a peculiar form of strabismus divergens, which certainly deserves to be thoroughly investigated and separately described. Sometimes, especially at first, the squint is intermittent, and manifests itself only either on fatigue. . . . Not unfrequently, too, the one eye is used in distant, the other in close vision. . . . As to its pathogeny, it is easy to see that, in the first place, binocular vision in these cases has not much value; secondly, that, particularly in distant vision, the double images of ordinary objects are scarcely observed, and the patient thus easily abstracts from the impression of the strongly myopic eye; thirdly, that the limited mobility in this case affects only the one eye, and a relative deviation outwards must therefore meet with less difficulty.

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The connexion between myopia of the two eyes, and strabismus divergens was formerly not completely overlook. Joh. Mueller even describes a *strabismus myopum*. 'It is known', thus he commences the explanation of the mode of development, 'that shortsighted people look at very near objects only with one eye, while the other eye, which is also nearsighted, completely turned away and directed to a distance, sees indistinctly or not at all'. This is the state which we have called *relative diverging strabismus*. It has been described by Buffon, as occurring in his own eyes. In his own case he introduces the difference of the images in the two eyes into the explanation; but in general he finds in the extraordinary convergence required by myopes, the reason, 'that the sight is fatigued and less distinct than in looking with a single eye'. Mueller assigns the first place to the same cause, but in addition points to the increasing refraction produced by the convergence.

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Our investigations have thus led us to a striking result, which may be expressed in the following antithesis:—

Hypermetropia causes accommodative asthenopia, to be actively overcome by strabismus convergens.

Myopia leads to muscular asthenopia, passively yielding to strabismus divergens.

§ 32. *Hygiene. Treatment. Spectacles. Illustrative Cases. History of Myopia*

The cure of myopia belongs to the *pia vota*. The more our knowledge of the basis of this anomaly has been established, the more certainly does any expectation in that direction appear to be destroyed, even with respect to the future.

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Treatment is, alas, partly a matter of fashion. Thus discharging the aqueous humour from the anterior chamber of the eye, is now the order of the day. Some have even spoken of applying this method in myopia. If it be intended thereby to make the cornea flatter, the object will not be attained in this way, . . . besides the paracentesis referred to is not always itself equally harmless. We formerly lived under the rule of the myotomists. Rendered rash by ignorance, some have actually employed their operation of the relief of myopia, and have even persuaded themselves that they had thus accomplished a cure. The truth is, that they in general subjected not myopic, but rather hypermetropic, eyes, which they mistook for myopic, to the operation ,and that even in these the latter was ineffectife. However, in another point of view, where myopia really exists, tenotomy may sometimes be applicable. If the muscles are, as a result of extension, permanently too much upon the stretch, and if the bulb is consequently harder, the displacement backwards of the insertions by tenotomy might diminish the pressure, and thus one of the conditions for further development might be removed. Division of the tendon of the rectus externus, is, as we saw in the preceding section, not unfrequently indicated for promoting convergence in high degrees of myopia; now it has been proposed to divide the tendons of the rectus internus and rectus externus, in order to diminish the existing tension, and in some cases this has actually been done. Further experience must decide as to the value of the plan.

Lastly, the removal of the crystalline lens has also been suggested. When in a case of highly myopic structure of the eye, a lens affected with cataract has been successfully extracted, and a nearly emmetropic condition has been obtained, the operator has been exposed to the temptation of endeavouring, by the abstraction of a normal lens, to remove the myopia. A patient, who was an amateur in dioptrics, endeavoured to induce me to perform this operation!

But I need not say, that such a momentous undertaking, doubly dangerous where a myopic eye and a transparent lens are concerned, without that, even in the most favourable case, any real advantage is to be expected, would exhibit culpable rashness. Not only would the staphyloma posticum continue equally threatening, but we should also have sacrified the accommodation—an advantage which that of somewhat larger images than would be obtainable by neutralising glasses, could by no means counterbalance.

From the above it follows, that the idea of curing high degrees of myopia with developed staphyloma posticum must be abandoned. The question is, whether slight degrees can really be cured. That, through senile metamorphosis at an advanced period of life, they may give way, we have already seen. In young persons, on the contrary, I have never established the fact of any diminution of the myopia. Where the latter appeared, on superficial observation, to have taken place, spasm of accommodation had been in operation. It has, however, often been asserted that slight degrees of myopia have yielded to the employment of suitable measures. Some years ago Berthold (1840) proposed the use of a certain desk, called *myopodiorthoticon(!)* by which the myope was compelled to remain at a great distance from what he was reading, while this distance was systematically increased. Burow however, shows clearly, that no diminution of the myopia is to be expected from this plan, as the accommodation for the farthest point is only a passive, and not an active operation, and he supplies the proof from the experience of his own eyes. Berthold's desk was also tried in vain at Köningsberg; and according to Von Hasner the attempt at Prague was attended with no better result. However, the last-named writer expressly states, that myopia depending upon slight degrees of staphyloma scleroticæ, may, particularly in the commencement, be again diminished by restraining the eye from looking at near objects. Respect for Hasner's accuracy cannot prevent me from doubting the correctness of this assertion. I have, *under all circumstances*, found steady increase of M in young individuals; its diminution I have never observed.

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The task of the oculist in myopia resolves itself into the following:

1. To prevent the further development of the myopia, and the occurrence of secondary disturbances.

2. By means of suitable glasses to render the use of the myopic eye easier and safer.

3. To remove the asthenopia muscularis by the use of glasses or by tenotomy.

4. To combat the secondary disturbances of the M.

I. In the exposition already given lies, I think, the proof, that where predisposition exists, continued accommodation for near objects promotes the development of staphyloma posticum.... We have remarked that accommodation, as such, is not in this case in operation, for in it only the form of the crystalline lens is changed, and in M the latter has undergone no change. In a mediate way, therefore, through accessory circumstances, it must be, that accommodation for near objects promotes staphyloma posticum. Of such circumstances two especially come under observation: *strong convergence and a stooping position*. As to the first, in order to see acutely, myopes must bring the object within the region of accommodation, and where M is somewhat advanced, binocular vision under these circumstances requires a strong convergence. Children and young myopes are even accustomed, particularly in bad light, to bring the objects much nearer to the eyes than the degree of the myopia, properly speaking, requires. This strong convergence increases the tension of the eyeball by pressure of the muscles, perhaps also by pressure against the surrounding tissues, and increased pressure promotes the staphylomatous distention.... Now strong convergence may be avoided in various ways. In the first place we cause the patient to look much at a distance. But we cannot absolutely forbid looking at near objects, and we therefore give spectacles which bring the farthest point, *r*, to a sufficient distance; for example, to from 16 to 18 inches. At the same time the patient is to be strongly recommended not to look at a shorter distance than 16″ or 14″, ... a ruler of this length may serve as a measure to parents and masters as well as to the myope himself. Moreover, it is desirable that often (for example, every halfhour) work should be discontinued for a couple of minutes.—In very high degrees of M, only one eye is usually employed in vision, and thus convergence is excluded. This appears to me to be often a desirable condition: in strong M binocular vision loses its value, and the tension which would be required for it cannot be otherwise than injurious. Now, in such cases, for reading no spectacles are given; in the first place, because the acuteness of vision has usually somewhat decreased, and the diminution of concave glasses is now troublesome; in the second place, because with the retrocession of *r* injurious efforts at convergence and at binocular vision might be excited. In any case the spectacles should be so weak as to avoid these results.

A stooping position was also mentioned as a promoting cause of M. This position leads to accumulation of blood in the eye: under the influence of gravitation, the afflux of blood takes place, in fact, under higher pressure, and until the efflux, too, more pressure remains in the veins; and with the augmented pressure of blood the tension of the fluids in the eye increases. The symptoms of irritation connected with hyperæmia, which in young people usually accompany progressive myopia are, I think, for the most part also to be ascribed to the cause just mentioned. Even in non-myopes an unpleasant feeling of pressure in the eyes speedily occurs when the face is held horizontally. Now the increased tension of the fluids certainly promotes, as such, the development of staphyloma. But in yet another way the accumulation of blood is still more injurious, namely, by promoting, perhaps even by exciting, the inflammatory affections under whose influence the staphyloma is so rapidly developed. In the hygiene of myopia, therefore, the very first point is to guard against working in a stooping position. While most work takes place in a horizontal plane, myopes are only too much inclined to it. Such a habit is usually opposed on the supposition that the thoracic organs suffer from it. Without denying this, I think, however, that it must be forbidden chiefly for the sake of the eyes. In general everything will be useful for this purpose which was recommended for the avoidance of strong convergence: to keep objects removed as far as the degree of myopia permits; to intermit work frequently; by suitable glasses to bring *r* to a sufficient distance. But we may also add: to read with the book in the hand, and in writing to use a high and sloping desk. To this last I attach much importance. Rectilinear drawing on a horizontal surface is decidedly very injurious to myopes. Again, with respect to the thoracic organs, many think that in writing a standing position is to be recommended. For that I see no particular reason. It is sufficient that the height of the desk suit the height of the head, and that the inclination be as great as circumstances permit. . . .—Further, those who are highly myopic must be earnestly dissuaded from everything which gives rise to increased action of the heart, and to tendency of blood to the head. . . .

II. The prescribing of spectacles for myopes is a matter of great importance. While emmetropic and hypermetropic eyes do not readily experience any injury from the use of unsuitable glasses, this may in myopes, particularly on account of the morbidly distended condition of the eyeball, and of the tendency to get worse, be very dangerous.

There exists in general a dread of the use of too strong glasses. It is laid down as a rule: rather too weak, or no glasses, than too strong. Too strong glasses make hypermetropic eyes myopic, and myopic eyes hypermetropic. The rule, therefore, cannot be equally true for both. In fact, it is in general much less injurious to produce a certain degree of myopia than of hypermetropia, in which last particularly much is required of the accommodative power. The rule would therefore be more correctly stated thus: in hypermetropia we must beware of giving too weak, in myopia of giving too strong, glasses; a rule the second part of which we should especially insist upon. But even by this little is gained. Not using glasses, or using too weak glasses, may also be injurious to myopes. All the circumstances must therefore be studied, which can exercise an influence on the choice of glasses. It is difficult to reduce these to definite rules. But to attempt to do so is our task.

On a superficial view, we should suppose that we have only completely to neutralise each degree of myopia, in order to obtain all the advantages connected with the emmetropic eye. The case is, however, quite different. If in neutralised myopia the eye is equal in its farthest point to the emmetropic, with respect to the relative limits of accommodation for each convergence there is a great difference.... The indication exists only:

1°. *When the glasses are used exclusively for distant vision*, for example, in a double eye-glass, which is only at intervals held before the eyes. Evidently, in looking to a great distance with such a glass the accommodation is in a state of rest, and its use can therefore never cause any injury. But so soon as the same glasses are used for shorter distances in looking at drawings, plates, &c., the exceptions, of which I shall hereafter speak, come under observation.

2°. *When the myopia is slight in reference to the range of accommodation, and the eye is otherwise healthy*. In this case, neutralising glasses may be worn as spectacles, and may be used even in reading and writing.

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In order to obtain all the advantages of concave glasses, the myope must begin early with them. If the myopia amounts only to a fourth or a third of the range of accommodation, we may immediately wholly neutralise it. If it amounts to more, we must usually begin with weaker glasses, and replace the latter at the end of six months with stronger.... In this respect great individual differences exist, chiefly dependent on the position of the relative range of accommodation. It this be unfavourable, we must more slowly increase the strength of the glasses. The effect of wearing glasses is, in fact, that the relative range of accommodation is displaced, becoming gradually the same as the position proper to emmetropic eyes, and therefore the binocular farthest point approaches the eye, while the absolute farthest point *r* by no means does so.—The myopia thus neutralised is less progressive, because both too strong convergence and a stooping position are avoided. But if the tendency to these is so great that they still occur in neutralised myopia, the use of glasses is dangerous, and must be discontinued, so soon as it appears that the myopia is particularly progressive. In this case it is necessary for a time to forbid all close work.—Besides, if in the cases mentioned the use of concave glasses is desirable, it is not so necessary that we should always be compelled to adopt them. Women particularly have a right to be allowed some liberty in the matter.

Many circumstances forbid the complete neutralisation of the myopia. They are connected with:

a. The degree of the myopia. . . . In the highest degrees, from 1/5 upwards, perfect neutralisation is not pleasant for close work, because, with regard to the usual diminution of the acuteness of vision, the images become too small. We should then rather bring *r* to 12 or 16 inches and let the patient wear these spectacles, with which a lorgnette with glasses of — 1/12, — 1/16, respectively, is also given, which may for distant vision be held before the spectacles. The idea that there is anything injurious in this combination is an unfounded prejudice.

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b. The range of accommodation.

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Moderate degrees of myopia, for example of 1/10, we can no longer completely neutralise at thirty-five years of age. So long as only distant objects are viewed with neutralising spectacles, all is tolerably well; but even in speaking with people we hear complaints of the tension required in order to see the eyes and face acutely, and work is, on the whole, not to be maintained with them. We should then confine ourselves to glasses, which bring *r* to about 24″, giving, if necessary, still weaker ones for working, and at the end of six months or more, we should examine whether we can increase a little, without causing asthenopia. . . .

c. Acuteness of vision. This has a great influence in the choice of glasses. . . . Von Graefe has forcibly insisted on the great danger of giving strong glasses for near objects, where the acuteness of vision is diminished. The objects, especially letters in reading, then appear smaller, and from the need of seeing them under a greater visual angle, such shortsighted amblyopes, in order to be able to bring them nearer, put their accommodative power with all their might upon the stretch, and promote the existing staphyloma. But, on the other hand, without glasses, the convergence is still stronger, and the tendency to the bent position is still greater. We thus find ourselves in a sad dilemma, which is to be avoided only by, in great part, forbidding close work. The most favourable circumstance is when in near vision convergence does not take place, and thus only one eye is used. Less injury is then to be expected from reading without spectacles, with the book in the hand, but writing must be avoided. In the same cases we may permit older persons to wear partially neutralising spectacles, and with these spectacles, aided by a reading-glass, occasionally to peruse something, which may in this way be done at a greater distance. . . . In any case we should insist upon moderation in reading, and on the selection of large print, although the latter is also attended with particular difficulties.—For the purpose of distinguishing pretty well at a distance in the highest degrees of myopia with diminished acuteness of vision, there is no other means than the use of a double eye-glass, or of the very portable glass-conus of Steinheil* for a single eye. In such cases, a wholly neutralising concave glass makes the distant images appear so small and the objects so remote, that vision is by no means satisfactory. Imperfectly neutralising glasses in a stenopæic frame, which limits the remaining circles of diffusion, answer still better.

d. Age. The influence of age is, for the most part, comprised in the diminuation of the range of accommodation, and of the acuteness of vision. At a very advanced time of life, we need attend less to the future than to the present. We may therefore, in order with diminished acuteness of vision to make reading still possible, in the slighter degrees of myopia, even with convex glasses, bring r' to 6″, 5″, and even closer to the eye. We should give only such a form of glasses as the patient can easily see over. Old people seldom know how to derive much benefit from glasses *à double foyer*.

e. The nature of the work, and the distance at which it is to be performed. He who in youth neutralises his myopia, can, if his sight be otherwise good, also, later in life, perform ordinary work at any distance required. He who, on the contrary, either could not or would not wear spectacles, retains the relative range of accommodation peculiar to myopes, and now, when for any particular object vision is required at a somewhat greater distance, he cannot use completely neutralising spectacles. The rule is with the glasses, therefore, to bring the farthest point precisely to the distance at which acute vision is needed. The necessity for this is felt most in ladies, for the reading of music, when r must be brought to from 18″ to 24″. Meanwhile, they can, for distant vision, use a neutralising eyeglass. It is also in general desirable in writing (in reading it is less necessary), in order to prevent a stooping position and strong convergence, to bring r to from 14″ to 16″, sometimes even to 18″, to make ledger-work possible. Lastly, in order to see the writing in lectures, especially in the pulpit, the farthest point must be brought precisely to the requisite distance. Particular attention is necessary—even though

*A simple solid conus of glass, about one inch long, the base convex, the opposite surface concave, with a smaller radius than the convex. It acts as a Galilean telescope: parallel rays, refracted on the convex surface, are converging in the glass, and, refracted again on the concave surface, obtain a diverging direction, and can also unite on the retina of a corresponding myopic eye. The magnifying power increases for the glass-coni, required in high degrees of myopia.

spectacles were always worn—in the case of elderly people, who have lost their power of accommodation, and have not perfect accuracy of vision. . . . They read the smallest writing at 3″ or 4″ distance, and are surprised that they cannot with spectacles see much larger writing at 18″. They do not consider that the distance is from four to six times greater, and that by the concave glasses the images are still further diminished. Consequently there is nothing to be done, but to write particularly large.

We have examined the direct influence of glasses on observation, and on the estimation of what is observed . . . As to the indirect influence (the result of longer use), we became acquainted with the displacement of the relative range of accommodation, and the approximation of the binocular nearest point. We may still add that the at first incorrect estimation of magnitude, distance, and form, is tolerably quickly lost. It is remarkable how myopes, when using spectacles, immediately begin, unconsciously, to write larger than before, and how, after some time, they involuntarily resume their smaller handwriting, unless with considerable energy they resist the tendency to do so. Another result of wearing spectacles is, that by being accustomed to look nearly through the axes of the glasses, the eyes gradually limit their movements. After the removal of the spectacles, too, this limitation continues, and the movements of the head especially provide for the necessity just mentioned, giving a peculiar bearing to myopes who are accustomed to wear glasses.

III. We have already seen that in high degrees of myopia the internal recti muscles are often insufficient. . . . The insufficiency first makes itself known by asthenopia muscularis in binocular vision for near objects. Sometimes we find (at least temporarily) the proper remedy for this state of things in concave glasses, which bring r_2 to from 12″ to 14″. . . . In using them we may, if it seems necessary, somewhat diminish the mutual distance of the glasses, by which less is required of the internal muscles. In other cases the use of spectacles may itself give rise to asthenopia muscularis. Thus, in very high degrees of myopia relative diverging strabismus is a very common occurrence. . . . When, in such cases, r is by concave glasses brought to a greater distance, the effort at binocular vision sometimes returns; and the musculi recti interni are then obliged to exert themselves so powerfully, that asthenopia muscularis is unavoidable. Now this is not only troublesome and fatiguing, but is it also injurious, as it affects the further development of the myopia. If the one eye, so soon as it is covered, perceptible deviates outwards, and on removing the hand again turns inwards, in order to resume its former direction, we may expect the occurrence of asthenopia muscularis. It is often difficult enough to decide what is to be done in such cases. For the rules applicable to insufficiency of the internal muscles in non-myopes, by no means hold good in the asthenopia muscularis of myopic individuals. In the former the condition referred to is, in the first place, free from danger, and it is even allowable to try by systematic practice with prismatic glasses to excite the energy of the internal muscles. In myopia, on the contrary, cure of the insufficiency of the internal recti muscles is not to be thought of. Once begun, the insufficiency develops itself more and more, in double proportion, when, as is usual, the myopia is progressive. Often no other result is possible, than the exclusion of the one eye, with diverging strabismus. . . . Seeing the danger connected with strong action of the musculi recti interni, and the prospect of not being able to prevent the progress of the insufficiency, I have often asked myself, whether we must not simply submit to the tendency to outward deviation, which removes the asthenopia muscularis by the intervention of relative strabismus divergens. Von Graefe is of opinion that we should decide upon this sacrifice only in excessive myopia. A middle course may, however, also be adopted: we may allow reading without glasses, that is with the exclusion of one eye; but for writing and other work, which, to prevent a stooping position, must be performed at a somewhat greater distance, we should give prismatic-concave glasses. The concavity of these should be such as to bring the farthest point to from 12″ to 16″, and the angle of the prism should be so great that in looking to a distance of from 12″ to 16″, covering one eye should no longer be followed by any outward movement. Von Graefe is a great advocate of this combination, which, if it is arranged with strict care for individual cases, really renders binocular vision, without asthenopia, possible. If we are particularly successful we may allow these glasses to be used also in reading; if the difficulties are not altogether removed, their use must be limited to writing, but even in this moderation must be observed; and if, after repeated efforts, the patient continues to complain, we should not hesitate to sacrifice the one eye.

'The proper principal remedy', says Von Graefe, 'is above all tenotomij of the musculus rectus externus'. . . . It is, however, comparatively rarely adopted, so long as there is merely simple insufficiency of the recti muscles, without strabismus divergens. . . . It will, in fact, in general be admissible only when, after the operation, no permanent converging strabismus in distant vision, even in looking somewhat towards the side operated on, is to be expected. Von Graefe has from this point of view established the indications with great accuracy. The condition, *sine qua non*, for tenotomy is this: that under the attempt at single vision, a sufficient divergence of the visual lines should appear to be possible. This should be tried (after neutralisation of the myopia) with prismatic glasses; we should investigate, with what prismatic glasses, held with the refracting angle outwards before the eyes, single distant vision is still attainable. The strongest glasses then, which can still be overcome, give the measure of the possible divergence. It is allowable now so to perform tenotomy that this possible divergence shall be completely removed.

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But we must not suppose that with the removal of the possible divergence, we have always made binocular vision for near objects easy: when deviation of the eye behind the hand, at the distance at which binocular vision is desired, is much greater than the utmost divergence which we are allowed to correct by tenotomy, we shall, after this correction, retain an insufficiency for this distance, which, with binocular vision, will still give rise to asthenopia. We must, therefore, in such cases bear in mind that after tenotomy, the correction must be supplied by prismatic-concave glasses. Hence, therefore, it also follows, that when in distant vision only comparatively very weak prisms can be overcome, the operation certainly effects almost nothing, and where it appears that no divergence is possible, tenotomy is absolutely contra-indicated. . . .

IV. *Therapeutic Treatment.* For myopia, as such, there is no therapeutic treatment. Myopia consists in an anomaly of which only hygienic measures must, if possible, prevent the further development. But it is not unfrequently complicated with symptoms of irritation and inflammation; and with other pathological deviations of different kinds and with respect to these it is the duty of the therapeutist, to the best of his ability, to interfere.

. . . .

In the foreground appear symptoms of irritation at the period of puberty, characterised by . . . fatigue and pain in the eyes, especially on exertion in the evening. Under such circumstances we should be particularly strict with respect to the hygienic directions, which are in themselves in many cases sufficient. It is also of great importance to keep the feet warm. Often, too, a douche on the closed eyelids is agreeable. If the symptoms do not give way, we may, with avoidance of a stimulating diet, combine some derivation on the intestinal canal, and we may in addition recommend the application, to the frontal and temporal regions, of a stimulating embrocation, composed, if there be any coexisting external irritation of the eyes, rather of non-volatile ingredients. At the same time, especially when it appears that the myopia is rapidly progressive, all tension must be avoided. So far as work is permitted, this must be accomplished in slight degrees of myopia without spectacles, and in higher degrees *r* must be brought accurately to twelve inches. If fatigue or pain should occur, work must in either case be suspended; and if the use of spectacles appears more rapidly to cause fatigue, we should not lay stress upon their adoption, but take care only that the patient maintains a proper position in whatever work he still performs. If it be suspected that the symptoms of irritation have excited spasm of accommodation, as often occurs in high degrees of myopia in youth, we should employ sulphate of atropia, partly to test the truth of the supposition, partly to remove the spasm and to prevent it returning on each effort to see. We may then even continue this application for some days, whereby the myope becomes accustomed to look at the greatest distance of distinct vision; unnecessary convergence is thus prevented, and from this plan no injury is to be apprehended, provided we cause the patient to avoid strong light, or to moderate it by means of grey glasses. In case of a relapse of the symptoms of irritation, with spasm of accommodation, the application of Heurteloup's artificial leeches to the temples, followed by twenty-four hours' stay in the dark, with gradual transition to light, has been found very useful.—In spite of all efforts, however, these symptoms of irritation in some constantly recur. If, moreover, the myopia is rapidly progressive, the patient's state is serious enough to make it necessary to warn him against choosing an occupation in which close work would be constantly required; above all, such myopes should not be office-clerks. But such cases are rare: with few exceptions the inconveniences disappear before the twentieth year.

At a later period of life, the acuteness of vision sometimes diminishes in high degrees of myopia in a few months in a manner to cause considerable uneasiness. In these cases the hyperæmia at the borders of the atrophy often leads us to suspect the existence of progressive myopia, while to this state of things other signs of irritation are usually added. If, in such instances, no organic changes are ophthalmoscopically to be observed in the region of the yellow spot, we almost always obtain, within a few weeks, a considerable improvement of the acuteness of vision, by the weekly abstraction of blood after Heurteloup's method, by keeping the patient in a moderate light, and by making him avoid tension of the eyes, combining this plan, according to circumstances, with the use of the douche and of a stimulating embrocation, with derivation by the intestinal canal and stimulating pediluvia. Even when there are perceptible morbid changes in the yellow spot we need not despair, so long as subjectively a defined scotoma does not remove direct vision. In person of 60 years and upwards, with myopia of 1/5 and even of 1/4, I have, by following the above directions, seen the acuteness of vision rise from 1/30 or 1/20, to 1/4 or 1/3, and thus become quite sufficient for writing and reading. It is quite a different thing when a circumscribed scotoma, ophthalmoscopically perceptible in the yellow spot, is also perceptible to the patient. This indicates a profound disturbance in the seat of direct vision. Blindness is in general not particularly threatened thereby; but improvement of direct vision is not to be expected, and if both eyes are equally affected, the patient must prepare himself for the impossibility of reading, writing, or performing minute work.—In cases of accessory chorioiditis disseminata the same directions are to be observed. In such we must expect repeated improvement and aggravation of the affection. After many years, however, the result usually becomes so unfavourable, that ordinary work can no longer be performed. Motes are at the same time often present in the vitreous humour. Especially under these circumstances it is usual to prescribe a long course of small doses of preparations of iodine or mercury. I too, have repeatedly done this, but I would not venture to assert, that I have seen favourable results from it. Many patients give themselves more trouble about these motes than they deserve. If no definite morbid changes threaten the yellow spot, we may give a comparatively favourable prognosis; we should advise that the attention should be as much as possible withdrawn from them, and the attempt to do this should be seconded by causing the patient to wear nearly neutralising glasses, made so as at the same time to moderate the light, and thus to make the shadows of the motes appear less defined.

Complaints of persistent photopsia . . . occur chiefly in diffuse atrophy, and indicate a state of irritation of the optic nerve. I have, in addition, to the above-described treatment, tried numerous remedies against it but, so far as I recollect, always in vain. The complaints were, in some cases, especially in nervous women, lamentable, and it has often surprised me, that, with such signs of continual irritation, the acuteness of vision was, in the course of even some years, but slightly diminished.

Against the most melancholy complications of myopia, effusion of blood, and detachment of the retina, treatment is almost powerless. In cases of effusion of blood in the vitreous humour, we may expect absorption, leaving behind it some opaque motes and membranes. The metamorphosis, under which the absorption takes place, is a spontaneous process, which treatment cannot promote, and the physician has therefore to confine himself to hygienic rules, and to such derivative or constitutional treatment as may appear to be adapted to each individual case. Pressure, by means of a bandage applied at intervals, might probably favour absorption, but when the bandage is taken off the tension of the fluids is diminished, and, as appears on ophthalmoscopic investigation, the vessels are distended, whereby the danger of fresh effusion must necessarily be increased. After repeated relapses, the vitreous humour remains opaque, and the fundus oculi is sometimes wholly invisible.—Occasionally, after repeated effusion of blood in the vitreous humour, local detachment of the retina occurs, in some cases certainly in consequence of blood accumulated between the retina and the chorioidea. Partial absorption is here also to be expected, but the detached portion of the retina never again resumes its functions.

The prognosis in detachment of the retina by a serous fluid, such as often occurs in high degrees of myopia, is somewhat less unfavourable. . . . In very rare cases absorption may occur, which many endeavour to promote by means of all kinds of remedies (mercurials, preparations of iodine, derivants, sudorifics), very problematical in their action; but in general improvement of the sight depends upon the fluid sinking to beneath the seat of direct vision, or upon a diminished morbid condition of the parts of the retina bordering upon the detachment. Rupture of the retina is so far advantageous, as the danger of further detachment appears thereby to be lessened. This fact it was which chiefly suggested the idea of dividing the detached part by incision. Sichel had already at an earlier period advised the discharge externally of the effused fluid, by puncturing the sclerotic in the seat of the detachment. This is attended with no difficulty whatever; but it does not appear that any advantage is obtained by it. The incision of the detached part was performed chiefly by Adolf Weber and by Von Graefe, with a two-edged needle, carried from the inside through the vitreous humour. In this manner a communication was established between the fluid accumulated behind the retina and the vitreous humour, with which it mingled; and the difference of pressure, which plays a part in the origin and further development of the affection, was thus removed. No injurious effect resulted from the operation; in some cases, at least at first, some improvement was observed; but experience has as yet by no means decided, whether, and in what cases, permanent benefit is to be obtained by this method: hitherto it has been employed almost exclusively in old and nearly hopeless cases. It has, indeed, appeared, that in staphyloma posticum the danger of extension of incipient detachment, and consequently of increasing destruction of sight, is greatest. . . . In all cases of recent detachment of the retina, in addition to the ordinary hygiene of the eye, jolting, vibration, &c. (in carriages and on railways), as well as violent exertion in fatiguing work, are to be strictly forbidden.

For the sake of illustration I will, in conclusion, endeavour to sketch, in a few lines, the most frequently-occurring types of myopia.

Slight degrees of myopia escape the observation of the patient himself.

I. Mr. S. brings me his son, a boy of 15 years, who has been rejected for nearsightedness at the Military Academy. 'The lad is not nearsighted, he reads the smallest writing still farther than he can reach'. At twenty feet he sees only No. 60, with — 1/22 No. 20, with — 1/20 no better, with — 1/24 and particularly with — 1/26 less acutely. He has therefore M=1/22, and the rejection is legitimate. Ophthalmoscopically scarcely a trace of atrophy is found, but the papillæ are red. He has latterly worked very hard, in the evening, too, with moderate light, in order to prepare himself for his examination. In doing so he found no inconvenience. He had indeed last year observed, that he could not recognise people so far off as before, but he did not attribute this to nearsightedness, because he could see the finest object sharply at the distance of two feet.

My opinion is: that the myopia will increase a little. To prevent it increasing much, let hem work by good light (by preference by daylight), holding up his head, at the distance of from 14″ to 16″, on an inclined plane, with intervals of some minutes every half-hour. I add, 'Be of good cheer, my young friend, you can be whatever you wish, except a soldier*; towards your eighteenth year (with M about = 1/16), you will get spectacles to wear and to work with, and you will put these off for work about the age at which others begin to wear glasses.'

II . . . .

With diminished range of accommodation the myopia can no longer be neutralised.

III. Dr. L., aged 37, with myopia = 1/9 and otherwise sound eyes, has for the last twelve years, now and then, worn spectacles, which corrected about from 1/2 to 2/3 of his myopia, but he has always read and written without glasses. The degree of the myopia has at this time somewhat, but certainly not much increased. Not long ago he consulted an optician, who gave him — 1/9 to wear, with the advice to continue to work without spectacles. Dr. L. immediately found that these glasses were disagreeable to him; walking and looking at a distance, he found all very well, but at the distance of two feet he could not see acutely without an effort, which inconvenienced him at table, in speaking to people whom he wished to look at, and under many other circumstances. He asked me what he was to do. My answer was: 'If you had commenced in your twenty-fifth year with neutralising spectacles, or if you had, at least, used your weaker glasses also at your work, you would now find no trouble with neutralising spectacles with convergence at two feet, and even at one foot, in accommodating for that distance. You are now obliged to keep to weaker glasses, for example, — 1/12 with which you still see perfectly sharply at three feet, and also sufficiently well at a great distance. You are tall, and are therefore inclined to stoop forward, and it is consequently desirable that at work you should accustom yourself to spectacles, which, however, must certainly for the present not be stronger than — 1/20; by degrees their strength may be somewhat increased, and perhaps you may succeed, within a couple of years, in accustoming yourself to — 1/12, without their use being attended with symptoms of asthenopia, in which case you may, without any injury, easily keep the same glasses of — 1/12, under all circumstances, for half a score of years'.

IV . . . .

Spasm of accommodation may supervene upon the symptoms of irritation.

V. T.W., aged 17, was nearsighted from childhood, and has for some

*In England M does not disqualify an officer.

time been unable to continue working, in consequence of rapidly-increasing pain in the eyes, which are also permanently sensitive. I found myopia of 1/2·7, somewhat stronger still in the left eye; moreover, capillary hyperæmia of the optic disc; at its outside a perfectly atrophic, white, sharply-defined crescent, 0.8 mm. broad in the transverse direction (the axis), straightened retinal vessels, no trace of chorioiditis, rather small pupil, easy convergence of the visual lines up to 2 1/2″ (he then also read binocularly), scarcely any subconjunctival injection, no prominence of the eyes, eyelids healthy, but a tendency to approximate them, not merely in order to see better, but also on account of some intolerance of light. He showed me spectacles of — 1/9, which he had worn, and had also used at work, but by the advice of others, he had afterwards laid them aside, and he had since not got on better. The acuteness of vision amounted to only 13/20. This latter circumstance chiefly induced me to prescribe a Heurteloupian abstraction of blood* from both temples, and to make him remain for twenty-four hours afterwards in the dark. After gradual transition to the light, the degree of myopia was again, with the aid of glasses, determined in the most accurate manner, and was found = 1/3·4; at the same time the acuteness of vision had increased to 17/20. Instillation of sulphate of atropia now brought the myopia to 1/3·7. The patient was still kept some days in a half-darkened apartment; subsequently the double abstraction of blood was again had recourse to, and the hygienic rules which have already been repeatedly mentioned, were strictly enjoined. Thus at the end of a month the acuteness of vision had risen to 18/20, and the myopia was established as 1/3·6. He now got spectacles of — 1/5, both to wear and also in order occasionally to read and write for a quarter of an hour, which *could* thus be done at the distance of about 10″, and therefore *must* be done. From time to time slight attacks of pain still occurred, which disappeared on strict rest. The spectacles were subsequently strenghtened to — 1/4·5. These glasses, held close to the eye, brought the farthest point to 14″, which was quite sufficient.

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The occurrence of fatigue during work indicates the existence of insufficiency of the musculi recti interni.

VII. Miss v. R., aged 18, had for some years been constantly obliged to suspend her work, in consequence of a feeling of fatigue and tension. She has in vain tried various spectacles. I establish $M = 1/7$, $S = 1$, with the ordinary crescentic atrophy; the eyes are otherwise sound and the eyelids healthy. I suspect insufficiency of the recti interni. While she

*Heurteloupian abstraction of blood is accomplished by means of an artificial leech making a circular wound, and yielding much blood on exhaustion by means of a glass cylinder. (The instrument is to be had at Luer's, Paris. Its price is fifty francs.)

reads at 6″ with both eyes, I bring a small screen before the left, and observe it deviate outwards behind the screen. On removing the screen the eye again converges sufficiently. Having made some inquiries, I find that, after having read for half-an-hour, the left eye is always drawn outwards, that this gives her an unpleasant sensation, and that the effort to overcome the deviation fatigues her still more. Thus, she had herself already remarked the insufficiency without having been able clearly to account for it, and without having spoken of it. On approximating an object, she converges up to 4″, after which the left eye rapidly and strongly deviates. However, on lateral movements the excursions appear normal; towards distant objects the eyes are also properly directed, and they maintain this direction when one eye is covered; a prism, too, placed before one of the eyes, with the angle upwards, gives double images of a remote light, without lateral deviation, one of the images being almost directly above the other; while a prism of 6°, with the angle outwards, gives intersected double images, which do not disappear. Thus it is evident that our patient can diverge little more than normally, and yet that she has comparatively much too great difficulty in converging. With glasses of from — 1/12 to — 1/8 she can, looking at from 13″ to 16″, maintain the convergence much longer, but yet not sufficiently: the covered eye now always deviates also, still directly outwards. By combining — 1/12 with a prism of 8° the difficulties appear to be removed, and the now covered eye actually scarcely any longer alters its direction. Besides such glasses, she receives a double eye-glass with simple glasses of — 1/7. With this she is exceedingly pleased, but the prismatic combination wearies her. She would willingly undergo tenotomy, which was spoken of, but as, undoubtedly, even in looking straight, and particularly in looking to the left, double images at a distance would remain, I do not think the operation indicated. Finally, I give her glasses of — 1/7, with the axes closer to one another than the axes of the two eyes; and if she has to work only one hour, she gives the preference to these, above the prismatic combination. She has to be particularly careful not to use these spectacles in looking at remote objects: on account of the position of the glasses she would in doing so be compelled to diverge somewhat, which could not act otherwise than injuriously upon the power of the recti interni.

The insufficiency may sometimes be completely corrected by tenotomy.

VIII. Mr. C., a mechanic, with M = 1/8, has, except the ordinary crescent, sound, sharpseeing eyes. Yet his work fatigues him after a short time, and he thinks it not well to continue using his sight. His looking at a distance did not exhibit the ordinary apparent convergence, but rather gave the impression of divergence. This immediately suggested to me the idea of insufficiency of the recti interni. On examination, it appeared that in unconscious distant vision he had the tendency to divergence, which was absent when he saw acutely through glasses of — 1/8; that he, however, aided with — 1/8, for the sake of single vision, could overcome a prism of 12° with the angle outwards, and consequently could considerably diverge. When, in reading at a distance of 8″, a screen was brought before the one eye, this evidently deviated outwards, to turn again inwards on the removal of the screen, and it appeared that this movement was scarcely greater than that which was observed after the removal of the prism of 12°, in looking at a distance. Consequently the insufficiency with a certain convergence, made itself not much more strongly felt than in distant vision. Tenotomy was therefore indicated. It was immediately performed, first, on the left eye, the effect of which was still unsatisfactory; then also on the right eye, when it was at first too great, so that remote objects appeared single only in the direction to the right of the middle line; but forthwith convergence to 8″ took place, with the greatest ease, and after some weeks the double images ceased also at a distance. The success was complete. Fatigue was no longer mentioned, particularly not after our patient, by my advice, had begun to wear glasses of — 1/16, and to use them at his work.

Note to Chapter VII

We are indebted to Kepler for the earliest knowledge of the nature of myopia. He laid the foundations of dioptrics in general, and in particular of physiological dioptrics. The influence which spectacle-glasses have exercised in this direction is extremely remarkable. . . . Their great importance in the history of science was demonstrated in the observation that they had led to the invention both of the microscope and of the telescope. After perusing the works of Kepler, I go still further, and think I may maintain that the development of physiological dioptrics has proceeded from spectacle-glasses. Alhazen showed about 1100 that the eye is not the source of light, but that the light proceeds from visible objects and enters the eye. With respect to the formation of pictures in the eye, he conceived wholly incorrect ideas. It is still stranger that we must say the same of Johannes Baptista Porta, who, although he compared the eye with the camera obscura invented by him, was of opinion that the pictures were formed on the anterior surface of the lens (1558 and 1593). His contemporary, Maurolycus (1575) arrived at more correct conclusions. This writer comprehends that the crystalline lens is to be compared with an ordinary convex lens, looks upon it as more convex in myopes, flatter in presbyopes, explains the action of convex and concave glasses, but nevertheless gives, in order to avoid the inversion of the images upon the retina, a totally confused idea of the action of the lens, and makes the images fall on the plane of the optic nerve, without mentioning the retina.

It was in 1601, Kepler himself informs us, that D. Ludovicus L. B. a Dietrichstein, put the question to him, why farsighted people distinguished near objects better through convex glasses, while nearsighted people saw distant objects more distinctly with the aid of concave glasses. Kepler was not acquainted with the work of Maurolycus. The only answer which he was at first able to give was, that convex glasses magnified near objects. But Von Dietrichstein, not content with that, rejoined, that the question did not relate to magnitude, but to distinctness: for that concave glasses, which make objects smaller for all eyes, could otherwise assist no one. When, after three years' study, Kepler is at length in a position to give an answer: 'responsum,' he says, 'si non satis clarum et indubium; satis certe tardum', his thankful tone testifies of the stimulus which he had received from the question of the man whom he calls, 'Mæcenatum meorum præcipuus'. ... It is evident, and Kepler himself says it, that he could not at first answer the question proposed to him, because he had no correct idea respecting vision. Here, now for the first time, we find the formation of inverted images upon the retina (some years later demonstrated in the curious experiments of Scheiner), contended for upon good grounds, and explained by the meeting of the rays, proceeding from each point of the object, again, in one point, upon the retina, in consequence of refraction by the cornea, and especially by the crystalline lens. Kepler knew also ,that in order to form a sharply-defined image upon the retina, the object must be at a given distance; and with this is connected the answer respecting the action of spectacles.

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For the first time we find the necessity of change of form in accommodation demonstrated. 'It is not possible, that the retina maintaining the same position in the eye should receive a defined image both from near and from remote objects'. 'Some see remote objects distinctly, near objects confusedly (presbyopes); others see near objects distinctly, remote objects confusedly (myopes); others see near and remote objects confusedly (morbid conditions); some, finally, see both distinctly'. Of these last he says: 'They accommodate for different distances by altering the form of the eye. 'Qui vero alterutra', thus he continues, 'solum distincte vident, oculum habent sanum quidem, sed jam induresccntem, adsuefactum et quasi senilem'. This he applies both to myopes and presbyopes. He places both in one line. He has thus, although himself myopic, overlooked the accommodation of myopes. Kepler develops his idea respecting the mode of origin still more fully in the following manner: He who in youth practices himself for distance and for near objects, in old age, becomes presbyopic, because practice diminishes with advancing years, and the parallel condition of the visual axes is the most natural: 'but he who is from childhood occupied with study or fine work, speedily becomes accustomed to the vision of near objects, and with the advance of years this increases, so that remote objects are more and more imperfectly seen'. Thus in Kepler's view nearsightedness consists in the condition of accommodation for near objects having become unalterable through partial or one-sided practice. ...

Thus we see that Kepler looked upon myopia and presbyopia as opposite conditions, and this was in his position perfectly logical, for he admitted no accommodation in either state.

This vision of myopes was still farther investigated and explained by Scheiner (1625), and subsequently, especially by Dechales (compare p. 172 of this book). But still Kepler's error always remained: observers were not aware of the accommodation of myopes. It is almost incomprehensible that, with the distribution of neutralising spectacles, for which rather correct directions were given, oculists should have overlooked the accommodation in young people; but yet I have not been able to ,satisfy myself that any writer of the seventeenth century directly mentions it. It is by Robert Smith (1738) that we first find it clearly expressed. He not only remarks that a myope sees distant and near objects acutely through the same glasses, but he also shows that no more accommodation is required for that purpose than for the short range which the myopic eye possesses without spectacles.—With the demonstration of the accommodation of myopes, the opposition of myopia and presbyopia should at once have disappeared.

The most important point which remained to be investigated was the organic basis, *the efficient cause* of myopia. With respect to this we find among the earlier writers no definite idea.

. . . .

Only so far as they were based partly upon observation, do they deserve to be remembered, and this was not altogether wanting. Thus Boerhaave (1708), in his lectures *de Morbis Oculorum, prælectiones publicæ*, 1750, published by Haller from manuscripts of different hearers, said: 'Infinita sunt in oculo, nec unquam explicanda quæ hos effectus (myopiam) facere possunt, duas vero saltem saepissime *observatas* causas hic proponemus', and, as such, he names: 1°. *Nimia oculi longitudo*; 2°. *Corneæ* *convexitas nimia*. These two were indeed more than a mere optical fiction. Deceived by the greater depth of the chamber of the eye, observers thought that, viewed in profile, they saw a more convex cornea in myopes. And certainly it was also a matter of observation that in highly myopic individuals the eyeballs are often large and prominent. We find this fact already mentioned by much earlier writers than Boerhaave. . . . But still this cause was in general not sufficiently put forward, and until a few years ago no decided opinion whatever was adopted. Von Graefe (1854) even acknowledges that previously to his examination of eyes with staphyloma posticum, he thought that the cause of myopia was to be sought in the vitreous humour.

. . . .

Now we are aware that it was an advance when, putting aside other causes, writers adhered to the increased length of the visual axis. Such an elongation was anatomically first found by Scarpa (1801), in two females eye, and was decribed by him under the name of *staphyloma*, because it appeared to be a *morbid distention*. This was perhaps the reason why it did not occur to Scarpa to bring the deviation he had established into connexion with myopia, for observers were at that time far from suspecting that an atrophic condition was connected with myopia. Subsequently, Von Ammon remarks (1832) ,that the staphyloma posticum of Scarpa is not of such rare occurrence as had been supposed, and that the distention is usually greatest at the posterior pole,—always without seeking a connexion with myopia. The first who states that he had found in the dead body the eye of a nearsighted person *pear-shaped* is Ritterich (1839); but it was in the dissections of Arlt (1856), who, in various eyes of myopes, found an evident elongation of the visual axis, formed at the expense of the posterior wall, that the great importance of this distention with respect to myopia was studied and generally recognised. To this it certainly contributed much, that after the invention of the ophthalmoscope, the peculiar changes in the fundus oculi of myopes were discovered in different quarters which changes were unmistakably connected with the posterior distention of the bulb.

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CHAPTER VIII

Astigmatism (As)

§ 33. *Definition of Astigmatism. Regular and Irregular Astigmatism*

Ametropia, comprising the lesions of refraction, is resolved, according to § 6, into two opposite conditions: myopia and hypermetropia. Every lesion of refraction belongs to one of these two. Sometimes, however, it happens that in the several meridians of the same eye the refraction is very different. . . .

The asymmetry, on which this difference depends, is proper to all eyes. Usually it exists in so slight a degree, that the acuteness of vision is not essentially impaired by it. But exceptionally it becomes considerable, and occasions an aberration of the rays of light, which interferes with the sharpness of sight.

This aberration, dependent on an asymmetry of the eye, may be designated as *astigmatism*. To make it clear, we must glance at the aberrations of light in general.

Rays of light which, sufficiently prolonged, all meet at one side in the same point, form *homocentric* light: they have a common centre. The diverging light, emitted from a point of any object, is therefore homocentric. . . . Consequently the rays of light, proceeding from any object, and received by the cornea, form cones of homocentric light. . . .

In general, we may say that homocentric light, refracted by a spherical surface, continues homocentric: that, namely, the rays behind the refracting surface either unite again into one point, or proceed in a direction as if they all were derived directly from a point situated before the refracting surface.

The homocentricity has, however, not continued perfect. . . . To this deviation from homocentricity the name of 'aberration' is given; and we distinguish two aberrations of different origins: the *chromatic* and the *spherical*. The first depends on the nature of the light, the second on the form of the refracting surface.

Chromatic aberration is the result of a difference in refrangibility of the rays of light. . . . Rays of unlike nature, find their focus in the axis, at different distances from the refracting surface, the violet and blue rays at a shorter, the red at a longer, distance. The dioptric system of the eye also necessarily presents this chromatic aberration. Under ordinary circumstances, however, the latter scarcely interferes with the sharpness of vision[1]. I shall not dwell further upon it, as it has no essential connexion with our subject.

Rays of light of equal length of undulation, and as such, of equal refrangibility, form homogeneous light; the light is also of similar colour, and is therefore called *monochromatic*. If such rays fall parallel on a spherical surface, and at the same time at an equal distance

*Helmholtz, *Physiologische Optik*, in *Allgemeine Encyklopaedie der Physik*, Leipzig, 1856.

from its axis, the homocentricity is perfect. But if they strike the surface at different distances from the axis, they cease to be directed exactly to one point: the farther from the axis they strike the surface, the nearer to the surface do they cut the axis. This deviation is called *spherical aberration:* it is the *monochromatic aberration* (that is, the aberration of rays of like colour) belonging to refraction by a spherical surface.

The dioptric system of the eye also has a monochromatic aberration. The latter is in it even rather considerable, and is highly complicated. For our purpose it is to be distinguished as

a. An aberration, which has reference to the rays refracted in one and the same meridian.

b. An aberration, dependent on the difference in focal length of the different meridians of the light-refracting system.

The first represents *irregular* astigmatism. It is dependent chiefly on the structure of the lens, and its leading phenomenon is the polyopia uniocularis. Morbid deviations may also produce irregular astigmatism. Of these I shall speak in the last section of this chapter. The second gives rise to *regular* astigmatism, which is capable of correction. It is the principal subject of this chapter.

The Rev. Dr. Whewell has, as Mackenzie informs us, designated the defect, described by Airy as existing in his left eye, by the name of astigmatism. This word is derived from α priv. and στιγμα, from στιζω, pungo and signifies that rays, derived from one point, do not again unite into one point. The entire monochromatic deviation in the eye we may therefore call astigmatism, and this meaning I have given to the term in question. Whewell had applied the name only to the regular form. By the word astigmatism, used without more precise definition, regular astigmatism will, in the sequel of this work, be understood.

§ 34. *Regular Astigmatism in the Normal Eye*

If we determine successively the farthest point, at which fine horizontal and fine vertical threads or stripes are acutely seen, we obtain unequal distances. The great majority of eyes discover a shorter distance for horizontal than for vertical stripes.

. . . .

The asymmetry is of such a nature that the focal distance is shorter in the vertical meridian than in the horizontal.

. . . .

The correctness of this view appears further from the form of the diffusion-images of a point of light. In accurate accommodation the diffusion-spot is very small and nearly round, while a nearer point appears extended in breadth, and a more remote one seems to be extended in height.

. . . .

From figure 42 it is evident, what successive forms the section of the cone of light will exhibit. In the middle of the focal interval, D, it will be nearly round, and anteriorly through oblate ellipses, C, with increasing eccentricity, it will pass into a horizontal line, B; posteriorly through prolate ellipses, E, it will come to form a vertical line, F, while before the focal interval a larger oblate ellipse, A, and behind it, a larger prolate ellipse, G, will be found.

To this, as we have seen, the diffusion-images of the eye in general correspond.

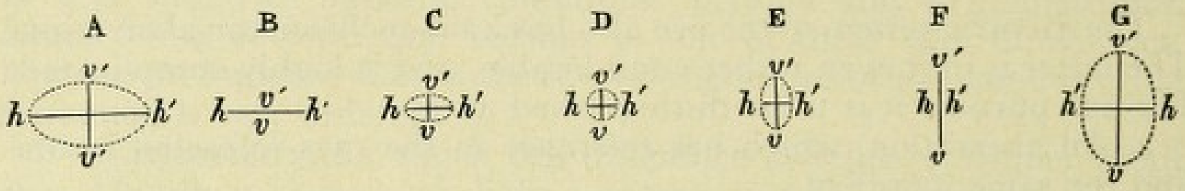

Fig. 42.

. . . .

We have thus far assumed that the maximum of curvature coincides with the vertical, the minimum with the horizontal meridian. And the rule in fact is, that they nearly do so. But to this rule there are numerous exceptions. Not unfrequently the deviation from the ordinary direction is very considerable; and it even occurs that the maximum of curvature coincides nearly with the horizontal, the minimum with the vertical meridian. So Thomas Young, the discoverer of astigmatism, found it in his own eye, and I too have met with some cases of this nature.

In general there is no difficulty in determining the direction of the principal meridians. The mode of doing so is included in the experiments above described, in proof of the existence of astigmatism. Were we so perfectly conscious of our accommodation that we could accurately state, what lines in the annexed figure are seen quite sharply at the maximum, and what at the minimum of augmented tension, the directions of the maximum and minimum of curvature would at the same time be known. That consciousness is, however, seldom very accurate.

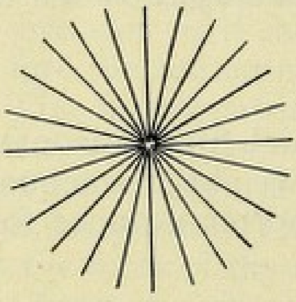

Fig. 43.

. . . .

The result is often surprising when the eye, made slightly myopic (for example 1/60) by a glass is made to look towards a remote point of light, and a negative glass (for example — 1/30) is alternately held before the eye and taken away. The diffusion-image then is extended in each time two opposite directions.... By quickly pushing the glass to and fro, the two images are (in consequence of the persistence of the impressions) persistently and simultaneously seen, and in some then exhibit the form of a cross.

. . . .

By this experiment we can satisfy any one that this eye is not free from astigmatism.

. . . .

The cause of regular astigmatism is to be sought partly in the cornea.

. . . .

On the lens depends irregular astigmatism; to it polyopia uniocularis, to it the rays of the diffusion-images of a point of light owe their origin. The direct proof of this is furnished by the fact, that in the condition of aphakia, when the lens is wholly absent from the eye, all these phenomena of irregular astigmatism are removed. In numerous cases I have satisfied myself of this.

. . . .

Astigmatism, the result of a positive cylindrical lens, may be removed by a second of equal focal distance, either by a negative, whose axis is parallel to the first, or by a positive, whose axis stands perpendicular to that of the first. Thus, also, the astigmatism of the eye may be corrected by a cylindrical lens; . . . the focal distance of the cylindrical lens required for this purpose defines the degree of the astigmatism: it is inversely proportionate to the focal distance of the correcting lens, expressed in Parisian inches.

So long as astigmatism does not essentially diminish the acuteness of vision, we call it normal. It is abnormal so soon as disturbance occurs. If it amounts to 1/40 or more, it must be considered as abnormal. . . .

The asymmetry of the dioptric system of the eye was first observed by Thomas Young (1793), in his own person. The distinguished natural philosopher, whose brilliant merits in the domain of physiological optics were first duly estimated by Helmholtz, was himself nearsighted. In relaxation of the eye, consequently in determination of the farthest point, he saw in his optometer, held in a horizontal position, the double images of the thread intersect one another at seven inches from the eye, on the contrary at ten inches, when in a vertical position. This indacates, on reducing the English to Parisian inches, an astigmatism of about 1/25; and it is therefore strange that Young, as he himself remarks, had experienced no disturbance from it. The optician Cary, to whom Young communicated his discovery, stated to him that he had before often found that nearsighted people distinguished objects much more acutely, when the glasses suited to them were held in a particular oblique direction before the eye: now by this manoeuvre, at least when strong glasses are necessary, a certain degree of astigmatism may be corrected.—Young, too, had already studied and delineated the form of the diffusion-spots. The source of astigmatism he sought in the crystalline lens, because it continued when he plunged his cornea into water, and replaced its action by that of a convex lens. He now assumed an oblique position of the crystalline lens as the cause, and even thought that from the diffusion-images of a point of light it might be deduced, that the two surfaces of his lens were not centred. —In a double point of view, therefore, Young's eye presented an exception: the refraction was stronger in the horizontal than in the vertical meridian, and the cause lay principally in the lens.

. . . .

In order to be able to calculate what astigmatism the crystalline lens possesses, the direction and degree of astigmatism for the whole system, and for the cornea the radii of curvature in its *axis, and indeed in the meridians of maximum and minimum*, must have been known. Now we may admit that . . . the principal meridians usually approach to the horizontal and vertical directions, . . . ; but still I considered the deviation too great to allow of our determining the *slight* astigmatism of the crystalline lens (as difference between the total and that found for the cornea) *by simple subtraction*.

A more accurate investigation, formerly promised, and now accomplished with the zealous co-operation of Dr. Middelburg, has shown, indeed, that such substraction is not admissible.

. . . .

If the crystalline lens takes part in regular astigmatism, it may do so in either of two ways. In the first place, by the form of the surfaces of curvature: these might very well be ellipsoids with unequal axes, of which the maximum and minimum need not coincide with those of the cornea; respecting this, however, nothing is with certainty known. In the second place, by an oblique position of the lens, which would have a corresponding influence. That this influence sometimes exists, at least in higher degrees of astigmatism, is, as shall hereafter appear, directly proved. And that it obtains in the crystalline lenses of my own eyes, the study of the diffusion-images of a point of light have convinced me: before and behind the central part of the focal space the intersection of the fasciculus of rays, derived from a point of light, has precisely such divergent forms as take place, in an oblique position of a convex lens, upon a screen.

. . . .

It would be instructive to be able to receive rays, refracted at the top of an ellipsoid, on a screen. As this is, however, not a rotation-body, it will scarcely be possible to grind it of such a form. But we may obtain nearly the same by combining with an ordinary spherical lens a cylindrical one of much greater focal distance.

Such combinations are to be found in the boxes made at my suggestion by Nachet and Son, of Paris, for the investigation of astigmatism.

The light should first be allowed to fall on the symmetrical spherical lens, separated from the cylindrical one by a diaphragm with a round opening. As a cylindrical lens we should use a combination of two plano-cylindrical lenses, a positive and a negative of equal focal distance (lens of Stokes), one of which can turn round the axis of the case. We thus obtain the effect of a single cylindrical lens, whose astigmatic power is $=0$, when the axes of the cylindrical surfaces of curvature are parallel, and on turning to 90° gradually ascends to that of the sum of the two lenses. By thus connecting the combined cylindrical with the spherical lens, we can communicate to it all the degrees of astigmatism. It then appears, on moving the screen, that the focal interval is greater, that the lines bounding it are longer, and the sections of the fasciculus of light in the course of the focal interval are greater, according as the cylindrical lens is stronger, that is, as the astigmatism is greater.... The whole form of the refracted bundle of light is very strikingly seen in tobacco-smoke, when the solar image is used as object.

Sturm assumed that the focal interval, which is the result of asymmetry, should make any accommodation of the eye for different distances superfluous. This opinion no longer needs refutation. Its inaccuracy becomes at once apparent when we reflect, that the focal interval for the dioptric system of the eye would be much too small, to contain in itself the whole range of accommodation, and that, were it long enough, the acuteness of vision would suffer considerably by the great diffusion-images, as in a high degree of astigmatism is actually the case.

. . . .

§ 35. *Disturbances and Phenomena in High Degrees of Astigmatism*

We have seen that a certain degree of regular astigmatism occurs in all eyes, and therefore cannot be considered as abnormal. We do not call it abnormal until it attains to such a degree that the accuracy of vision perceptibly suffers from it. For equal lengths of the focal interval, this is the case sooner, in proportion as the pupil is larger. Our observations should therefore be made with an average size of the pupil, under sufficient illumination.

1. The disturbance manifests itself first, when stripes of different directions lying in the same plane have to be distinguished. If these stand far from one another, the accommodation usually regulates itself almost involuntarily, in order to see them acutely alternately, and the disturbance may still be unobserved. If they are close together, the diffusion-images of the one direction fall over the defined images of the other, for which the subject is accommodated, and confusion ensues. In most capital Roman letters this soon occurs.

. . . .

2. There exists a certain indifference for spectacle-glasses of nearly equal power. It is impossible to make a definite choice. In diminished acuteness of vision, proceeding from other causes, this indifference does not exist, or at least it is present in a much less degree. This phenomenon led me long ago to suspect that the diminished acuteness of vision, often peculiar to hypermetropia, might be dependent on abnormal astigmatism. The phenomenon finds its explanation in the long focal interval, whose sections as diffusion-images are nearly equally disturbing, and in whose range, with moderate difference of glasses, the retina easily maintains its position.

3. The diffusion-image of a point of light alters, in modification of accommodation, not only in size, but also in form. Only when the middle of the focal space corresponds to the plane of perception is the image nearly round; in every other state of accommodation it is extended in one or other direction. This is already the case in the ordinary degree of regular astigmatism, as we have seen, but at high degrees thereof it is particularly striking. In such we soon find a spherical glass, with which a point of light at a distance exhibits itself as a stripe of light, and at the same time a modifying spherical glass (whether positive or negative), which, placed before the first, makes the stripe of light assume a precisely opposite direction. In the required strength of this modifying glass we possess a means of determining the degree of astigmatism. By the alteration of direction of the stripe of light, on alternately placing the second glass in front, astigmatics are especially impressed. He who has sufficient control over his accommodation, without using a modifying lens, can voluntarily produce similar change, of form of the diffusion-images.

4. The influence of the direction of stripes on their distinctness is exceedingly great.

. . . .

The alternating distinctness of the stripes of opposite directions, on applying and removing the modifying glass, is very striking even in slighter degrees, while on a line, which cuts the two opposite stripes at an angle of 45°, it has scarcely any influence.

5. If the stripes of different directions consist of short lines as in the annexed fig. 44, these at a certain distance coalesce for *all eyes*, and we therefore see only the principal stripe. On drawing near, the strongly astigmatic eye observes the transverse lines much sooner in the stripe which is most feebly seen, than in the clearest.

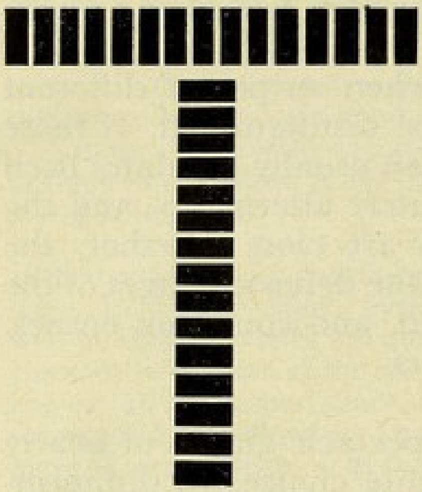

Fig. 44.

6. Lines of equal length in the two opposite directions do not appear equally long, and this gives rise to the incorrect estimation of the form of the objects: a square exhibits itself as an oblong.

Here two different causes come into play. In the first place, in accurate accommodation, successively for erect and recumbent lines, those situated in the meridian of greatest curvature (in general the erect lines), for equal lengths, form longer images upon the retina. The cause is to be sought in the position of the nodal points, or rather of the second nodal point. The farther this point lies from the retina, the larger will the retinall image be, and . . . the nodal point lies more anteriorly in the meridian of greatest curvature. In strong astigmatism this difference may amount to more than one mm., that is, about 1/13 of the distance between the second nodal point and the retina.

In the second place, diffusion is to be taken into consideration. If a vertical line be acutely seen, a horizontal line presents a diffused appearance: it seems broader. Now the superior and inferior boundaries of a square may be considered as horizontal lines: consequently, when the eye is accommodated for the vertical limits of the square, the latter appears larger in the vertical dimension.

. . . .

—The effect of diffusion here described obtains in looking at a clearly illuminated square upon a dark ground; it is inverted in the case of a dark square, observed upon a brightly illumined ground.

7. The acuteness of vision is very considerably improved by looking through a slit of from one to two millimètres in breadth. In these experiments the stenopæic apparatus may be employed, the slit of which can be narrowed and widened at pleasure. The improvement in the power of vision is greatest, when the slit is held in the direction of the maximum or minimum of curvature. . . . The improvement of the acuteness of vision, in looking through a slit, is a very significant phenomenon. It affords a direct proof that the rays, refracted in the meridian of one of the principal sections, unite nearly in a point, and that consequently the existing disturbance of vision depends on asymmetry. What

is more, we can determine the difference of the state of refraction in the meridian of the maximum and minimum of curvature in the way described, with the aid of spherical glasses, as shall be more particularly described in the following chapter.

It is also instructive that, in looking through a slit, not coincident with one of the principal sections, the objects are drawn out. . . .

8. In high degrees of astigmatism the phenomena of dispersion are very peculiar. Helmholtz observed that, in general they are much more distinct when, instead of white light, such light is employed in the investigation as consists of only two prismatic colours of the greatest possible difference in refrangibility. . . . In experimenting with the light of a lamp or of a wax-candle, a dark blue cobalt-glass, which transmits only the extreme red, with indigo and violet in large quantity, is quite sufficient. . . . On looking with slight myopia (or accommodation for a near point) through such a cobalt-glass towards the flame of a candle, its edges are blue, and the centre reddish; in slight hypermetropia a beautiful red border is seen around the candle and the centre is blue. Slight degrees of ametropia are immediately distinguishable by this means. In high degrees the diffusion-images are too large, to enable us to observe the difference of colour with equal distinctness. On looking through a violet-glass at a small opening in a dark screen turned towards the daylight, we see, in accommodation for the violet rays, the opening surrounded by a red, in accommodation for the red we see it surrounded by a violet margin. . . . If, on the contrary, an astigmatic person sees such an opening as acutely as possible, and if, on the violet-glass being then pushed before his eye, blue margins appear at the superior and inferior, and red at the two vertical edges, the subject is shown to be myopic in the vertical, and hypermetropic in the horizontal, meridian. If he sees the point of light drawn out to a line, the extremities and middle of the line are of different colours, and on altering the direction of the lines of light by the modifying lens, the colours also change.

All the above phenomena we may observe in ourselves. The only thing necessary for this purpose is to make the eye astigmatic, and this is effected by holding a cylindrical lens before it.

. . . .

To obtain in one's own person a simple and often-occurring case, we should make the horizontal meridian hypermetropic, with emmetropia of the vertical. An emmetropic individual needs to this end only to hold before the eye a cylindrical lens of — 1/20 with the axis of the cylinder perpendicular.

. . . .

Two remarks may be added: the dispersion has appeared to me to be greater in such artificial astigmatism than in the natural, and the difference in the size of the retinal images in the two principal meridians is more considerable. . . . The reason is evident: the cylindrical lens is, in fact, at some distance from the cornea, and its action here exercises more influence on the position of the nodal points, than if by modification of the corneal radius, the posterior focus had been equally displaced. Objects are therefore seen more drawn out, than in natural astigmatism of like degree.

. . . .

§ 36. *Diagnosis of Abnormal Astigmatism, and Determination of its Degree*

. . . .

A. Subjective investigation. Absence of the normal acuteness of vision supplies the first indication. If the disturbance has existed from youth, almost unaltered and in equal degree, without striking variations, there is reason to suspect that astigmatism is the cause. It is even exceptional to find this suspicion refuted by investigation. . . .

1. In every diminution of acuteness of vision, we begin by determining ist degree. We must remember, that in high degrees of myopia, for more than one reason, perfect acuteness of vision is usually not met with. A certain amount of imperfection in myopia, therefore, affords less reason to suspect abnormal astigmatism. Nevertheless the trial should be made.

2. Let then imperfect acuteness of vison be found. *We must now first determine, in what direction the principal meridians*, that is, *the maximum and minimum of curvature, are situated.* For this purpose we make use of a remote point of light. In my consultation-room one of the window-panes is of dull glass. In front of the centre of this glass is a black board, 35 centimètres square: in the middle of the board is a perforated metallic plate, before which a diaphragm can be pushed, with openings of from 1/2 to 10 mm. in diameter. The patient should now be directed to look towards an opening of from 2 to 4 millimètres in diameter, at a distance of from 10 to 15 feet, while by means of glasses we cause slight myopia to alternate with hypermetropia (compare p. 209). Even in the normal eye, an extension of the diffusion-image is, on this examination, usually observed in two opposite directions, indicating the maximum and minimum of curvature. But in abnormal astigmatism this is particularly striking. . . .

3. We have thus ascertained the direction of the principal meridians. We should now examine, *whether the rays, belonging to these, form more accurate images than those from the whole refracting surface.* For this purpose, we should hold, successively in each of the principal meridians, the slit of a stenopæic apparatus, set to the breadth of 1 or 2 mm., and ascertain whether the acuteness of vision be thereby increased. If not, we should then try the addition of ordinary positive and negative glasses . . . If, even with the aid of these, no greater acuteness of vision be obtained, than existed without the use of the slit, it is almost certain that astigmatism is not to be considered as the cause of the disturbance.

. . . .

4. Let there be improvement of acuteness of vision; the existence of abnormal astigmatism is thereby proved. Now the question is: *what is the state of refraction in each of the principal meridians?* This appears from the strength of the positive or negative glass, with which in each of these meridians the greatest acuteness of vision is obtained. We usually find for both a certain degree of ametropia. It is now of importance, accurately to determine this degree. . . . The determination is unattended with difficulty, when a certain degree of myopia exists in both principal meridians. But if hypermetropia be found in one or both meridians, it is, at least in the case of young persons, probable, that the degree is not accurately shown. For involuntary tension of accommodation conceals in part the existing hypermetropia. . . . Were the tension unaltered in the subsequent determination for the two principal meridians . . . the degree of astigmatism would be known. But this equality of tension is not to be expected. Moreover, it is not sufficient to know the degree of astigmatism, it is also necessary to know that of the hypermetropia in the two principal meridians. Now this knowledge is certainly and accurately obtained only by repeating the experiments during artificial paralysis of accommodation produced by means of a mydriatic: the hypermetropia necessarily exhibits itself entirely as manifest hypermetropia.

. . . .

5. *The degree of astigmatism is found from the difference of refraction in the two principal meridians.*

I. *Myopic astigmatism*, to be distinguished into:

a. Simple Am, with M in the one, E in the other meridian.

. . . .

b. Compound myopic astigmatism, or myopia with astigmatism, M + Am, M existing in both principal meridians.

. . . .

II. *Hypermetropic astigmatism*, likewise to be distinguished as:

a. Simple Ah, with H in the one, E in the other principal meridian.

. . . .

b. Compound, being H with astigmatism, H+Ah, H existing in the two principal meridians.

. . . .

III. *Mixed astigmatism*, with M in the one, H in the other meridian. Of this we may distinguish:

a. Mixed astigmatism, *with predominant myopia*, Amh.

. . . .

b. Mixed astigmatism, *with predominant hypermetropia*, Ahm.

. . . .

The above is in general sufficient for the diagnosis and determination of the degree of astigmatism. The method recommends itself by its simplicity and facility of application. In general it deserves to be preferred to any of the following modes. Only the control described under

8 must not be omitted. This is, properly speaking, nothing more than trying whether the glasses employed in the investigation, described under 4, are really suitable. If the control proves accurate, the investigation in the condition of artificial paralysis may, even where hypermetropia exists, for the most part be omitted.

The methods still to be described, come under consideration in particular cases. They cannot be passed over in silence, least of all that of Stokes, which, for its ingenuity, deserves to be known, and also sometimes yields good service. Employed as a control, it certainly affords the most accurate indication.

6. *Modified method of Young.* Young determined the distance at which the double images of the wire of his optometer, in accommodation for the farthest point, held alternately vertically and horizontally, appeared to intersect.

. . . .

7. *Method of Airy.* . . . A point of light . . . is moved along a graduated scale, for example, that of the optometer. We then find a greatest distance, at which the point of light appears as the most slender line, and a shortest distance at which it again becomes a thin line, perpendicular to the first. The distances then give about the degrees of myopia in the principal meridians.

If it be desired to apply this and the preceding methods to non-myopic subjects, the eye must be rendered myopic by a suitable convex glass. . . .

In both cases the accommodation must remain at rest. This can, however, scarcely ever be accomplished, and therefore in the majority of instances, this method leads to incorrect results.

8. *Modified method of Airy.* In order to meet the last difficulty, the accommodation may be paralysed by means of a mydriatic. In strong myopia Airy's method then affords tolerably fair results. But if no, or if only slight myopia, exists, a remote point of light deserves the preference. . . . To obtain a more accurate result, I made use of a very small point of light, produced by the reflexion of an illuminated little round opening upon a convex mirror. In some cases it was then satisfactorily ascertained, with what spherical glasses the point of light appeared as the slenderest streak, successively in two opposite directions. In the majority of instances, on the contrary, this remained undecided. The cause of this lies in the irregular astigmatism, which excludes defined lines as diffusion-images. Usually, secondary lines rapidly shot out, even before the principal line had become slender, in different directions, preventing an accurate determination of the glass required. Only in absence of the crystalline lens, whereby the irregular astigmatism was removed, did the results attain perfect accuracy.

. . . .

9. *Investigation with cylindrical lenses.* While at a distance letters without or with the best chosen spherical glass, are being seen as

distinctly as possible, we take a positive cylindrical glass of about 1/30, and turn it round before the eye. If astigmatism exists, it is observed that, in a definite position of the glass (...), the acuteness of vision greatly diminishes, but that in a position perpendicular thereto, it, on the contrary, increases. The acuteness of vision now often becomes still greater on approximating the object: the cylindrical glass may, in correcting the astigmatism, have rendered the eye myopic. We may now further try, with what strength of cylindrical glass, always held in the most advantageous position, the greatest acuteness of vision is obtained, which must always be tested by difference of distance of the letters, or by combination with spherical glasses. We then, however, obtain at last, with the sacrifice of much time, only a moderate result.

The method, although thus in itself objectionable, is very well adapted to control the results obtained by that described under 4. The latter shows from what combination of spherical and cylindrical glasses the greatest acuteness of vision is to be expected, and we should never neglect to try this, nor omit a comparison with slight modification of the lenses. We shall thus always be able to congratulate ourselves on a more complete improvement of the acuteness of vision, than was obtained by the use of the slit, which, if it be too narrow, takes away much light and is obstructive by diffraction, and if it be too wide, very imperfectly corrects the astigmatism.

10. *Method of Stokes.* The distinguished Secretary of the Royal Society had very well seen that Airy's method could lead to satisfactory results only when, together with the successive determination of the farthest points of distinct vision in the two principal meridians, the condition of accommodation of the eye underwent no change. . . . He proposes to define the degree of astigmatism, by means of an astigmatic lens, the action of which can be regulated in a manner as simple as it is ingenious, so as to make it assume precisely the degree by which the astigmatism of the eye is corrected. I have had such lenses prepared. . . . It consists of two cylindrical lenses, the one plano-convex of 1/10, the other plano-concave of — 1/10.

. . . .

They are turned with their flat surfaces towards each other, leaving a very small interspace.

. . . .

It thus appears, that by turning round from 0° to 90° the astigmatism ascends from 0 to 1/5, and we can calculate the astigmatism for each angle *a*, which the axes of the lenses make with one another. For the sake of convenience definite degrees of astigmatism are directly given upon the instrument, rendering the calculation unnecessary.

. . . .

The method answers best when the eye is by spherical glasses reduced to a certain degree of myopia, and it is then tried for near objects, with what action of the astigmatic lens the person can best read. In this however, it is more difficult to take care that the lenses be held perfectly centred before the eye: moreover, the opinion as to the acuteness of vision is not quite certain, and at all events we have learned only the degree of astigmatism, but by no means the refraction in each of the principal meridians.

For all these reasons the method described under 4. deserves the preference, and the astigmatic lens of Stokes is principally available as a means of control. If, for example, we have deduced from the results obtained, by what spherical glass the refraction in the two principal meridians is reduced to equal degrees of ametropia (either myopia or hypermetropia), we can, with the aid of the astigmatic lens, with great accuracy determine the degree of the astigmatism, and at the same time the instrument presents the advantage of enabling us in a simple manner to regulate it in its action. Its precision will enable us to discover and counteract little inaccuracies in the result obtained by the above-mentioned methods.

. . . .

B. We have now to treat briefly of the *objective signs* of astigmatism.

. . . .

1. Astigmatism occurs mostly in hypermetropic individuals. . . . Hence the objective signs of hypermetropia are already not without value. But the cornea often affords more decisive signs. Sometimes its asymmetry is immediately recognised: it is either shorther than usual in the vertical measurement, or it extends farther backwards (as the result of greater curvature), so that the section between the cornea and the sclerotic does not lie in one plane. In other cases, the difference in magnitude of reflected images in the vertical and in the horizontal direction attracts attention. A square, for example the board, above mentioned, is represented with a greater transverse dimension. The asymmetry of the cornea is then thus proved. . . . Even in the form of the sclerotic we again find this difference; we shall often be able to convince ourselves even in the living subject, at least in hypermetropic individuals, that the vertical axis of the eyeball is considerably shorter than the horizontal.

2. Examination with the ophthalmoscope affords likewise in hypermetropic individuals the most certain indication of the existence of astigmatism. In a normal eye we see (unless the observer be himself astigmatic) the vessels, proceeding in different directions from the optic disc equally distinct with equal effort of our accommodation. In an astigmatic eye this is no longer the case. We then observe that, in order to see accurately in succession the vessels running in different directions near the optic disc, we must alter the state of accommodation of our eye. The rule is, that the emmetropic individual, in relaxation of his accommodation, observes accurately vessels running horizontally; on the contrary, to see vertical vessels distinctly, he must induce tension of accommodation.

. . . .

At the meeting held at Heidelberg in 1861, Dr. Knapp called attention to a second phenomenon in the fundus oculi in astigmatic persons. I refer to the variable form of the optic disc. In the direction of the meridian of greatest curvature the dimension, in examining the non-inverted image appears more, in that of the meridian of slightest curvature it appears less, magnified; the reverse obtains in examining the inverted image. If, therefore, in examination by these two methods, the optic disc is elongated in opposite directions, the existence of As is, as Schweigger remarked, proved.

My friend Bowman recently informs me, that 'he has been sometimes led to the discovery of regular astigmatism of the cornea, and the direction of the chief meridians, by using the mirror of the ophthalmoscope much in the same way as for slight degrees of conical cornea. The observation is more easy if the optic disc is in the line of sight and the pupil large. The mirror is to be held at 2 feet distance, and its inclination rapidly varied, so as to throw the light on the eye at small angles to the perpendicular, and from opposite sides in succession, in successive meridians. The area of the pupil then exhibits a somewhat linear shadow in some meridians rather than in others'.

§ 37. *Cause and Seat of Abnormal Astigmatism*

. . . .

As to the normal, the *cause* is in general for the most part to be sought in the cornea; and the direction of the principal meridians, for the whole dioptric system, as well as for the cornea in particular, is of that nature, that the meridian of maximum of curvature usually approaches to the vertical, that of minimum, to the horizontal.

For abnormal degrees of asymmetry the same rules obtain. What is more, they here present still less of exception. If in normal astigmatism it is nothing unusual for the meridian of the maximum of curvature to make a smaller angle with the horizontal than with the vertical plane, in abnormal degrees I have found only a few examples thereof.

. . . .

Another question is, how far the crystalline lens also has influence. In my original Essay upon Astigmatism, I was not in a position to give a satisfactory answer to this query. The investigations recently carried out with Dr. Middelburg, have supplied me with the proof, *that with a high degree of asymmetry of the cornea asymmetry of the crystalline lens exists, acting in such a direction, that the astigmatism for the whole eye is nearly always less than that proceeding from the cornea.*

. . . .

It was calculated what the degree and the direction of the asymmetry of the crystalline lens must be, in order, in connexion with the values ascertained for the cornea, to elicit the direction and the degree of the astigmatism for the whole eye.

. . . .

I have called the astigmatism of the cornea greater than that of the crystalline lens: but, in fact, the astigmatism of the crystalline lens is greater than we have here found it. The calculation was made as if the crystalline lens were a single refracting surface, placed at an infinitely short distance from the anterior surface of the cornea; and we can easily understand, that the deeper position of the crystalline lens must diminish its influence in astigmatism. I have thought a more accurate calculation on this point superfluous.

. . . .

§ 38. *Cylindrical Lenses and general Rules for their Employment*
Regular astigmatism may, as has above been remarked, be produced by adding a cylindrical to a spherical lens.

. . . .

The glasses required for the correction of the different forms of astigmatism, may be reduced to three kinds.

I. *Simple cylindrical glasses* (fig. 45).... If both the surfaces are cylindrical, their axes are parallel. To give a correct idea of their form, they are represented both in a section perpendicular to the axis (fig. 45 I), and in a section, carried through the axis (Fig. 45 II), the surfaces being distinguished as *a*, the anterior, and *p*, the posterior.

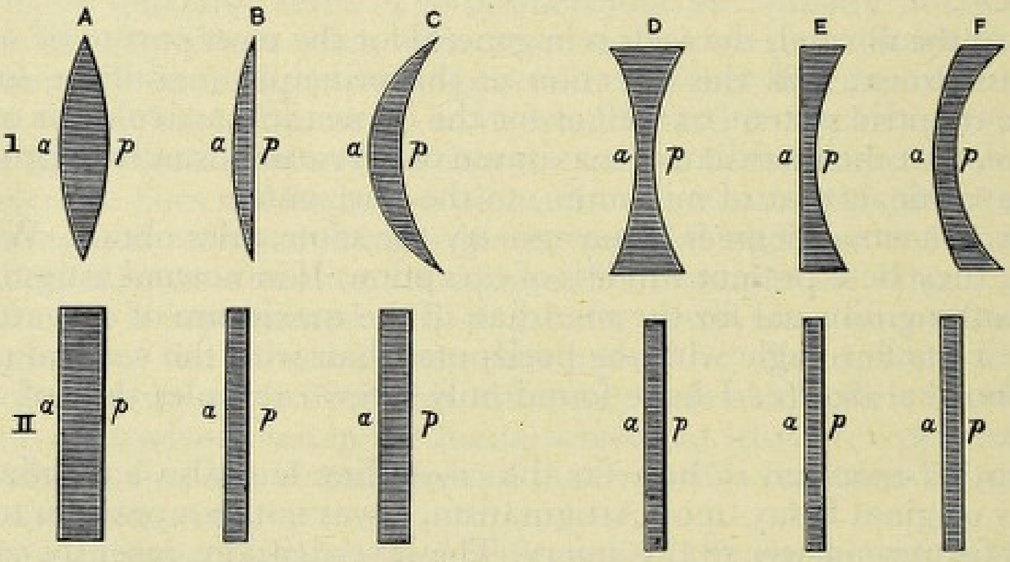

Fig. 45.

a. To the *positive* belong:

1. The bi-convex (A).
2. The plano-convex (B).
3. The concavo-convex or positive meniscus (C).

b. To the *negative* belong:

1. The bi-concave (D).
2. The plano-concave (E).
3. The convex-concave or negative meniscus (F).

Practically the same is true of the cylindrical as of the spherical glasses: the plano-convex and plano-concave produce the greatest aberration, the bi-convex (provided it be not too powerful) and the bi-concave are in general very satisfactory, and the menisci have the advantage of being periscopic.

. . . .

II. *Bi-cylindrical glasses* (fig. 46). These have two cylindrical surfaces of curvature, whose axes are directed perpendicularly to one another (I*a* and II*p*). . . . Of the bi-cylindrical one surface is in general convex, the other concave, as the two sections, taken in each of the two axes (Fig. 46, I*a*, II *p*), show. Such bi-cylindrical glasses, therefore, make parallel incident rays of light, after refraction, converge in the plane of the one axis.

III. *Spherico-cylindrical glasses.* Of these glasses the one surface has a spherical (Fig. I and II *a a*), the other a cylindrical curvature (I and II *p p*). Only those are used whose two surfaces are either convex (A) or concave (B). These lenses may be considered as the combination of a plano-cylindrical with a plano-spherical lens. . . . Now the action of a spherico-cylindrical lens is similar to that of the combination mentioned, and it may be expressed by the formula for each of the refracting surfaces, united by the sign of combination.

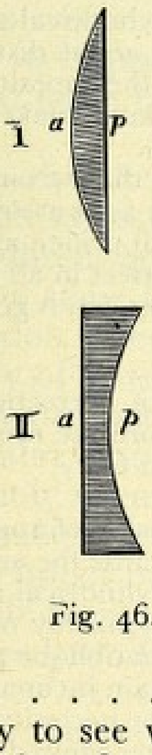

Fig. 46.

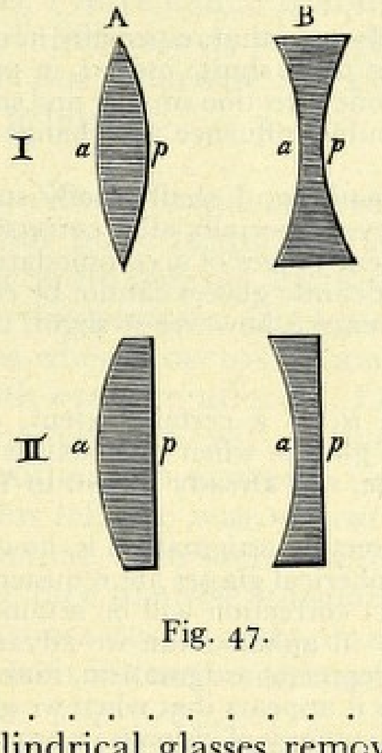

Fig. 47.

. . . .

It is now easy to see what cylindrical glasses remove the different forms of astigmatism. Suppose our object to be to correct the ametropia at the same time with the astigmatism, that is, to bring the farthest point of distinct vision to an infinite distance ($R = \infty$). We then find:

1. Simple myopic astigmatism is corrected by a simple negative cylindrical lens.

. . . .

2. Compound myopic astigmatism requires a negative spherico-cylindrical lens.

. . . .

3. Simple hypermetropic astigmatism, Ah, is corrected by simple positive cylindrical glasses.

. . . .

4. Compound hypermetropic astigmatism requires positive spherico-cylindrical glasses.

. . . .

5. Mixed astigmatism, lastly, yields to bi-cylindrical glasses

. . . .

The correction of regular astigmatism by means of cylindrical glasses is incapable of absolute perfection.

. . . .

The form of bodies, on correction of astigmatism, is elongated in a direction opposite to that in which, before correction, elongation existed. This too great displacement of the nodal points becomes less, the closer the cylindrical glasses are to the cornea, and for this reason also it is desirable, in the use of spherico-cylindrical glasses, to turn that surface towards the eye, whereby the nodal point of the cylindrical surface lies closest to the organ. If both be convex or concave, the one of least curvature should be turned towards the eye; if one be convex, the other concave, the concave one should be turned towards it.

. . . .

Moreover it is easily seen that, especially in using bi-cylindrical glasses, the distance from the eye ought to be short: indeed, in proportion as the distance increases, the images become in one direction smaller and smaller, in the opposite larger and larger, and under this double influence the change of form must make itself strongly felt.

. . . .

Finally, to omit nothing, I shall briefly state, that the accommodative changes in the astigmatic eye, especially after correction of the asymmetry, do not represent absolutely coincident ranges of accommodation in both principal meridians, so that the correction by definite glasses cannot be equally perfect in all states of accommodation. This difference is however so slight, that neither can it give rise to any practical difficulty.

. . . .

That astigmatism is, to a certain extent, capable of correction by convex and concave spherical glasses, when their axis is held before the eye at a certain angle with the visual line, was already known to Young and Cary.

. . . .

This means of correcting astigmatism is, however, capable of application only when relatively strong spherical glasses are required to neutralise the ametropia, and then, too, a more perfect correction will be attainable by cylindrical curvature of one of the surfaces. Only in aphakia can we advantageously, in my opinion, in order to correct a certain degree of astigmatism, make use of an oblique position of the glasses. Almost always it appears that when we give a certain inclination to the strongly convex glass, the acuteness of vision is improved, and the necessity of attending strictly to this point in every case of aphakia, is generally recognised.

Lastly, we must not omit to observe, that regular astigmatism might also be corrected by operation. Iriddesis, an operation brought into vogue chiefly by Critchett, would be serviceable in such cases, especially double iriddesis in opposite directions, as practised by Bowman and others in keratoconus. The pupil is thereby, in fact, changed into a narrow slit; and if the direction of this slit corresponds to one of the principal meridians, the aberration dependent on asymmetry would certainly be almost entirely excluded. The indication of this *double* iriddesis in keratoconus I cannot admit: in this case the cause of the loss of acuteness of vision is not the difference of curvature in the various meridians, but rather the conical curvature in each meridian.... But where there is only difference of curvature of the several meridians, that is in regular astigmatism, the narrow slit obtained by double iriddesis would undoubtedly very much promote acuteness of vision. However, considering that we have it in our power to obtain the desired correction by means of cylindrical glasses, I am, looking to the greater or less danger of the operation, and not less to the deformity which is the result of it, far from recommending its application.

§ 39. *Nosology and Clinical Study of Astigmatism. History of our Knowledge of the Subject*

Astigmatism is either congenital or acquired. In the great majority of cases it is congenital. If it be acquired, it is to be looked upon clinically as another form of disease, whose practical importance has become more and more evident to me, and of which I shall separately treat, after having first considered:

I. *Congenital astigmatism.*

This anomaly is of frequent occurrence. I am as yet without satisfactory statistics; but I certainly do not exaggerate when I assert that in forty or fifty eyes, one is, in consequence of astigmatism, disturbed in its function.

Boundaries between normal and abnormal astigmatism do not exist. When it attains the degree of 1/40, I have called it abnormal, because the disturbance of vision is then of that nature, that cylindrical glasses are desirable for its improvement. But otherwise it is evident, that the limit I have fixed upon is rather arbitrary.

. . . .

Astigmatism is often hereditary. Not unfrequently one of the parents labours under the same defect. But more frequently still it happens, that different children, born of the same parents, exhibit this anomaly, and mostly in the same form; in this case we are equally justified in calling the condition hereditary, as when it occurs in one of the parents.

In the majority of instances both eyes are affected. Often, however, one is completely or almost completely free. Mr. R. had in both eyes Ah between 1/6 and 1/7; in his brother, Ah existed = 1/9·3 of precisely the same form, only in one eye: his left eye was almost perfectly free from astigmatism. It is remarkable that, with such a difference between the two eyes, the upper part of the face likewise is usually asymmetric. Also, when a high degree of ametropia occurs only on one side, asymmetry of the bones bounding the orbit is a very common phenomenon.

. . . .

Thus far I have met with many more cases of abnormal astigmatism in men than in women. I do not, however, feel justified in assuming that this is not partly accidental. This point must remain for future decision.

. . . .

The disturbance of vision, connected with this anomaly, is very peculiar. It is neither to be compared with that proceeding from defects of the retina (amblyopia), nor with that from obscuration of the media, nor even with that which is the result of ametropia.

. . . .

In astigmatism, in contrast to amblyopia, the projection in the field of vision is as yet perfectly accurately defined, and is correctly described: thus the astigmatic individual will state, to the minutest particulars, under what partly black, partly grey lines, a figure, for example the compound roman letter W, appears. But the retinal image itself, . . . deviates in form and in distribution of light so much from the object, that he is not in a position to recognise the latter from it, at least when the images of different adjoining objects cover one another, and the component lines, in all directions and with different degrees of distinctness, cross one another. . . . It is now easy to understand how, in the endeavour to guess at the form of objects, . . . psychical fatigue is soon created, with which, under some circumstances, as the result of the excessive tension of accommodation, phenomena of asthenopia are combined. It is therefore no wonder that astigmatic persons should feel so exceedingly pleased at the correction of their anomaly, and should manifest their pleasure in a more lively manner than ordinary ametropic individuals.

. . . .

Case I. *Simple myopic astigmatism.* Mr. O., student in divinity, now twenty-one years of age, consulted me three years since. I diagnosed myopia about = 1/16, complicated with amblyopia. The degree of myopia was, however, not strictly definable, on account of the diminished acuteness of vision. The latter, in fact, amounted to scarcely 1/3, so that the patient could distinguish ordinary print only at a short distance, in which the existing myopia was very serviceable to him.

He had large prominent eyes, clear media, only a trace of atrophy of the membranes, on the outside of the optic disc,—moreover, this disc was redder than is normally the case, without being redder than it usually appears in young myopic persons, who read and write much. He thought that his power of vision had latterly diminished; but he had never had easy sight, and had never been able, particularly in the evening, to continue long at a time engaged in close work.

Such a disturbance is very common in myopes. But in them it has usually developed itself at a definite time, and as the result of continued work in a stooping position, while the power of vision had previously been quite sufficient. I have therefore doubted, whether in this case the cause of the amblyopia was to be sought therein, and moreover, derivative means, artificial leeches, cold douches to the eye, &c., were employed in vain. Finding no improvement, the patient ceased his visits.

Some weeks ago he again presented himself. His power of vision, he stated, was so defective that he feared he should not be able to continue his studies. He was anxious, before finally making up his mind, to consult me once more. My former notes were referred to. I immediately suspected that astigmatism, previously overlooked by me, must exist in this case.

. . . .

At a distance — 1/10 *c*, the axis coinciding with the horizontal principal meridian, was found excellent: with it the acuteness of vision rose, under favourable circumstances, nearly to 3/4. The patient had never before had an idea what acute vision was, and felt uncommonly happy.

. . . .

Epicrisis, or critical remarks. The case here described is one of the thousands, in which astigmatism has been looked upon as amblyopia, and has been treated as such. If the aimless and energetic treatment was only vexatious to the patient, his joy, when he found his sight at all distances improved by suitable glasses, was indescribably great. He was accustomed always to hold even large print at a very short distance from the eye, partly in order by looking under a greater angle to make amends for his diminished acuteness of vision, partly, as an associated movement, with the convergence and tension of accommodation, to contract his pupil, and thereby to diminish the diffusion-images. On this excessive tension of accommodation required for more accurate definition, depend the phenomena of asthenopia, usually observed in astigmatic persons. Probably the amblyopia remaining after correction of the astigmatism, is likewise a result of the excessive strain connected with the strongly stooping position so injurious to the eye.—It will have been observed that the patient saw better at a distance with tolerably strongly-negative spherical glasses; this, too, appears attributable to the fact, that the tension of accommodation required in the use of these glasses, gave rise to constriction of the pupil, and thus to diminution of the diffusion-images.

. . . .

Case II. *Compound myopic astigmatism.* While these sheets are passing through the press, a case occurs to me, remarkable enough to justify its insertion here. Mrs. F., nearsigthed from youth, and having in neither eye perfect acuteness of vision, complained some years ago, of occasionally recurring flickerings before the right eye.

. . . .

The left eye gives M about=1/11, but at the same time possesses acuteness of vision of only 1/3. Ophthalmoscopically, no abnormity was found. Suspecting astigmatism, I turned, while the eye was armed with — 1/9, 1/24 *c* round before the eye, and thereupon , the axis being horizontal, the acuteness of vision immediately rose to 2/3, to descend, when it was perpendicular, below 1/10. . . .

With the aid of the stenopæic slit I found:

in V, $M = 1/14{\cdot}5$;

in H, $M = 1/9$,

indicating an astigmatism of $(1/9 - 1/14{\cdot}5)$ about $1/24$.

. . . .

The right eye is found to be affected by the same form, and by almost the same degree of As as the left.

. . . .

Remarks. I have already stated, that in almost all the cases of abnormal astigmatism observed by me, without exception, the principal meridian of maximum of curvature approximated to the vertical position. . . . Here, in fact, just as with Young, the maximum of curvature coincides nearly with the horizontal meridean, the minimum of curvature with the vertical. The patient had not been aware that she saw less acutely than other people. I therefore think it probable that Young also, whose astigmatism was of about the same degree, incorrectly ascribed perfect acuteness of vision to himself; and should many of his accurate observations be adduced as proofs of the contrary, I would state, on the other hand, that my patient drew and painted very respectably. This apparent enigma is easily solved. Myopic persons are accustomed, in order to see more acutely, to squeeze their eyelids close together: the narrow slit thus produced diminishes the circles of diffusion in the vertical dimension. . . . While ordinary myopes, from narrowing the slit, derive advantage only in looking at remote objects astigmatics find their power of vision improved also for near objects. . . . My patient undoubtedly also made use of narrowing the slit, even in looking at near objects, and the question is whether Young did not also do so. Meanwhile she was loud in her commendation of the advantage obtained from a cylindrical glass: little pictures especially were with it seen much more acutely. . . .

Narrowing the slit between the eyelids, so universal in myopia, does not belong to astigmatism in general. Especially in hypermetropic astigmatism it is almost always absent. This would appear to have its explanation in the fact, that in this instance, in the horizontal meridian a high degree of hypermetropia exists, which, not being overcome by the accommodation, leaves great diffusion in this direction, and therefore affords no advantage. Could the eyelids admit of a vertical slit, hypermetropic astigmatics would undoubtedly have made use of it.

Hypermetropic astigmatism. Most cases of abnormal astigmatism belong to the hypermetropic form.

. . . .

The majority of cases belong to *simple* hypermetropic astigmatism. . . . However, I have also seen numerous cases of compound hypermetropic astigmatism, rising even to H 1/7 in the principal meridian of strongest curvature with H 1/5 in that of weakest.

. . . .

The function of the eye characterises the condition as H, with diminished acuteness of sight. With this a great degree of asthenopia is connected. . . . One of the patients (with Ah = 1/18) aged 26, recorded the following:—'My occupation is that of a clerk. The first effort to work was the most painful. Thereupon dazzling soon followed, obliging me to shut my eyes, and to keep them closed for some time. After that my work went on somewhat better, but I found it impossible to work all the forenoon; I was constantly obliged to leave off. At the end my eyes were painful, and I felt best when I walked for a considerable time in the open air, out of the sun. In the evening, by gaslight, my work went on at first pretty well, but soon red dazzling came on. I was then obliged every time to leave off, and with fatigued and painful eyes I returned home'. He got 1/18 *c* to work with and to wear. Thereupon he communicated to me: 'On using the spectacles I found, even on the first day, an incredible improvement (his acuteness of vision was, in fact brought from 2/7 to 3/4). Next day I experienced no painful affection, and I found it easy to work uninterruptedly the whole morning. I saw everything infinitely sharper. In the evening I experienced not the slightest inconvenience from the light. In the open air, too, when I walk without the spectacles, I am free from pain. Spectacles which I had before tried (ordinary spherical glasses), had been of no use to me'.

. . . .

Case IV. *Compound hypermetropic astigmatism.* Mr. R., aged 18 years, has never seen acutely; he stated that he observes a shadow along the margins of objects; at his work he has always sought for strong light, and has nevertheless soon perceived symptoms of asthenopia. Notwithstanding this, he has applied himself pretty closely to study. Some years ago he had consulted an oculist, who had referred the disturbance to congenital amblyopia, and had therefore considered it to be incurable. This opinion found the more acceptance, as his brother (with a normal condition of the right eye) had in the left a disturbance, corresponding to that in the two eyes of our patient. In his parents, and the other children, the acuteness of vision is satisfactory in both eyes.

. . . .

The radii of curvature of the two corneæ were measured, in the first place, in the horizontal plane in like manner in the vertical plane.

. . . .

Hence it appears that the cornea exhibits a high degree of astigmatism (the difference of the radii of curvature in the visual line gives for the right eye, As = 1 : 6·374, for the left eye, As = 1 : 6·8).

. . . .

The application of the method of determining the refractive condition in the two principal meridians, with the aid of a slit, I had not yet learned. Moreover, I still possessed only one cylindrical glass, and that of 1/8. This glass, held at most 1″ from the eye, improved the sharpness of vision from 2/7 to 2/3. The question is, whether with ample choice of glasses no greater acuteness of vision would have been attainable. Probably, in order wholly to exclude asthenopia, this eye would, for proximity, require a spherico-cylindrical glass, while provisionally, a simple cylindrical glass is sufficient for distance: for in the range of accommodation of youth, the then remaining total hypermetropia of 1/28 is easily enough overcome.

. . . .

We have seen that when the cornea, by itself, produces an abnormal degree of congenital astigmatism, the lens may increase, but commonly diminishes the same. . . . But in a few cases it occurs that the existing abnormal degree of astigmatism may be said to be dependent on the crystalline lens; and a very remarkable case of this nature is described by Dr. Knapp, in which the peculiar form of the crystalline lens was the cause of an astigmatism, in great part regular. Less rarely, an abnormal position is the cause. This condition may, in the first place, be congenital. Numerous cases have been known in which the lens was situated so eccentrically, that the equator passed through the plane of the pupil, and thus a portion of the plane of the pupil remained without a lens. In this case, then, astigmatism exists in a manner to produce great disturbance, but it is of an irregular nature, and cylindrical glasses are incapable, in this instance, of producing any improvement. Some cases, however, occur, where the displacement of the crystalline lens is so slight that the latter still occupies the whole plane of the pupil, but at the same time has so oblique a position, as to give rise to a considerable degree of tolerably regular astigmatism.

. . . .

II. *Acquired Regular Astigmatism*

Depending on the Cornea. In all the foregoing, acquired astigmatism has scarcely been mentioned. I must acknowledge that, until a short time ago, I thought it of little importance. Very seldom does it depend on an oblique position of the crystalline lens caused by partial luxation; and if disturbances of the cornea be its cause, irregular astigmatism is almost without exception to be expected. I therefore supposed, *a priori*, that cyclindrical glasses would in this case but little or not at all remedy the disturbance of vision. The result has, however, in many instances proved the contrary. In a case of a central speck upon the cornea, I performed iridectomy, and obtained a well-formed pupil, only in the centre admitting some diffuse, but otherwise regularly refracted, light through the cornea. Nevertheless, the acuteness of vision was very imperfect. . . . The letters had a strange form; in an oblique direction they exhibited an irregular prolongation. On ophthalmoscopic investigation, the movement of the objective lens appeared to produce a considerable parallax. I tried the combination of a convex with a cylindrical glass, and the acutenness of vision was nearly doubled. Ordinary print could now be read.—The matter is, *a posteriori*, evident enough. The existing astigmatism may be resolved into a regular and irregular astigmatism, and after correction of the regular, the irregular causes less disturbance. *I have found that in many cases in which, on account of opacity of the cornea, iridectomy, or iriddesis is performed, great advantage may be obtained by a cylindrical glass.* Let it be tried only, whether a cylindrical glass of, for exeample, 1/30 *c*, turned round before the eye, will not produce alternately increased and diminished acuteness of vision; and when the required direction is thus ascertained, it remains only to find out in these cases, to what strength of cylindrical glasses the preference is given. . . . *After the extraction of cataract, too, the cornea often acquires a form, which gives great value to the combination with a cylindrical glass.*

Cylindrical glasses are also often very useful in acquired modifications in the form of the cornea, without the necessity of performing any operation upon the iris.

Case VII. M. Kr., a girl aged 14, has, some years ago, lost the left eye, in consequence of perforating ulcers of the cornea, with subsequent atrophy. On the lower and inner part of the right eye, too, remains a cicatrix from destruction of tissue and prolapse of the iris. The pupil is thereby drawn downwards and inwards, but it is otherwise unaltered, and only little diffused light enters the eye. Nevertheless, the acuteness of vision leaves much to be desired, and is scarcely improved by the total cutting off of the diffused light. Moreover, there exists a tolerably great degree of myopia, with which, therefore, amblyopia seems to be combined. Supposing that the form of the cornea might be the cause of the diminished acuteness of vision, I made an examination, and found, in fact, that a point of light was seen with — 1/3 as an obliquely vertical, with — 1/6, removed somewhat further from the eye, as an obliquely horizontal line. By the use of the slit, held in one of the two directions, the acuteness of vision was very considerably improved. With — 1/30 *c* minute work could now be performed close to the eye, which without cylindrical glasses was altogether impossible.

. . . .

Note

History of our Knowledge of Regular Astigmatism

In Mackenzie's justly-celebrated book (A Practical Treatise on the Diseases of the Eye. London, 1854), and still more completely in the excellent French edition by Warlomon tand Testelin (Traité pratique des Maladies de l'oeil, par Mackenzie. Paris, 1856), we really find almost everything comprised, which science, up to the dates of the publication of those works, possessed upon the subject under consideration. From them I have for the most part become acquainted with its literature, and whenever I had no opportunity of consulting in the original the works mentioned in them, my friend Mr. Hulke, of London, with great readiness and in the most obliging manner, consulted them for me, and sent me accurate extracts from them.

It is remarkable that we find the subject treated of almost exclusively in English literature. In the first place we meet with two men, of whom England may well boast: Thomas Young, who discovered normal astigmatism, and the Royal Astronomer Airy, who first recognised and described the assymmetry of his own eye as a defect.

Respecting Young's observation, I have above (compare p. 456), already stated what is necessary, in connexion with other investigations relating to the subject of normal astigmatism.

Airy's case (1827), on the contrary, described in a manner worthy of the great master, must here occupy us more fully. It relates to a high degree of compound myopic astigmatism. Thus, according to his method, Airy could determine the farthest point of distinct vision in the two principal meridians, and at the same time the direction of the latter: in the vertical (with an inclination of 35°) R was=3·5″, in the horizontal, R=6″. Hence he calculated the glass required for correction, and also stated the reasons, why a negative spherico-cylindrical glass is to be preferred to a negative bi-cylindrical one.

. . . .

Airy's observation seems at first to have attracted attention at Cambridge: to Stokes (1849), namely, we are indebted for the astigmatic lens for determining the degree of astigmatism, and Dr. Goode (1848), who studied at Cambridge, first communicated some fresh cases of this anomaly. Just like Airy, he had astigmatism in one of his eyes, to which his attention was directed by the observations of the Astronomer Royal on the subject.... Chamblant, the optician at Paris, prepared for him a plano-cylindrical lens, the cylindrical surface of which was ground with a radius of 9″ concave. Goode states that, with the aid of this glass he saw both near and distant objects acutely.

. . . .

Goode found three other gentlemen in the University of Cambridge, whose astigmatism in one eye was improved by a plano-cylindrical lens of 12″ radius.

. . . .

Further, the cases are known which are appended by Hays to the American edition of Lawrence's work (Lawrence *On Diseases of the Eye*, edited by J. Hays, Philadelphia, 1854, p. 669). The first is that of a clergyman, whose description affords an excellent picture of simple myopic astigmatism. With the naked eye he saw vertical, with a concave glass horizontal lines distinctly. That he did not perceive both lines equally acutely, escaped him, until, by the use of negative glasses, the distinctness was inverted. After an able analysis of his case, the patient came to the conclusion, that he should need a cylindrical glass for correction, but he did not venture to decide whether it should be convex or concave. Hays' note states merely that M'Allister, the optician, ground for him a plano-cylindrical (positive or negative?) glass, and that vision was remarkably improved by it.

'We have', continues Hays, 'within the past year seen two cases in which this defect of vision existed.

The subject of the first was a lady, sixteen years of age, who consulted me in consequence of her vision being so defective as to materially interfere with her education. I accompanied her to Mr. M'Allister's, and found that, with the assistance of a double concave lens of high power, she could read sufficiently well with her left eye; but none of the ordinary glasses, either concave or convex, would enable her to distinguish ordinary-sized letters with her right eye.... Mr. M'Allister furnished me with some mathematical diagrams, which, being shown to the patient, she stated that circles appeared to be ovals, the circles appearing elongated perpendicularly. Various other trials were made, all, however, tending to show that objects seemed to her to be elongated in their perpendicular, and shortened in their transverse diameters. Mr. M'Allister, having fortunately some lenses, plane on one side, and with a concave and cylindrical surface on the other, I soon found one which corrected the distortion. I had prepared for her spectacles with a double concave lens of the proper number for her left eye, with a plano-concave cylindrical lens for the right eye, with which she can read ordinary print with either eye, and still better when using both eyes.

. . . .

§ 40. *Irregular Astigmatism*

Irregular astigmatism may, as well as the regular, be divided into *normal* and *abnormal*. The normal form is connected with the structure of the lens; the cornea does not participate in producing it. The abnormal degrees, on the contrary, which considerably disturb the power of vision, may depend upon irregularities of the cornea as well as upon those of the lens.

We commence with *normal irregular astigmatism*. The principal phenomenon attending this irregularity is known under the name of *polyopia monocularis*. With some attention any one can observe this polyopia in himself. . . .

1°. Let a small *black* spot, on a *grey* or *white* ground, be gradually brought nearer to the eye than the distance of distinct vision: most people will then observe that the black spot passes into a circle of greyish spots, . . . It is desirable in this and in the following experiment to keep our eye, without alteration, accommodated for the farthest point, in order that the magnitude of the pupil may continue the same; we must therefore, if not myopic, arm the eye with a positive glass, say of 1/6 — 1/10, in order thus, while the eye continues relaxed, to be able to bring the point to either side of the distance of distinct vision. If we subsequently carry the spot beyond the distance of distinct vision, and for the greater correctness of comparison we may for the greater distance, take a proportionately larger point, several spots usually again appear; but in this case a central darker spot remains, around which the other paler spots are more or less regularly grouped. This central spot was absent when the black spot was nearer than the distance of distinct vision: on this account with equal deviation of accommodation we distinguish better (the diameter of the pupil being assumed to be unchanged), when the eye is acommodated for a too near, than for a too distant, object.

2°. We may repeat this experiment with a *white* spot on a *black* ground. As white spots, we may make use of small granules of whitelead, got by scraping an ordinary visiting card, and spread upon black velvet. Among these granules we find a great variety of sizes. If we take one of the largest, of about 1/6 mm. in diameter, the experiment will yield nearly the same results as were obtained with the black spot. It will then, however, more distinctly appear, that each spot is radiatingly elongated, and exhibits dispersion,—with the blue turned towards the centre, when the spot is nearer than the distance of distinct vision, with the red towards the centre, if the point lies beyond it.

3°. Let the experiment be repeated with one of the smallest granules. The radiatingly elongated spots have now given way to slender rays, which, when the granule lies nearer than the distance of distinctness, do not run together in the middle, and which, on the contrary, have a white spot in the centre, when the object is beyond the distance of distinct vision.

4°. Let the observer look at a little point of light, for example, at a small opening turned towards the light. . . . The phenomena are then observed, in proportion to the magnitude, precisely as they have been described under 2° and 3°.

By these experiments we have now learned that polyopia, in looking at a small object, is the same phenomenon as that of the rays, under which at a distance a bright star or light appears, for which the eye is not accommodated. To each principal ray corresponds one of the marginal spots, under which the black dot appears. Therefore, too, those have the most distinct polyopia, who in a point of light perceive a comparatively small number of distinctly separated rays.

5°. Let a small point of light, a little reflected image or an opening of 1/8 mm in a metal plate, turned towards the sky, be gradually brought near the eye. Having arrived nearer that the distance of distinct vision, the point of light divides into a certain number of bright rays, and even, when it has reached the anterior focus, the circle of diffusion in the retina being as large as the pupil, the rays are still visible: they are the lines of light of the well-known entoptic image (compare fig. 29), which occurs in most eyes under this form. The transition of the bright rays into the lines of light of the entoptic image is very easily observed. While the light in the entoptic luminous circle, attaining on the retina the magnitude of the pupil, has been more uniformly divided, the few very bright rays, of which the image of a star almost exclusively consists, are therein only faintly represented by the said lines of light. The number and direction, however, remain precisely the same.

From these experiments it appears, that polyopia uniocularis, rays of stars, and radiating lines of light in the entoptic spectrum are dependent on the same cause. . . .

Now we have already, in treating of the entoptic phenomena, seen that the lines of light of the entoptic spectrum are to be sought in the crystalline lens: on moving, in fact, the eye behind the point of light, no parallax is perceptible, and their cause therefore lies nearly in the plane of the pupil, and consequently in the lens. Hence it follows, that both the rays emerging from points of light and the polyopia, have their origin in the lens. This is more decisively proved by the circumstance, that all these phenomena are wanting when the lens is absent from the eye (aphakia). Moreover we can now further show that the cornea has no essential part therein. In the first place, in examining the reflected images of the cornea, if such irregularities were here present, as are required for the explanation of the phenomena in question, they must have been apparent. And, in the second place, I have excluded the action of the cornea by plunging my eye into water in a little bowl, bounded by a convex glass replacing the cornea, and the phenomena have then continued under the usual form.

If the cause be thus situated in the lens, the question suggests itself, how these phenomena are to be explained by it. In the first place we observe, that the form of the rays, under similar circumstances perfectly constant for each eye, immediately reminds us of the peculiar structure of the lens, namely of the radiating figure from which its fibres proceed. Those of the anterior surface we can observe in any one in the living eye, by lateral focal illumination (Helmholtz), especially by employing a lens, and better still with the aid of the phacoidoscope (compare p. 17. The lines of the posterior surface differ in form and in direction. Meanwhile the crystalline lens is by those lines divided into irregular sectors. Now the explanation of the polyopia is this, that each sector forms a separate image. The proof of this I have given twelve years ago, by moving a rather small opening (about 1/2 mm. in diameter) before the pupil. . . . We thus see a simple image when the opening corresponds to a given sector, and when by shifting the opening we come to the boundary between two sectors, two faint images appear, of which, on further displacement, that first seen disappears, while the one which has supervened remains alone and brighter. On more rapidly moving the opening it appears as if the little image of light jumps, which really happens in the transition from one sector to another.

In proportion as we accommodate with more precision, the multiple images approach one another, and finally coalesce into one image. However, even with the most perfect accommodation, they do not exactly cover each other. In the first place, regular astigmatism, and in so far the cornea also, here plays a part. This regular astigmatism manifests itself precisely by the fact, that the images placed opposite to each other more speedily reach each other in one direction than in the opposite. The result of this is, that a point of light always appears somewhat angular, and even a black spot undergoes a peculiar change of form on a slight play of accommodation, without at the same time ceasing to be black. But even when we completely correct the regular astigmatism by means of a suitable cylindrical glass, all the multiple images do not meet precisely in one place: in one direction or another a single one projects beyond the rest into the centre, and accurate consideration of a point of light shows that all have not even their focus exactly in the same axis.

In this, therefore, lies, in the first place, *an element or irregular astigmatism*. A *second element* we find in the image of each sector in itself. It is very difficult by experiments to get a correct idea of the image of each sector. The impression of light on each point is, in fact, not proportional to the strength of the light, and consequently we obtain a different result with respect to the distribution of light, in proportion to the brightness of the light with which we experiment. On repeating the experiments above stated we had abundant opportunity to satisfy ourselves of this. While, for example, a bright fixed star (Sirius I have often taken as the object), with slightly hypermetropic arrangement of my right eye, gives seven or eight extremely fine bright rays, partly ramifying towards the periphery, and terminating at a short distance from the centre, a less bright luminuous point appears rather as a circle of spots, with comparatively very strong illumination in the periphery, about agreeing with the circle of spots under which, with a similar arrangement, we see a black spot. The rule, however, remains with each illumination, . . . that each image is elongated . . . so that we can in it distinguish an outer and an inner margin, which last is turned towards the centre of the circle of diffusion. We can now further satisfy ourselves:

1°. That the image of each sector is astigmatic. Through an opening of about 0·5 mm., held before a given sector, a fixed star, which under the greatest magnifying power remains a point, forms, with the most perfect accommodation, an image on the retina, which, were it accessible to our investigation, would certainly be very perceptible. The light of a lantern, seen at a great distance through a single sector, is nearly as great as if we had approached it by half the distance. By using monochromatic light, the astigmatism of each sector remains unmistakable.

2°. That the image has spherical aberration. In the circle of diffusion, formed by a spherical lens from a monochromatic point of light, the light is not uniformly distributed. Before the focus of the rays (as both construction and direct experiment readily show) the illumination is strongest at the outside, behind the intersection, in the centre of the circle of diffusion.

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We have thus indicated *two causes of normal irregular astigmatism*, namely, the imperfect coincidence, even after accommodation, of the images of the different sectors, and the astigmatism proper to the image of each sector in itself.

In the image of each sector we can, moreover, easily recognise the chromatic aberration. In front of the intersection each image is red at the outer, and blue at the inner margin; behind the intersection the outer margin appears blue, and the central light is reddish. Now, if we examine the multiple images of a thin line, the lateral images have also coloured edges, and only the central image is uncoloured. It is very instructive, as Helmholtz has done, to combine a line with a point, placed near the extremity of the line. We now see, especially with adjustment for a greater distance, different lines close to one another, and we can satisfy ourselves that these, in each direction of the line, correspond to the multiple images of the point of light to which they are directed. It is now evident, that the edges of the central line will be colourless, because the radiating elongation of the sector-image, whence it arises, lies in the direction of the line, and the colours thus fall over one another. We obtain the sharpest, brightest, and most achromatic line, by giving the line such a direction, that two opposite radiating sector-images cover one another on the line. On the contrary, the lateral images of the line have coloured edges, and are at the same time fainter and broader: their section is equal to the longitudinal section of the elongated image, to which they correspond.

The phenomena here described may also be observable at the boundaries of brightly illuminated surfaces, with imperfect accommodation, as the transition from the bright to the dark takes place through two or three degrees. Even with perfect accommodation, some can satisfy themselves by the fact, that they see the bright moon as images covering one another. I was particularly struck with the distinctness and well-defined boundary, over the whole surface of the round images covering one another, of an opening, through which the nearly homogeneous light of the flame of aclohol containing salt was seen. But more especially when the accommodation is not perfect, we see in that experiment a number of circles, for the most part covering one another, and by covering a portion of the pupil we can never make one of these circles *partly* disappear—cut a segment off it: the circle only grows faint, to disappear suddenly and completely, when the whole sector of the lens belonging to that circle is entirely covered.

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The astigmatism, of which we have thus far spoken, may be considered to be normal. The acuteness of the power of vision suffers very little under it, and least of all when we look with both eyes together, and when these have about the same refraction. We never find the astigmatism of both eyes exactly equal. The images of the same point, formed on the two retinas, therefore, deviate a little from one another. Both, however, coalesce in idea, and the correctness of the judgment respecting the form of a point or of a very small object, sometimes gains considerably thereby. Thus the acuteness of vision, apart from the stereoscopic effect, is greater with two eyes than with one.

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Abnormal irregular astigmatism. This has its seat either in the cornea or in the lens. As to the cornea, the *kerato-conus* or *cornea conica* first comes under observation. High degrees strike the eye at once. Slight degrees, on the contrary, are often enough overlooked. The disturbance of the power of vision frequently suggests the idea of amblyopia, combined with myopia. Three cases have already occurred to me which were long treated as amblyopia. That in this instance an anomaly of refraction, and indeed astigmatism, is the cause of the diminished sharpness of sight, is evident. . . . In high degrees, the mere inspection of the curvature and profile at once satisfy the observer, that the radius of curvature in the centre of the cornea is much shorter, so that the rays falling thereon from each cone of light must much sooner unite. Especially in reference to these rays the eye is myopic.

There must, however, be not only a difference in focal distance, but the foci are also imperfect even for small portions of the refracting surface, and moreover, do not all lie in the same axis. The high degree of astigmatism connected with this state, therefore, needs not to be further proved. It would be very troublesome if, in order to recognise slight degrees, we should be obliged to have recourse to the ophthalmometer, in order to determine the radius of curvature in different parts of the cornea. Fortunately, we have a more practical auxiliary. The already long-existing disturbance of vision leads us to resort to the ophthalmoscope, chiefly with the idea of finding the cause in the fundus oculi, and unexpectedly we discover the anomaly of the refracting surface. This has happened to me more than once. Sometimes the degree was still so slight, that even after the discovery of the true cause the observer, on taking a profile view, could not satisfy himself as to the state of things, so that full certainty as to the existence of the anomaly was attainable only with the ophthalmometer. How the ophthalmoscope exhibited it is very simple. In the inverted image, where there is a tolerably wide pupil, we overlook a rather large portion of the fundus oculi; the image, therefore, of one part or other, for example of the optic disc, remains in the field of vision . . . on shifting the lens held before the observed eye. At the same time, however, the rays, which, proceeding from the optic disc, strike the eye of the observer, pass each time through other parts of the cornea: now if its curvature is irregular, the result is, that the form of the disc each time alters, that it shortens in this direction, extends in that direction, and, moreover, is never seen acutely in its integrity. In somewhat higher degrees, too, the side of the conical projection opposite to the incidence of the light is darker, as if shaded.

Where the form is favourable and the position advantageous, stenopæic spectacles may produce considerable improvement. If this assistance be not sufficient (the field of vision too small, the spectacles an annoyance), an improvement by operation may be attempted. The chief object of the operation is easily stated: we desire to place the pupil before that part of the cornea, whose curvature is most uniform and approaches most nearly to the spherical, in order that a sharper image may be formed in the visual line, and especially that direct vision may be improved. *A priori* it will be evident, that this object will be more easily attained by a small pupil, not only because the circles of diffusion are thus rendered smaller, but particularly because we may expect the less difference in the radius of curvature, the smaller the portion of the cornea is, which participates in the formation of the image. Bowman (1859) has made the pupil slit-like by double iriddesis. Von Graefe confined himself to iridectomy. Both obtained favourable results with respect to the acuteness of vision. Von Graefe proposed besides to produce diminution of the pressure in the eye, which result of iridectomy had in his hands obtained such brilliant and useful application in glaucoma: he hoped thus to oppose the further development of the conicity, if not to lessen the existing degree of it. Bowman, on his part, has actually seen diminution of the conicity take place after iriddesis. The results of the latter operation upon the power of vision are still more favourable, so that at present iriddesis, by which we also obtain a small pupil, seems to deserve the preference. Theoretically, however, the slit-like pupil, obtained by double ireddesis, appears to me, narrow as it may be, not the most favourable: when the direction of the slit is horizontal, the diffusion for vertical lines will still be considerable, and though for horizontal lines the eye will have little diffusion, ti will be highly myopic. It certainly seems better, by simple iriddesis, to exclude the apex of the cone. By means of stenopæic spectacles (with artificial mydriasis) the most suitable place and form of the pupil can be discovered, and perhaps also the seat of most favourable curvature may be sought with the ophthalmometer; and when by this or any other mode we have ascertained where and in what form the pupil must act most advantageously, the further task of operative surgery is, to apply the means so as to realise what is found to be desirable.

To be classed with conical cornea, though usually producing less disturbance, are *partial bulgings* or flattenings of this membrane, which, in consequence of suppuration or of softening, not unfrequently occur. These are often accompanied with so much opacity as to render the displacement of the pupil by irriddesis or iridectomy desirable. But the astigmatism is not thereby removed, since the clear part of the cornea has lost its regular curvature. In the acute process of softening or suppuration it is a matter of recognised importance, to keep the form of the cornea as perfect as possible. To attain this object, repeated experience shows that timely support by means of a bandage causing pressure, cannot be sufficiently recommended. Von Graefe has remarked, that after iridectomy the form of the cornea gradually improved, and I have repeatedly found this confirmed. Moreover, it appears, that in these cases improvement is often to be obtained by cylindrical glasses, the asymmetry being partly reducible to regular astigmatism.

To the very ordinary causes of altered, and consequently irregular arching of the cornea, belongs the *extraction of cataract.* Especially when prolapsus iridis or threatening prolapsus has existed, whereby the pupil has lost its central position, or where, with forward projection of the flap, the wound-surfaces do not perfectly correspond, we seldom obtain a completely normal arching of the cornea. If the deviation is slight, the power of vision may still be quite sufficient; but on accurate investigation it now appears that the acuteness is defective, and the astigmatism is in this instance also partly capable of correction by giving an oblique position to the convex glass, or by combination with a cylindrical one.

A common cause of irregular astigmatism we find further in *spots on* *the cornea*. That slight spots cause much more disturbance by scattering diffused light in the eye, than by reflecting and cutting off a part of the light, has been shown many years ago, and hereupon the indication for stenopæic spectacles was subsequently founded. Even in my first communication I had referred to the irregular refraction of light, connected with spots. How much effect this has, the ophthalmoscope afterwards taught me. Through a rather transparent spot we distinguish the fundus oculi with tolerable accuracy; but, while, in the mode described above, the rays are brought consecutively through different parts of the spot to the eye of the observer, he is surprised at the extremely irregular displacement, shrinking and distortion of the forms, connected with a peculiar glancing, very characteristic for any one who has once seen it. Spots, whose existence was not perceived on superficial inspection, sometimes, on examination with the ophthalmoscope, produced in a remarkable degree the phenomena just mentioned. Thus by ophthalmoscopic investigation we are led to examine the cornea with focal illumination, and then we find, in a scarcely perceptible opacity, the cause of the astigmatism, and at the same time of the diminished acuteness of vision, which at first suggested the presence of other causes. . . .

This occurs chiefly when superficial ulceration of the cornea has existed.

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So much with respect to the cornea. As to the crystalline lens, irregular astigmatism may by it in two ways attain a high degree, namely, by a change in the lens itself, and by displacement of the lens.

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Even independently of the changeability by accommodation irregularities are developed in the lens, which when the eye is still in a state of rest manifest themselves as irregular astigmatism. Usually, as Giraud-Teulon observed, this astigmatism increases at a more advanced time of life, especially when opacity of the lens is superadded.

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Besides, it very seldom occurs, that multiple images remain, when by the assistance of suitable spectacles the accommodation has been made as perfect as possible. . . .

The irregular astigmatism which depends on displacement of the lens, produces much more disturbance, especially when the lens has only partially remained in the plane of the pupil, and the rays, therefore, in part, refracted solely by the cornea, penetrate to the retina. This may take place in incomplete luxation, whether spontaneous, or produced by external injury; but it appears to occur more frequently as the result of congenital ectopia of the lens. Of this I have seen remarkable cases, three of which belonged to the same family. In such instances the power of vision is very imperfect. Just like highly hypermetropic individuals, the patients see near objects comparatively better, though still very defectively.... The glasses required were similar to those indicated in aphakia. On accurate examination with the ophthalmoscope and with focal illumination this result cannot appear strange. If the lens even in the normal eye is less homogeneous near the equator than near the axis, this is especially true of the abnormally situated lens.... At the side of the lens the fundus oculi is seen perfectly clear; through the crystalline lens it usually appears less clear and acute. This we observe especially in examining the inverted image, as we can then see the optic disc in two closely adjoining pictures, one larger and brighter by the side of the crystalline lens, the other smaller and less brilliant, formed by the co-operation of the crystalline lens.

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In a still youthfull lad, labouring under congenital ectopia of the lens, cataract was developed; in proportion as the lens became more opaque, the sight improved. I had absolutely no inducement to operate on this cataract, even after it had become ripe, although the diffuse light still continued somewhat inconvenient.

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CHAPTER IX

Difference of Refraction in the two Eyes

§ 41. *Occurence, Phenomena, Results*

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Exceptionally it occurs that both eyes differ much originally from each other, particularly with respect to their refractive condition. Thus, as we have already remarked, this asymmetry of the eyes is usually combined with asymmetry of other parts, especially of the orbit, and of the bones composing it, so that the difference of the eyes is reflected both in the form of the forehead and of the face. Since my former observations on this subject, I have taken much pains in endeavouring to discover fixed rules on this point. In this, however, I have not succeeded. I can only in general maintain, that at the side where the strongest refraction, or rather the longest visual axis occurs, the orbit (and with it the eye) is situated closer to the median line, while its surrounding edges are placed more forward.

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All imaginable combinations of refraction occur in fact. With emmetropia of the one eye, the other may be either myopic or hypermetropic; hypermetropia or myopia may occur in very different degrees in the two eyes; lastly, the one eye may be hypermetropic and the other myopic. It is remarkable that, when astigmatism occurs only on one side, there is in general in other respects harmony of refraction on both sides; that is, with H of the one eye, we find hypermetropic astigmatism of the other; with M of the one, myopic astigmatism of the other.

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As to the use of the eyes, with difference of refraction, this is possible in three ways: 1°. binocular vision, 2°. vision with each of the two eyes alternately, 3°. constant exclusion of the one eye.

1. *Simultaneous vision with two eyes*, even when the eyes were similar, was formerly doubted. It was asserted, that, although both eyes are properly directed, only one eye sees at the same time, and that in this the eyes relieve one another. This assertion has long since been refuted. But it certainly is true, that we usually abstract from the one eye more easily than from the other. . . . If a distant object be covered with the extended finger, this covering will by most people be effected for the right eye. Now where there is difference in refraction that eye is used, with which, at the required distance, vision is most acute and easiest. But if the ordinary observation of an object be in question, there may be binocular vision even with unequal eyes, within the limits of easy convergence. . . . Experience, in fact, shows that in spite of the unequal magnitude and unequal acuteness, the images of the two retinas assist one another in observation: not only are the solidity and the distance

more correctly estimated, but even acuteness of vision and the facility of reading, writing, &c., may gain thereby. This, indeed, cannot surprise us. In the first place, even for normal and equal eyes, there are no absolutely identical or corresponding points, and it is certain that such are much less still to be expected, when, from original inequality of the two eyes, the condition for connecting these points by practice more and more perfectly in a symmetrical position, has been wanting (compare p. 65). In the second place, as will more particularly be seen, the feeble tints of diffuse images forthwith disappear, when the acute image of the second eye is combined with them. . . . How unequal in magnitude and acuteness the two retinal pictures of a near object, viewed laterally by both eyes, often are in equal eyes! In truth, the second eye is rarely disturbing to vision, unless, in consequence of an opacity, it admits much diffused light in the retina; and that even this disturbance is by no means the rule, is proved both by the rarity of the deviation of an eye affected by cataract, and by the possibility of the development of cataract in one eye being totally unobserved.

To satisfy ourselves, whether both eyes take part in vision, we cover them alternately, having fixed an object, by putting the hand before them. Whichever eye we cover, that which has remained uncovered must continue to fix without movement, and if the covered eye had deviated behind the hand, it must, on removing the latter, immediately again occupy its former place. If the result of this examination leaves any doubt, we place a weak prismatic glass with the angle inwards before the one eye, whereupon, if vision is binocular, double images arise, which are overcome by a distinct movement inwards.

When there is a difference in refraction, we can determine the farthest and nearest point of each eye separately. If the acuteness of vision is sufficient in both, we usually find the ranges of accommodation also equal. . . . But still we should be very much deceived, if we supposed, that in binocular vision the distance for which accommodation takes place could be equal. . . . Even a slight difference in refraction we are not able to adjust by accommodation,

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By no tension whatever can we succeed in getting a sharply defined image for both eyes together.

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Besides, the one eye accommodates sharply, at the expense of the other, rather than by average tension of accommodation to obtain half acute images in both eyes. . . . But even when in consequence of too great difference in refraction, the second eye no longer assists, it at least produces no disturbance.

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Not unfrequently it has occurred to me, that the patient has thought that with one eye he could scarcely distinguish anything, notwithstanding that the acuteness of vision was still tolerably good. I have found this in high degrees both of myopia and of hypermetropia. That the power of vision of a strongly hypermetropic eye . . . has been overlooked, cannot surprise us; but it is singular that clever and well-informed men have so often continued ignorant that they still see satisfactorily with their strongly myopic eye, when they only bring the object near enough. In these cases the unused eye has often deviated somewhat, and indeed almost without exception in the outward direction. This direction I have even met with, when the deviated eye was strongly hypermetropic, provided that myopia, or at least emmetropia, existed in the other used eye. In general, I must observe that deviation is never produced by difference in refraction. At most the latter may be the cause, why the deviation was not prevented, and it is, in fact, no longer prevented, so soon as the difference in refraction is so great that the one eye loses all importance for binocular vision: this eye is then equivalent to a blind eye, and just like the latter, therefore deviates outwards. But if the eye has still any co-operation in binocular vision, vision is improved by it, and certainly the deviation never arises in order to prevent binocular vision, as has been asserted.

2. *The eyes are alternately used.* In difference in refraction it not unfrequently occurs, that the one eye is employed for near, and the other for distant, vision. . . . Now, in these cases, it may appear as if the range of accommodation is extraordinarily great. Thus one of my friends boasted, that at a distance he saw with perfect acuteness, and that in vision for near objects he was inferior to none. On examination this was at once explained. His right eye was emmetropic, and his left presented myopia = $1/5{\cdot}5$. He was himself not aware of this. After his twenty-eighth year this last eye began to deviate outwards, and was thus excluded from binocular vision; but the continues to use it, when he wishes to distinguish very small objects. Thus a deviated myopic eye is most certainly preserved from amblyopia, while, on the contrary, that which has deviated inwards becomes amblyopic throughout the greater part of its field of vision. That it is of importance, if possible, to preserve it from amblyopia, need scarcely be observed.

3. *One eye may, in observation, continue wholly excluded.* Under this head two kinds of cases are to be distinguished: those in which a morbid condition of the eye (*e.g.*, detachment of the retina) has set in, and has given rise to the exclusion with deviation, and those where the deviation was primary, and the disturbance of vision is the result of want of use. With respect to the first we may be silent. As to the last, we must distinguish between the deviation inwards and that outwards. In the deviation outwards the field of vision is enlarged, and extends over objects, which are not seen by the other eye. In the deviation inwards the field of vision is diminished, and that of the deviated eye falls more over the other. This may produce confusion, and therefore we mentally neglect the impressions received on the corresponding part of the deviated eye, which consequently, so far as the common binocu-

lar field of vision extends, becomes amblyopic. . . .

A word still as to the *acquired* differences in refraction. They are limited chiefly to aphakia and to loss of accommodation in one eye. The mode in which vision takes place in aphakia of one eye has been investigated by Von Graefe, particularly with reference to the question, whether it is desirable to operate for cataract in one eye, while the other is sound? His answer is, that, taking everything together, 'the operation for cataract in one eye, with important advantages, is attended with no essential injury, and is therefore always indicated, if we can, with tolerable certainty, reckon upon a favourable result'. In this opinion I can cordially concur. Particularly in active young persons, in whom at the same time the danger of the operation is slight, the advantages of a wider field of vision, diminishing the risk of wounds upon the second eye, the removal of the deformity and the greater self-confidence inspired by the possession of two eyes, throw a considerable weight into the scale. Moreover, I can confirm the observation of Von Graefe, that in young persons the existence of combined vision can often be established, whereby the estimation of distance and solidity is improved, and that where combined vision is wanting, the lensless eye at least extremely rarely causes any disturbance.

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§ 42. *Treatment and Optical Remedies in Difference of Refraction in the Two Eyes*

In the establishment of the indication, the principal thing is to determine, whether binocular vision exists, or not.

Where *binocular vision* is present, at any distance, the point is to maintain this, and if possible, to render it capable of extension over a greater region. In the choice of glasses we start from the more acutely-seeing eye, to which the other must remain subordinate. . . . The question then remains, what glasses the other eye requires?

At first view we might suppose, that for this latter we should have simply to choose the glass that brings the farthest point to the same distance, at which it lies for the first eye. This is in fact the opinion of laymen: 'My eyes differ, consequently I need different glasses',—such is the ordinary reasoning. It is so evident, so palpable and apparently so logical, that we cannot be surprised at it, the less so, as the so-called 'opticians' support it, and are quite prepared to put two different glasses in the same frame. It is, however, far from being the case, that we should keep to this rule. Even from habit a great difficulty arises. One person has, in spite of hypermetropia in one eye, in his youth always seen and read without spectacles, and has never experienced any difficulty in binocular vision. Another reads admirably and suffers no fatigue, although his eyes are in different degrees myopic. If we now give such people . . . different glasses, whereby the range of accommodation in both eyes becomes more equal, we shall often enough find the proverb confirmed 'le mieux est l'ennemi du bien'. The cause of this is principally that when the distance of distinctness is made equal, the images of the two eyes are not equal, but different, particularly in magnitude. Within certain limits a difference in magnitude, such as, with equal eyes, can be produced by a combination of a positive and negative glass for the one eye, is, as is shown by the experiment, attended with no essential difficulty. . . . It is well known that this is equally the case when we look at two uniform figures, with a slight difference in magnitude, through the stereoscope. It is the result of the varying and imperfect correspondence of the symmetrical points which must result from the ordinary use of the eyes, in which letters and other forms are so often met with at somewhat unequal distances from the two eyes. But if the difference in magnitude exceeds a certain degree, double vision becomes evident, which the person is inclined, by deviation of one of the visual lines, to separate still further. The same thing occurs when the same distance of distinct vision has been produced in cases of great differences in refraction by difference of glasses. We might turn highly periscopic glasses (whose nodal points lie outside the body of the glass) for the one eye with the convex, for the other with the concave surface towards the eye, or by a peculiar combination of a concave and a convex glass, different for each eye, we might endeavour to bring the resulting nodal points on both sides to an equal distance from the retina, and thus to make the images equally large; but the method is very delicate, and I can scarcely imagine that it will ever be adopted in practice. This has led me to adopt the rule to give similar glasses for both eyes, when the binocular vision of eyes of different refraction is acute and easy at any distance without glasses, and shifting of this distance is necessary.

But may we never deviate from this rule? Undoubtedly. In the first place we may do so when the difference in refraction is slight, amounting to not more than 1/48 or 1/36. I have met, particularly, with myopes, who have for distant vision given the preference to such corresponding difference in glasses. Moreover, where there is a greater difference in refraction, we may, by a moderate difference in glasses, partly correct this; for example, with M = 1/12 in one eye, and M = 1/8 in the other eye, we may give a glass of — 1/12 for the first and at the same time one of — 1/10 for the other eye; but the difference in glasses can rarely exceed 1/40 or 1/30. Lastly, there may often be an advantage in producing by different glasses, in imperfect acuteness of vision, nearly accurate images on the two retinas, by whose co-operation then the power of distinguishing is sometimes really increased. This refers especially to hypermetropes. . . . But under all circumstances the combination of the different glasses ought to be tried, to ascertain if it is really suitable. . . .

When an eye takes part in combined vision, its function is maintained, even when it constantly receives very imperfect diffused images.

Particularly the field of vision continues in its integrity, and if the acuteness of sight may somewhat diminish, it returns, when more is required from this eye, for example, when disturbance occurs in the other and on systematic practice. This last I consider in every case desirable, especially in high degrees of ordinary hypermetropia, likewise in aphakia; it is accomplished, the eye ordinarily used being closed, simply with a convex glass. Thus remaining unenfeebled, this eye is then always ready to afford assistance so soon as the other may come to fail, and at the same time it can still better aid in binocular vision.

A highly myopic eye can practise without a glass. This, however, has usually deviated outwards, and it then belongs to another category; namely, to those cases in which

Binocular vision is absent.—It is chiefly under this head that the remarkable examples fall, in which a defect in refraction is looked upon by the patient as total uselessness. I will communicate a couple of them.

I. Mr. R., aged 58, an architect, has from his youth been much occupied with architectural drawing. In this he has always made use of his left eye. Since an attack in the eyes, from which he suffered, he has seen less acutely with that eye. 'It is my only eye,' he says, 'and I am much perplexed'. I establish the existence of M=1 : 11·5, S=0·6, diffuse light being warded off, and of synechia, with opacity of the anterior surface of the crystalline lens, the result of iritis. On glancing with the ophthalmoscope also into the right, somewhat outwardly deviated eye, I find it free from synechia and see with 1/10 the fundus oculi scarcely diffused in the non-inverted image: the eye was therefore hypermetropic. On asking him how he saw with that eye, I received for an answer that at a distance everything was confused, and that he could distinguish nothing near with it. His amazement, when he looked at a distance through a glass of 1/10, is still vividly before me. 'I actually see better with this eye,' he exclaimed, 'than I ever did with the right, even with the aid of my concave glass'. Objects appeared to him at the same time much larger, and if he looked at those with which he was acquainted, he thought the distance shorter than it really was. With 1/6 he read without difficulty; with 1/5 he distinghished the smallest type. His hypermetropia amounted to not more than 1/9; S being at the same time=0.7.

Two points here deserve our attention. In the first place, that in apparent disuse the eye had continued so good.

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II. Mrs. L., aged 40, has a number of general ailments, and to them she ascribes it, that during the last six months her sight has fallen off very much. 'With the right eye she has never seen'. It is rather strongly deviated outwards. The left eye has M=1 : 5, S=10 : 70; the diminished acuteness of vision is dependent on chorioiditis disseminata and motes in the vitreous humour. A glance into the right eye with the ophthalmoscope shows me with 1/10 at a distance the inverted image of the fundus oculi, bearing a rather considerable circular atrophy. It therefore appears that the myopia has here a much higher degree; and while I now approximate No. 1 to 2″, she reads it without any difficulty, to her own amazement: 'She had never tried this'. In this eye M was $=1:2\cdot5$, $S=10:40$, and with a glass of — 1/5 she could still read satisfactorily with this eye. While the left eye was under treatment, I advised her to practise the right eye cautiously, partly without a glass, partly with — 1/5. Thus S within some months increased to 9 : 20, and the eye was, and continued, much more useful than the left.

In general, the optical treatment in difference in refraction, is much easier where there is deviation of one eye than when there is binocular vision. In this case, we keep the better eye for ordinary use, and keep up the other by regular practice, with exclusion of the better. In rare cases, with deviation outwards, the one eye is used exclusively for distant, the other for near objects. . . . Lastly, almost always with deviation inwards, and not unfrequently also with deviation outwards, the one eye is wholly out of use: perhaps it was even originally less sharpsighted, and now it is quite amblyopic. If it no longer fixes on closing the other eye, there is nothing to hope for. Practice is then in vain.

The question, when it is expedient, in deviation, to perform tenotomy, cannot be here investigated at length. A couple of remarks may here be made. As the result of my investigation, I have assumed that difference of refraction never produces strabismus, but only does not prevent its occurrence. Consequently, from the difference in refraction, a decided contra-indication to tenotomy is never to be deduced. We must say only, that binocular vision can acquire no particular value. But is not tenotomy performed for appearance' sake, even when one eye has lost its sight?—A second remark is, that in the highest degrees of myopia an eye deviated outwards acquires, through simple tenotomy, a better position in looking at distant objects, but seldom learns to converge.

In aphakia of the one eye, with normal acuteness of vision of the other, especially with deviation of that eye, some practice with a convex glass is to be recommended, in order to prevent retrogression of the acuteness of vision. Some minutes daily are sufficient.

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II. ANOMALIES OF ACCOMMODATION

Introduction

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Accommodation depends upon muscular action. We are here therefore to expect the anomalies which are proper to muscles in general: paralysis and spasm. In connexion with the former, the action of mydriatics; in connection with the latter, that of myotics, is to be studied. Each investigation must be based upon a knowledge of the nerves, which are implicated in either condition, and we have to treat thereof in connexion with the movements of the iris, which are associated with those of accommodation.

We therefore treat, in three chapters, of:

I. The influence of the nerves upon accommodation and upon, the movements of the iris.

II. Paralysis and debility.

III. Spasm.

CHAPTER X

Influence of the Nerves upon Accommodation and upon the movements of the Iris

§ 43. *The Movements of the Iris*

The mechanism of accommodation has already come under our consideration (§ 4). Here we may therefore confine ourselves to the movements of the iris.

The movements of the iris are of two kinds: reflex and voluntary. Reflex action is exhibited as constriction of the pupil, in consequence of the stimulus of incident light upon the retina. Fontana (1765) has shown that the light falling upon the iris produces no remarkable contraction. We have confirmed this result by causing the image of a small distant light to fall, by means of a convex lens, upon the iris, whereby during slight perception of light, a doubtful contraction occurred, which gave way to a strong contraction so soon as the light, entering through the pupil, excited a vivid perception. That this contraction takes place by reflex action of the optic nerve upon the oculomotor nerve in the brain was proved by Mayo (1823) by striking experiments upon pigeons. Nevertheless, the experiments of Harless (1850) and of Budge have shown, that even after death, so long as irritability remains, the pupil still contracts upon the continued action of light.

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When light falls upon one side, the pupil contracts on both sides: the contraction on the same side we call direct, that on the opposite side, we call consensual. When in the absence of the direct, consensual contraction is present in one eye, we are justified in inferring the existence of blindness in that eye. If both are present, or both are wanting, no certain conclusion is to be drawn as to the power of vision.

We may accurately study these two, as well as the accommodative (Listing), by ourselves, after the entoptic method. A small opening in an opaque plate, held at about 6‴ from the eye, and turned towards the light, gives, in the vitreous humour a bundle of nearly parallel rays, of the size of the pupil, and is therefore seen as a round, illuminated disc, whose diameter increases and diminishes with that of the pupil. If both eyes had been closed, and if one be now opened, the pupil is seen almost immediately to contract, and then slowly and vibratingly to dilate again. The consensual contraction, on the contrary, according to Listing (1845), does not begin until 2/5 second after the opening of the other eye, lasts about 1/5 second, after which the pupil again dilates slowly and vibratingly for some seconds. The consensual dilatation, he observed to commence about 1/2 second after the closing of the other eye, and with diminishing rapidity to continue for one or two seconds. This last continues in my eyes considerably longer. The whole course of consensual contraction and dilatation, which, with Listing, lasts 2·1 to 3·1 seconds, with me occurs ten times in the minute, and therefore lasts six seconds. The difference has reference especially to the duration of the consensual dilatation, whose maximum it is difficult exactly to determine.—In these experiments the closing must, for more than one reason, be effected only by holding a screen before the eye.

The accommodative movement is, as well as the accommodation itself, to be considered voluntary. It is true, we contract our pupil, without being conscious of the contraction of muscular fibres, but this holds good for every voluntary movement. When a person raises the tone of his voice, he is not conscious that by muscular contraction he makes his chordæ vocales more tense; he attains his object wihout being aware of the means by which he does so. The same is applicable to accommodation for near objects, and to the contraction of the pupil accompanying it. The fact that this last is only an associated movement, does not deprive it of its voluntary character, for there is perhaps no single muscle which can contract entirely by itself.

E. H. Weber has discussed the question, whether the contraction of the pupil is associated with the convergence of the visual lines, or with the accommodation. From his experiments of seeing acutely the same object, alternately through concave and through convex glasses, he came to the conclusion that the pupil neither contracts nor dilates without change of convergence. Cramer (1853) repeated these experiments. . . . In my experiments with Dr. de Ruiter, I came to the same conclusion as Cramer, namely, that tension of accommodation, even without increase of convergence, is attended with contraction of the pupil. Now, on repeating the experiments, without the use of glasses, and being able, the fixation of the same point remaining unchanged, to put my accommodation alternately more and less upon the stretch, I find that, especially in looking at a remote object, each stronger tension is combined with contraction of the pupil. . . . That increased convergence of the visual lines without change of accommodation also makes the pupil to contract, is easily proved by simple experiments with prismatic glasses.

Listing observed that the accommodative contraction of the pupil takes place almost contemporaneously with the will, just as is the case in movements of ordinary muscles. It is, however, easy to show that, even if contraction and extension commence almost simultaneously with the will, they by no means take place with the rapidity whichis peculiar to voluntary muscles. By alternating the accommodation for a remote and a near object, I cannot voluntarily strongly contract and dilate the pupil more than thirty times in the minute.

§ 44. *The Ciliary System and its Function*

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The parts enumerated derive their nerves from the ciliary, also called the ophthalmic, ganglion. This ganglion gives off from 10 to 16 minute branches, the ciliary nerves, which perforate the sclerotic, not far from the optic nerve, and proceeding straight forwards between the sclerotic and the chorioidea, reach the ciliary muscle and the iris, and give some filaments to the cornea. One or two ciliary branches come directly from the naso-ciliary nerve, perforate, as well as the others, the sclerotic, and, according to Bernard's statement (1858) finally pass into the conjunctiva and the iris, but not into the cornea: their origin indicates that they act chiefly as nerves of sensation.—Into the ciliary ganglion three so-called roots enter: the short root from the oculo-motor nerve, the long root (often existing double) from the nasociliary nerve; and, lastly, a branch, derived from the sympathetic nerve in the neck. In the ciliary ganglion numerous ganglionic cells are met with. What the connexion is between the three kinds of nerve-fibres enumerated and these ganglionic cells, has not been ascertained, nor whether fresh nerve-fibres here have their origin, joining the ciliary nerves. All the ciliary nerves, the commencement of whose course we have already described, divide in the first instance near at hand and farther up the outer surface of the ciliary muscle into two, and afterwards into more numerous branches, which form a rich plexus (*orbiculus ciliaris* of W. Krause), whence many little fasciculi penetrate into the ciliary muscle. I examined them in 1853, with Dr. de Ruiter, in white rabbits.

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In the meantime, in the peripheral distribution of different nerves, especially in those of the involuntary muscles, ganglionic cells are found, and this is true also of the ciliary nerves.

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Except the above-mentioned one or two ciliary nerves of separate origin, all the branches destined for the iris and for the ciliary muscle proceed from the ciliary ganglion. In this ganglion consequently the function is comprised. The question is therefore, properly, what influence each of the three nerves exercises on the ganglion. . . .

The action of the oculo-motor nerve upon the sphincter of the pupil is established beyond doubt. Not only is the pupil dilated and immovable in paralysis of this nerve, but on irritating the nerve in the base of the brain in animals, we see it strongly contract. If Volkmann and E. Weber had, in opposition to previous investigations, seen dilatation produced by irritation, Budge (1853) showed that this was to be ascribed to simultaneous irritation of the sympathetic branch running in the neighbourhood, and retaining its irritability longer, and Nuhn (1853) who in a decapitated criminal had likewise seen dilatation, recognised, after experiments on different animals, the same source of error as Budge had indicated. In the beheaded man also, contraction of the pupil on irritation of the nerve in question was subsequently seen. Most decisive, however, are the cases of complete paralysis, because they show that this nerve is the condition *sine quâ non*, both for reflex and accommodative movement of the pupil, and for the accommodation itself.

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The only fact which exhibits the influence of the intervening ganglion, is the comparative slowness of the contraction of the pupil.—Whether the oculo-motor nerve sends also some sensory filaments to the internal eye, cannot be ascertained.

The influence of the sympathetic nerve upon the pupil was discovered even before 1727, by Petit: after dividing the nervus vagus he found the pupil smaller. That Petit had correctly ascribed this phenomenon to the division of the sympathetic nerve, which, in many animals, is in the neck united with the nervus vagus, was proved by Dupuy (1816), who observed the same phenomenon after extirpation of the first ganglion. The accuracy of the fact was still further demonstrated by the careful experiments of Reid (1839). Budge and Waller (1852) have the merit of having shown, that the filaments of the sympathetic nerve acting on the pupil arise from the spinal cord, and pass into the anterior roots of the two inferior cervical, and the six superior dorsal, nerves. . . . The difference of the two pupils after division of the nerve is greatest while the eyes are exposed only to faint light. . . . The difference in magnitude is, however, permanent; at least we have seen it continue in dogs and rabbits longer than six months; Budge has observed it even for a year.

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The foregoing shows that the action of the sympathetic root consists in a persistent exaltation of the tone of the radiating fibres. Thus the dilatator pupillæ is with constant force the antagonist of the sphincter muscle. The action of the sphincter changes, as we have seen, both with the incidence of light and with accommodation; but if the sphincter is paralysed, the pupil is immovable. Meanwhile we may assume that, just as for the vaso-motor nerves, the tonic action in the dilatator muscle may, under certain still unknown circumstances (irritation of the fifth pair?) somewhat fall and rise.—It has, indeed, hypothetically been assumed that the sympathetic nerve acts also upon the accommodation. Though it might appear somewhat rash absolutely to deny an influence for which the analogy of the iris may be appealed to, yet we find that it is supported by no fact whatever. We are acquainted with no muscle capable of acting antagonistically to the ciliary muscle; nor have we any reason to admit the existence of *active* accommodation for distance. On the other hand, the action of the sympathetic branch on the tone of the blood-vessels is fully established. It is known that division of the sympathetic nerve in the neck is followed by considerable dilatation of the vessels of the head, most distinctly observable in the ears of rabbits, while irritation of that nerve is attended with contraction of the same vessels (Bernard). With Dr. van der Beke Callenfels (1855) I showed that the vessels of the pia mater are governed by the same nerve; and

I subsequently satisfied myself, with Dr. Kuyper (1859), that the vessels of the iris also contract on irritation of the sympathetic nerve, even when they are distended under the influence of the instillation of digitaline or in consequence of discharge of the aqueous humour, or, as I recently found in conjunction with Mr. Hamer, when after the action of the Calabar bean, the same irritation scarcely makes the pupil dilate. This last confirms my opinion, that this contraction of the vessels cannot be the mechanical result of dilatation of the pupil, but that it occurs independently.

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The influence of the nervus trigeminus upon the iris and upon the accommodation is still doubtful. By exclusion we may assume that this nerve gives sensation to the iris; for neither the oculo-motor nor the sympathetic possesses sensitive filaments by which the great sensibility of the iris might be explained. Moreover, sensation ceases when the nervus trigeminus is divided. The difficulty lies in the determination of the influence of the nervus trigeminus upon the motion of the iris. It has been found experimentally that irritation of the trunk of the fifth pair, as well as of its ophthalmic division (the nervus ophthalmicus Willisii) causes the pupil to contract. Now we are acquainted with no other contractions of the pupil than those produced by the reflex action of light, and by accommodation, and these both wholly disappear on paralysis of the oculo-motor nerve.... We are consequently led to assume that stimulation of the nervus trigeminus acts upon the ciliary ganglion, so as there either to increase the action of the fibres of the oculo-motor, or to diminish that of the sympathetic nerve. The influence still takes place, if the sympathetic and oculo-motor nerves have previously been divided. This is, however, by no means strange, since the ciliary ganglion and the internal nervous system of the eye continue permanently normal after the sections alluded to, as is proved, with respect to the latter, by the unaltered action of atropia and of the Calabar bean dropped into the eye.

The mechanism, whereby the nervus trigeminus acts upon the ciliary ganglion is, however, rather obscure. Since this influence, as we have seen, continues after division of the oculo-motor and sympathetic nerves, it must be capable of taking place without reflexion in the central organs. Indeed, we can, from the fact that on stimulation of a nerve the change of the electrical condition is continued in both directions, very well comprehend the direct influence of a stimulus, without assuming in the nervus trigeminus the existence of fibres, whose ordinary function should be centrifugal conduction towards the ciliary ganglion. But if such exist (in the nervus lachrymalis centrifugally conducting fibres are undoubtedly present), the contraction of the pupil which occurs in an irritated state of the peripheral sensitive filaments of the eye, might be explained by reflex action, upon those centrifugally conducting fibres, in the Gasserian ganglion. At any rate, in an irritated condition of the cornea, to which the ciliary nerves are distributed, reflex action even in the ciliary ganglion may be assumed from analogy, as, with reference to the secretion of saliva, reflex action through the submaxillary ganglion has been demonstrated by Bernard.

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In all that I had seen and read respecting the influence of division of the n. trigeminus, the doubt had occurred to me, whether this section did not act upon the pupil principally in consequence of the filaments of the sympathetic nerve being at the same time divided, which filaments, according to Budge, reach the ciliary, through the Gasserian ganglion. I therefore determined, in concert with Dr. P. O. Brondgeest, my assistant in the physiological laboratory, to make some experiments upon the subject. In rabbits the sympathetic nerve was exposed on one side of the neck, and was very gently stimulated for a moment (with the aid of the galvanic apparatus of Du Bois-Reymond) in order to ascertain that the exposed nerve acted on the pupil; thereupon the skin was again closed with *serres fines*, and the trigeminus was divided on the same side, in the manner indicated by Bernard. If anæsthesia of the eye was obtained without further general disturbance, the sympathetic nerve was, after a shorter or longer interval again stimulated, in order to see whether it had maintained its influence upon the pupil. The experiment succeeded in eleven rabbits.

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CHAPTER XI

Paralysis and Debility of Accommodation

§ 45. *Mydriatics and their Action*

A comparative examination of a number of substances and of preparations has shown, that the most useful mydriatics are to be found among the Solaneæ, and that of these the Atropa Belladonna is, for various reasons, to be preferred to all others, even to the Datura Stramonium and the Hyoscyamus niger. Above all, where strong action is not required, atropia (soluble in 450 parts of water), and where a stronger effect is indicated, the very soluble sulphate of atropia, which were first introduced into practice in England, are to be recommended. For the full effect, a drop of a solution of one part of sulphate of atropia in 120 parts of water is quite sufficient. If the instillation is followed in the course of an hour and a-half by pain and injection of the vessels, the preparation is not suitable, and there then arises, on its repeated employment, a peculiar inflammation, described by me as atropinism. Even when suitable, it produces in some persons, after having been used for many months, a similar inflammation, and it must then be altogether laid aside. In such cases other mydriatics are then seldom borne. Chemical reagents were not decisive in distinguishing the inapplicable sulphate of atropia. (Compare Kuyper, *Onderzoekingen over de kunstmatige verwijding van den oogappel*. Diss. inaug. Utrecht, 1849.) The internal exhibition of the remedy also, with which it is necessary to be cautious, produces mydriasis.

The principal phenomena consequent on the instillation of sulphate of atropia, are: 1°, increasing dilatation, followed by insensibility of the pupil; 2°, diminution, and soon total loss of accommodation.

. . . After the instillation of 1 : 120 the dilatation begins in man within fifteen minutes, and in the course of from twenty to twenty-five minutes attains its maximum, with absolute immobility. The younger the individual, and the thinner the cornea is, the more rapidly does the action occur.

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The *diminution of the accommodation* commences somewhat later than the dilatation of the pupil. The accommodation gradually returns after some days, together with the mobility of the pupil.

When, after forty-two hours, the pupil is somewhat smaller, a slight degree of mobility has also returned, and, at the same time, some accommodation is to be observed, which now rather rapidly increases until the fourth day, but is not perfect until after the lapse of eleven days. The observation was made on the eye of my assistant, Mr. Hamer, who has practised himself in very accurately determining his absolute nearest point at the maximum of convergence, while one eye is closed.

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The farthest point has, with a slight degree of M, continued nearly unaltered. Usually, it removes somewhat further from the eye. If there exists permanent tension of accommodation, such as is proper to H, and not unfrequently occurs in some amblyopes, astigmatics and in young myopes, this gives way under the influence of atropia, and *r* then removes to a much greater extent. With tension of accommodation, objects appear to become smaller (micropia): in this case we imagine the object nearer, and as the visual angle has not become greater, we suppose the object to be smaller.

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The loss of accommodation, after the action of atropia, is the more troublesome, because the pupil is so extremely wide, which, even in slight variation of accommodation, produces great circles of diffusion. . . . The *disturbance*, moreover, differs according to the *refraction of the eye*. Emmetropes see well at a distance, but can distinguish nothing near without convex glasses. Myopes complain less, because, although their distant vision is much more diffuse, they can still read, their farthest point remaining unaltered. In hypermetropes, even the slightest action of the mydriatic produces such disturbance, that without convex glasses nothing is distinguished.—If the mydriatic have been dropped into only one eye, the disturbance is the greater, because the defined image of the eye not operated on is so feebly illuminated, compared with the diffuse image of the other: the mydriatic eye is then by preference closed. . . .

With respect to the action of *weaker solutions* of sulphate of atropia, Dr. Kuyper has made some investigations.

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The *mode of action* of mydriatics I have investigated with Dr. de Ruiter. Independently of our researches, Von Graefe, as he stated to me by letter, had arrived at the same results. Our experiments have established beyond doubt the passage of atropia into the aqueous humour.

The action exhibits itself the more rapidly, the thinner the cornea, and the younger the animal is. Removal of the outermost layers of the cornea hastens the action (von Graefe).

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After repeated instillation in a rabbit, the whole eye was washed out with a broad jet of water: the aqueous humour then discharged, introduced into the eye of a dog, and long kept in contact with it (Von Graefe also injected it into the chamber), produced considerable dilatation of the pupil. This is incontestably the *experimentum crucis*. The quantity which penetrated is, however, extremely small, for the solution of 1 : 120,000 kept equally long in contact with the cornea, acted still more strongly. On internal administration and consequent mydriasis, the evacuated aqueous humour was inefficacious.

Lastly, the question is, through the intervention of *what nerves* the absorbed atropia acts. In the first place, we cannot admit that the matter acts directly upon the muscular fibre-cells: the similar nature of these contractile elements in the sphincter and the dilator should then lead us to expect a similar influence upon both, and strong dilatation of the pupil could not take place. We therefore infer that the atropia acts on the nerve fibres, or on the ganglionic cells. *a. The sphincter muscle becomes paralytic.*

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b. The dilator muscle becomes strongly contracted. The proof consists in the fact that, as Ruete (1813) was the first to show, in complete paralysis of the oculo-motor nerve, the size of the pupil is still considerably increased by atropia; additional dilatation also occurs under atropia after removal of the nerve in question in animals. To explain this we assume a stimulating action on the sympathetic nerve, which we can scarcely imagine to be persistent unless it takes place by the intervention of ganglionic cells. Of these it is known that they are specific in their action, and of a condition of persistent stimulation by a given substance we have an example in the action of strychnia brought into direct contact with the grey substance of the spinal cord.

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§ 46. *Morbid Paralysis of Accommodation*

Paralysis of accommodation as disease is by no means an unusual occurrence. Emmetropic and ametropic eyes are alike liable to it. It occurs too at every age, but in old persons, who have already lost their accommodation by senile changes, it is of little importance. As we know, that the accommodation is effected exclusively by the internal muscles of the eye, we can seek paralysis also only in the fibres of the short root of the ciliary ganglion. Now, in fact, it often occurs that only these fibres are paralysed, and in this case we have paralysis of accommodation alone: except that paralysis of the sphincter pupillæ, which derives its motor fibres from the same root, is usually combined therewith. But in about an equal number of cases there exists at the same time paralysis of other fibres of the oculo-motor nerve, and not unfrequently the paralysis extends even to all the branches of this nerve. It is remarkable, that while paralysis of accommodation very often occurs separately, paralysis in the domain of the oculo-motor nerve is comparatively rarely met with, without paralysis of accommodation. I may add, that so far as my experience goes, uncomplicated paralysis of accommodation occurs much more frequently in women, often too in children; paralysis of the oculo-motor nerve on the contrary, including paralysis of the accommodation, is much more frequently found in men, and ordinarily not until after the twenty-fifth year. In either case, the paralysis is rarely complete: generally speaking, it is only paresis, inasmuch as a certain, though usually only a slight degree of accommodation, has remained.

Uncomplicated paralysis of accommodation has only one objective symptom: dilatation and immobility of the pupil. The dilatation is not considerable; for even with complete paralysis, a wider pupil than the normal in the dark is not to be expected. Nevertheless, in complete paralysis not a trace of either accommodative or of reflex movement is to be seen. But I may add, that these cases are extremely rare. Further, the connexion between paralysis of the pupil and of accommodation cannot be called absolute: once I found satisfactory accommodation coexistent with absolute immobility of the pupil. . . . and, on the other hand, with perfect or almost perfect loss of accommodation, the motion of the pupil may be but little disturbed.

From all this it is evident, that the *subjective* phenomena are the most important. Now, upon these the refraction of the eye has a considerable influence.

Myopes, whose farthest point is not more than 14″ from the eye, find no difficulty in reading. . . . The disturbance is confined to this, that on the one hand, objects at a greater distance appear, on account of the greater circles of diffusion of the larger pupil, more diffuse than usual,—on the other, that within the distance of their combined nearest and farthest point, they cease to see acutely. Both disadvantages are in great part removed when the paralysis of accommodation is incomplete, and we then hear few complaints from myopes. It is only when they wear neutralising spectacles, and use them at their work, that they are on a footing with

Emmetropes.—These, on the occurrence of paralysis of accommodation, immediately resort to the oculist. They can no longer read nor write, and they are aware that an important disturbance exists: even when, as is usual, only one eye is affected, a certain dimness is, on account of the acute origin of the paralysis, forthwith observed, causing each eye to be separately tried, and thus the lesion is discovered. If we find that vision at a distance is acute, and with either concave or convex glasses becomes diffuse, while for near objects convex glasses are necessary, the diagnosis is made, which finds only a still further confirmation in the torpidity of the dilated pupil.

The paralysis of accommodation is productive of yet greater disturbance in *Hypermetropes:* not only for near, but also for distant objects, with respect to which an involuntary accommodation formerly easily overcame their hypermetropia, is their vision diffuse. It is evident, that such a condition suggests the idea of amblyopia, and I have already (p. 130) communicated a case in which the patient's father, himself a medical man, feared the worst. . . .

The phenomena are less characteristic when no complete paralysis, but only paresis is present. The myope then often experiences no actual disturbance; the emmetrope complains of fatigue only on tension for near objects, resembling the asthenopia of the hypermetrope; but the hypermetrope very rapidly experiences considerable asthenopia for near objects, and even difficulty in seeing acutely at a distance. In general with paresis of accommodation, asthenopia very quickly occurs; in the first place, because the wider pupil requires more accurate accommodation to distinguish satisfactorily; in the second place, because, just as in atropia-paresis, the relative range of accommodation is very unfavourably situated: while with the maximum convergence, the closest point is found comparatively little farther from the eye, with medium convergence, only a slight tension of accommodation appears to be possible.—Sometimes in paresis of accommodation micropia is also complained of.

The foregoing refers more particularly to the uncomplicated paralysis of accommodation. Often, however, this is, as we have seen, only *a part of a more general morbid condition*, and most frequently of *paralysis of the oculo-motor nerve*. If this is complete the upper eyelid hangs, and the outer angle of the slit even stands considerably lower than that of the other side—a proof that the (now paralysed) elevator of the upper eyelid is also the elevator of the conjoined lower lid. A very slight upward movement of the eyelid remains, in consequence of the fact that, on endeavouring to raise it, the musculus orbicularis palpebrarum, which is governed by the facial nerve, can relax itself still more: the latter muscle remains in any case capable of strong contraction. If we raise the paralysed eyelid, we find the cornea deviated outwards, and on looking to the opposite side it scarcely reaches the middle of the slit (paralysis musculi recti interni). On endeavouring to look upwards, the paralysed eye remains unaltered in its place (paralysis mm. recti superioris et obliqui inferioris). On endeavouring to look downwards, the m. obliquus superior, which is governed by the n. trochlearis, alone acts, and this, especially when the eye is turned outwards, produces a slight inward rotation around the visual axis rather than a downward movement of this axis. With these phenomena a misapprehension of the position, and an apparent movement of the objects, on every attempt at movement of the eye, are combined—the first dependent on an incorrect estimation of the position of the eye, the second on the loss of adequate correspondence between the attempt at movement voluntarily made and the real movement of the field of vision on the retina. The complaint of vertigo is thus explained.

In other cases only a part of the muscles, influenced by the third pair, is implicated in the paralysis; sometimes the m. levator palpebræ superioris, alone is affected, sometimes the m. rectus internus.

. . . .

Further, we observe that the fourth and sixth pairs are also affected (I have even seen a case in which only the musculus rectus externus and the accommodation were paralysed); and occasionally, too, paræsthesia exists in some branches of the fifth pair.—Lastly, the paralysis of accommodation is wholly subordinate to that of different parts of the body, and then depends upon disturbance of the central organs. Under all these combinations, however, the disturbance connected with paralysis of accommodation continues of the same kind.

On what morbid alteration the paralysis of accommodation depends, is often obscure. Experience shows that in sudden changes of temperature, particularly on exposure to storms or draughts of air, paralysis of the motor nerves of the eye, sometimes of a single nerve or of particular branches, not unfrequently occurs. When the days are extremely warm, and the evenings cool, a larger number of cases of this paralysis is in general met with. Such cases are called rheumatic, and are referred by some to an inflammatory affection of the nerve-sheath. The paralysis in these cases occurs suddenly; often it is observed on awaking in the morning. We may hope that after some weeks or months it will again give way, but at the end of six months such hope must be abandoned. If the other eye also subsequently becomes affected, as I have often seen it, the idea of constitutional predisposition is naturally suggested; but for this view there is frequently no ground. Only, syphilis is recognised as a constitutional cause, and it may produce paralysis even many years after infection. . . . The seat is especially considered to be central, when both sides are affected; . . .The prognosis is in such instances less favourable. Moreover, we find cases recorded in which injury, abscesses in the orbit, tumours in the cranial cavity, and different morbid changes in the brain were in operation, and credulous people have admitted hysteria and hypochondriasis into the list of causes.

On the subject of treatment we may be brief. The so-called rheumatic paralysis often gives way spontaneously, most frequently after two or three months. It is pretty generally the custom, under such circumstances, to apply an ointment with Veratria around the eye, and to give secale cornutum internally, and in this respect I myself follow the example of others; but it is very hard to satisfy one's self by comparative observation that this plan is attended with any benefit. The myosis, which is the result of the employment of Calabar, even in paralysis of the oculo-motor nerve, may in every case produce symptomatic improvement. How far this remedy is otherwise indicated, further experience must decide. On the supposition of the existence of constitutional syphilis, an antisyphilitic treatment is often tried, . . . frequently unattended with any marked result. Where the nervous system is more generally implicated, regimen and treatment are directed to that condition, without special attention to the paralysis of accommodation.

Respecting the use of spectacles in paralysis of accommodation, it is almost sufficient to observe, that there is scarcely ever any objection to bringing the point of distinct vision to the distance which the existing acuteness of vision and the nature of the work to be performed render desirable.

. . . .

We should bear in mind, that in the stationary refraction of the one eye, the same glass can be useful only for a given distance.

The principal objective phenomenon of paralysis of accommodation—the wide, immovable pupil—was the first to attract attention, and was designated by the ancients under the term *mydriasis*. But a dilated pupil being a symptom of amaurosis, the disturbance of vision in simple paralysis of accommodation was also looked upon as a slight degree of amblyopia, or was ascribed to the excess of incident light. Even in our own day this error is not unusual. It was in fact incredibly long, before ophthalmologists in general had a sufficiently correct idea of accommodation properly to comprehend its deviations.

. . . .

I know not who was the first to suggest clearer and correct ideas. But it seems as if these were included in the discovery of the principle of accommodation, and on that discovery, as it were, spontaneously came to light in different quarters, although Cramer, who discovered that principle himself, was still deceived as to the nervous influence in accommodation. A more accurate observation of the cases which presented themselves certainly proceeded from the introduction of the determination of the range of accommodation.

Mydriasis, as a symptom of blindness, almost always depending on a cerebral cause, does not belong to my subject. With respect to mydriasis, independent of paresis of accommodation, I might probably also be silent. I believe, in fact, that in the great majority of cases, either the paresis of accommodation was overlooked, or the existence of mydriasis was lightly assumed. Certainly it has not been sufficiently kept in view, that young children usually have large pupils, and thus all sorts of causes have been called upon, but especially the presence of worms, to explain a phenomenon which, in childhood, needed no explanation. Accurate determinations of the size of the pupil, the light being the same, may in each case be required: in my own investigations, in which the measurement was effected with the ophthalmometer, I was struck with the great similarity of the pupil in the same individuals at different times, the illumination and the accommodation only being equal.

. . . .

Von Graefe says he has observed mydriasis to be a precursor of mania.—That an irritated condition of the sympathetic nerve in the neck (irritation of the abdominal portion in animals does not produce mydriasis) might lead to uncomplicated mydriasis, without any influence on the accommodation, is, *a priori*, very probable; but the cases in which the occurrence thereof should be proved are almost wholly wanting in literature, and in nature I have so far not met with them.

§ 47. *Paresis of Accommodation after Diphtheria faucium and weakening of Accommodation*

For some years past a malignant disease, known by the name of *diphtheria faucium*, or *angina diphtheritica* (better *diphtherina*), has prevailed in certain countries of Europe. In the commencement of 1860 it began to manifest itself in several places in the Netherlands, where it is still prevalent, and even in the course of the past year carried many to the grave. In France and elsewhere, different forms of paralysis had been observed, as sequelæ of this diphtheria. Among these mention had been made of disturbance of vision, but without just appreciation of its nature. Soon after the occurrence of the disease, cases presented themselves to me, to the connexion of which with the angina in question I was led by a particular circumstance. It immediately appeared to me, that what was considered as disturbance in the function of the retina, was a simple paresis of accommodation; and I subsequently had opportunities of satisfying myself of the correctness of this view in a great number of patients.

The following is a history of the course of my observations on this subject:

I. Miss D., aged 26, applied to me on the 22nd of May, 1860, complaining of disturbance of vision. On examination, it was found that this disturbance depended on diminution of the power of accommodation. Remote objects were seen quite acutely, and were rendered diffuse both by convex and concave glasses: emmetropia, therefore, existed. The distance P of the *nearest point* was reduced for the right eye to about 24″, for the left 12″....

Rather more than five weeks previously the patient, then lodging at Bennekom, had suffered from inflammation of the throat. Having returned to Utrecht, she for the first time remarked, about fourteen days before, that she could no longer see near objects acutely. She could read only a few lines, and that not unless at a comparatively great distance; thereupon everything ran together; the letters were unrecognisable; the lines appeared to be strokes; the eyes were as if fatigued.

. . . .

In examining this patient, *a peculiar lesion of speech* did not escape me. I suspected that it must have depended on a congenital defect. Through motives of delicacy I was unwilling to ask the patient directly about it; nor did she allude to it.

II. About a fortnight after, a youth named R., aged 15, of fair complexion, pale, and rather slight, was brought to me. His complaints were in all respects the same as those of Miss D. The power of vision was, however, still more limited: at a distance he saw acutely; as for near objects, on the contrary, he could absolutely not read ordinary type. The closest point of distinct vision could not be directly determined; with glasses of 1/8 it lay at 7″. The pupils were large, reflex motion was slight, accommodation movement was scarcely perceptible.

It struck me that in this boy there was a lesion of speech similar to that in the case of Miss D. He, too, had suffered from sore throat. Moreover, he came from Ede, a village in the immediate neighbourhood of Bennekom. Still more: I heard that in the same Bennekom several other people, who had likewise suffered from inflammation of the throat, presented both disturbance of vision and difficulty of speech. This fact appeared to me to be truly important.

In R., I now, in the first place, investigated everything which had reference to the modification of the voice and speech.

The mucous membrane of the mouth and throat was normal, rather pale than red; the tonsils were scarcely swollen. *The uvula, however, was extremely long and was absolutely immovable.*

. . . .

With respect to speech, a double abnormity presented itsef, namely, *speaking through the nose*, and the accompaniment of many sounds with a *rattling or snoring accessory sound.* The rattling sound was evidently dependent on a quivering of the uvula which had come into contact with the root of the tongue, and it was strongly heard with particular consonants, as well as with the vowel *a* (as in able).

. . . .

I formerly paid much attention to the subject of articulation, and was therefore in a position to observe accurately the phenomena connected with that function. They often give the first indication to the oculist. I may therefore be allowed here briefly to explain them. When after a vowel, pronounced through the nose, the soft explosive consonant is to follow, the nose must be completely separated from the throat, at the same moment as the cavity of the mouth between the lips (with *b*), or between the tongue and palate (with *d* and *g*) is closed. If the separation does not take place at the same time, we hear the resonants *m*, *n* and *ng*, in place of the explosive consonants *b*, *d*, and *g*. For the mechanism is precisely the same for both, except that in the resonants there is a continuity between the cavity of the nose and that of the throat, which is wanting in the explosive consonants. Now if there be paresis of the palate, in the articulation of the vowels the nose is not completely closed, and it is evident, that on the effort immediately after to produce a soft ringing explosive consonant, the complete closing follows either not at all, or at least too late. Instead of *rub*, *head*, and *egg*, we therefore hear in our patient, *rum*, *hen*, and *eng*. On increased exertion they become *rump*, *hent*, *enk* (properly *engk*—for the *n* before *k* is always *ng*): the hard explosive consonant is added. The mechanism of this last, in fact presents no difficulty. After the sound of the voice has ceased, the closing of the mouth needs only to be interrupted by some impulse of air, to make the hard explosive consonants heard. The nose indeed remains open, but the sound of an explosive consonant is with a non-ringing voice much stronger than that of a resonant, and therefore we hear the first distinctly, the latter not so. Hence it will be understood that our patient had no difficulty in producing *rup*, *het*, and *ek*. For this the voice needed only to be brought to silence immediately after the vowel, then the resonant was not heard, and the interruption of the closing of the mouth caused the hard explosive consonant to be heard. If it be asked, lastly, why the soft explosive consonants could be produced better at the beginning of a word than at the end, the answer is simply that in that case the closing of the cavity of the mouth and the removal of the continuity of the cavities of the throat and nose needed not to take place precisely at the same moment. In pronouncing *band*, *door* &c., the cavity of the mouth was first closed and, before the voice was heard, a powerful effort was made to close the palate by the way to the nose. If this in great part succeeded, a sound was heard, which held the medium between the explosive consonant and the resonant, or, rather, because the closing still went on during the sound of the voice, it was as if the explosive sound was preceded by a resonant: *m*band, *n*door, &c.It needs no proof that, if the continuity had remained equally free, at the beginning of the words also, in place of the explosive consonant, only the resonant would have been heard.

The semiparalytic condition of the palate led me to suppose, that swallowing also would not take place regularly. When questioned on the subject, the patient stated, too, that he could swallow solid food only with great effort, and that in drinking he was obliged to proceed slowly and cautiously. Fluids passed very readily into the nose, and that usually gave rise to regurgitation into the larynx, and, consequently, to cough.

So much, as yet, with respect to the boy R.

Soon after I had an opportunity of again seeing Miss D. *The agreement of the phenomena relating to the palate, speech, and deglutition,* with everything noted above respecting R., was striking. The rattling accessory sound was, however, less, and she complained more of the secretion of viscid mucus in the throat, which there was much difficulty in removing.

The two cases here described kept up my interest. There could, it seemed to me, be no doubt as to the connexion between the paralytic symptoms and the preceding inflammation of the throat. Further investigation appeared, however, desirable, and I therefore repaired to Bennekom, where the physicians, Dr. Thomas and Mr. Ketting, with the greatest readiness, gave me all the information I requested; they also afforded me the opportunity of examining some other patients, in whom secondary paralytic symptoms had manifested themselves. The first four cases had proved fatal in the acute stage of the disease.

. . . .

Of the case, communicated under II., the result was unfortunate. The course of the disease had been violent, and was combined with swelling in both the throat and the salivary glands. The convalescence, nevertheless, appeared to be progressing favourably. Soon, however, the lesion of speech became developed, and shortly afterwards, that of the power of accommodation supervened. In other respects the patient now seemed to be perfectly well. But after I had seen him at Utrecht weakness of the limbs set in; the arms became so powerless that he could neither strip nor dress himself. The emaciation increased, and difficulty of breathing not unfrequently occurred. A first attack of violent dyspnœa subsided favourably. Some weeks later a second followed. In spite of all the stimulating remedies employed, the breathing became rapidly rattling, and the patient died with symptoms of so-called paralysis of the lungs. A post-mortem examination could not be obtained.

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CHAPTER XII

Spasm of Accommodation

§ 48. *Myotics and Myosis*

The year just elapsed has put us in possession of a myotic, which immediately proved itself an able opponent of the best mydriatics. It is the *ordeal bean* of old Calabar, obtained from the *Physostigma venenosum* (Balfour), belonging to the Leguminosæ. This remedy has at once superseded all myotics, before tried or recommended as such. . . .

Among the principal phenomena observed after the application of these agents to the conjunctiva, *contraction of the pupil and spasm of accommodation* are the most prominent.

The first effect, immediately after the application, is a brief irritation; upon this, after the lapse of four minutes, slight spasms supervene in the lower eyelid. The contraction of the pupil, and almost simultaneously, the spasm of accommodation now follow.

The *contraction*, after a sufficient dose commences after from five to ten minutes, attains its maximum after from thirty to forty minutes, at which it remains only a short time, diminishes slowly after three hours, and disappears entirely in from two to four days, occasionally being replaced even by some dilatation. The whole process is, therefore, more rapid than that of the effect of atropia, probably in consequence of a greater power if imbibition.

. . . .

With respect to the contraction and the phenomena connected with it the following are to be noted:

a. The diameter of the pupil becomes still less (from 1 1/2 to 2 mm.) than, in the normal condition, with the strongest light which can be borne and with the most powerful accommodation (Von Graefe).

b. The influence of the light does not, however, cease: one can easily observe in himself particularly the consensual contraction, employing the entoptic method, by closing and opening the other eye, as Von Graefe also did. The movements are slow; the consensual contraction lasts three, the consensual dilatation lasts four, seconds. Moreover, the pupil at the same time often appears to be somewhat angular. It is in the middle like a crape, and has a tolerably sharply circumscribed, more strongly illuminated diffuse border, which on consensual contraction is broader and has a dark-green tint, while the middle of the surface appears yellow. . . .

c. Especially in the commencement of the contraction involuntary spasmodic vibrations occur in the diameter of the pupil.

d. The illumination of objects is feeble, with an unusual brownish tint (Bowman). The effect is similar to that of solar eclipses, in which, notwithstanding sunshine with its usual strongly contrasting shadows, the light is unusually feeble. If the instillation has been performed on only one eye, the great difference in illumination is best seen on doubling the image by a prism.

e. The circles of diffusion of a point of light, situated beyond the distance of distinct vision, become less the smaller the pupil is, and vision therefore becomes much less diffuse beyond the limits of accommodation.

f. After the disappearance of the myosis the pupil sometimes becomes somewhat larger than before.

The *spasm of accommodation* appears from the altered position both of the farthest and of the nearest (*p p*) point of distinct vision. We have, moreover, to note the following:

a. In the determination of the farthest point clonic spasms of accommodation alternately arise, so that objects appear with the same glass alternately distinct and diffused. . . . In an hour after the employment of the myotic, the accommodation is again completely under control. . . .

b. The determination of the nearest point was effected with the aid of the most perfect optometrical instruments. The course of the points, as shown by these, is very satisfactory. In an earlier experiment of Mr. Hamer the action, after the application of a piece of Calabar paper too strongly impregnated, was much more violent, the painful spasms lasted more than six hours, and the pain increased so much on endeavouring to accommodate, that the idea of determining the nearest point was given up.

c. With *diminution* of the action, the range of accommodation is absolutely increased, most considerably after about 100 minutes, and this increase diminishes only slowly. . . .

d. The great effect upon the accommodation with slight impulse of the will is very important. This is still strongly felt when the farthest point has again returned nearly to its original position: 105 minutes after the application, the point of distinct vision lay, with convergence to 10″, for the right eye naturally at 10″; for the left, on the contrary, at 4″·5, thus nearly attaining the absolute nearest point.

. . . .

The relative accommodation has, therefore, approached to that of hypermetropes; much accommodation with slight convergence. . . .

e. . . .

f. So long as with a given tension accommodation takes place for a shorter distance than usual, objects appear larger (macropia).

g. . . .

Finally, it remains to be stated: that, according to Von Graefe, the acuteness of vision sometimes diminishes, particularly in the period of development of the spasm, probably in consequence of insufficient stability of accommodation, in any case, independently of the want of light from constriction of the pupil.

. . . .

With respect to the *mode of action*, similar experiments lead to a like conclusion as in the case of mydriatics. As to transition into the aqueous humour, however, Von Graefe could not directly satisfy himself from the myotic action on instillation into the eye of another animal. After repeated strong application, however, it succeeds, if the discharged fluid is long kept in contact with the eye into which it is dropped.

We have also been specially engaged in the investigation of the question, *by the intervention of what nerves* the Calabar acts.

... The increased refraction, in which a more powerful action of the muscles of accommodation is included, puts altogether beyond doubt a spasmodic contraction of the sphincter pupillæ, as being governed by the same nerve as the ciliary muscle, and associated with it in its action.... The nerve alluded to is the oculo-motor nerve, and, more especially, the short root, which this nerve sends to the ciliary ganglion. It is opposed to our idea of the similar nature of all nerve-fibres, that a particular substance, as Calabar, should have on some fibres a paralysing, on others a stimulating, and still more a tonic stimulating, influence. Consequently, in this case also, we prefer to assume an action upon specific nerve-cells present in the eye itself.

. . . .

We supposed that the action of Calabar, in cases of paralysis of the oculo-motor nerve, would elucidate the question still farther. In different quarters it was observed that this paralysis did not prevent the myotic action.... In a lady aged 32, there was absolute paralysis of the whole right oculo-motor nerve, which had set in gradually six weeks previously...; in this instance the strongest incident light on one or both eyes gave no appearance of contraction on this side. The Calabar employed, however, produced contraction, as strong as usual, and at the same time somewhat increased refraction.

. . . .

Meanwhile it is, on other grounds, more than probable, that Calabar, if it does not paralyse, at least lowers the action of the sympathetic nerve. When, in fact, by a moderate action of Calabar, the accommodation is brought at most by half into tonic tension, the pupil is already narrower than with intense light and strong accommodation; and this half takes place without the sphincter, which continues sensitive for reflex and accommodative impulses, attaining the maximum of its action: consequently, without diminished action of the dilator, such strong contraction is not explicable.

. . . .

The struggle between atropia and Calabar, when applied simultaneously, or soon after one another, is remarkable. When applied together, some contraction of the pupil and spasm of accommodation first occur, as the effect of Calabar. The spasm of accommodation still continues, when the action of the atropia on the iris gains the upper hand, and the pupil consequently becomes wider.

. . . .

We were particularly desirous to ascertain whether, with absolute atropia-paralysis of the sphincter and of the muscles of accommodation, a powerful employment of Calabar still has influence; and this, in fact, we most distinctly found to be the case, observing, moreover, that this influence was still greater upon the refraction and accommodation, than upon the diameter of the pupil.

. . . .

It appears, that the paralysis, produced by a specific agent, may be overcome by the effect of another specific agent, even in such a way that voluntary action again becomes possible.

. . . .

On the discovery of the physiological action of Calabar, it followed as a matter of course that this agent should be tried in various anomalies. In the first place, it is found to be useful to lessen the inconvenience of atropia-mydriasis; and according to Von Graefe the atropia process may be shortened by a systematic employment of the Calabar. How far it may lead to cure, or at least afford permanent benefit in paralysis of accommodation and in mydriasis, in which its use had already been suggested by Robertson, experience only can decide. But it is certainly important, that in ordinary paralysis of accommodation, . . . the pupil is contracted and the refraction is increased by Calabar: in a case of unilateral paresis of accommodation which occurred to me, and which very much interfered with binocular vision, the inconvenience was completely removed by a glycerine solution diluted with eight parts of water, used once daily. Thus, too, the myosis connected with the weak action of Calabar, may often be useful in many cases where a stenopæic apparatus improves the sight, as in diffusion of light (opacities of the cornea, &c.), in irregular astigmatism (keratoconus, luxation of the lens, &c.); further in aphakia, especially when the plane of the pupil is not clear. The improvement of the acuteness of vision in ordinary ametropia is indeed remarkable: precisely with very weak action of Calabar myopes distinguish much more accurately at a distance, and hypermetropes, under the double advantage of smaller circles of diffusion and of easier tension of accommodation, lose for a time their asthenopia. The great question, which practice has to answer is, whether Calabar is permanently as harmless for accommodation as atropia is, and whether the conjunctiva will permanently bear its repeated application. Until these points are decided, the future of Calabar in therapeutics cannot be foretold.

I have now to add only, that Von Graefe has advantageously applied the contraction of the pupil in glaucoma, in order to facilitate the performance of iridectomy, and that in his opinion the alternating action of Calabar may probably contribute to tear synechiæ.

. . . .

§ 49. *Spasm of Accommodation. Myosis. Painful Accommodation*

We have to distinguish different forms of spasm of accommodation. That which most frequently occurs is nothing else than an exalted tone of the muscles concerned in the latter function. . . . We have in hypermetropia found a permanent tension, which wholly or partially conceals the abnormal condition. . . . The increased tension is here the natural result of the persistent effort to overcome the existing anomaly of refraction. In amblyopes and astigmatics where the same sometimes occurs, it is explicable by the constant endeavour, in accommodating for the nearest point, to see the smaller objects under a greater angle. It is less evident, how myopes also acquire a tonic spasm of their accommodation. That this not unfrequently occurs, especially when the eyes are in a state of irritation, we have already observed. Dr. Fles now informs me, and I readily believe it, that he met with this condition in many cases in young persons, especially in boys, who had been prepared for an examination at one of the military schools. Partly irritation of the eye, reflected on the accommodating system, partly excessive tension of accommodation during the constant work, particularly with defective light, may be the cause of it. It is invariably the paralysis by atropia which reveals its existence. In young children under these circumstances, I have seen slight degrees of myopia give way even to hypermetropia, so extremely sensitive is their play of accommodation.

The tonic spasm of which we have here been speaking, seldom acquires much pathological importance.

. . . .

A case was described by Liebreich (*Archiv f. Ophthalmologie*, B. VIII. H. 2, p. 259).

Miss F., aged 21, complained of dazzling before the left eye; fatigue on exertion and nearsightedness had set in a year before after constant work, often continued at night. On examination it was found that with parallel visual lines, sight was acute at a distance with — 1/40, but that with commencing convergence, such strong accommodation supervened, that she then needed even stronger negative glasses to see acutely in the point of convergence, until finally, at the distance of 6″ both eyes could distinguish sharply without glasses. As the existence of spasm of accommodation was hence inferred, atropia was repeatedly dropped in, in consequence of which the myopia gave way to hypermetropia = 1/24. Meanwhile it appeared further, that the convergence was difficult, the possible divergence particularly great, while other symptoms indicated insufficiency of the mm. recti interni. The spasm of accommodation might be connected herewith; but still it was determined first to suppress this with atropia in both eyes, and the employment of the remedy was continued for fourteen days. When the accommodation had subsequently returned, the patient seemed to have recovered: the spasm had altogether given way, and even with glasses of 1/25, which were prescribed for her, distant and near objects were acutely seen, and work was continued without fatigue.

It was evident that in this case the insufficiency of the mm. recti interni had not been the immediate cause of the asthenopia. But might not the spasm of accommodation, with the long-continued excessive tension, have been produced by the effort to overcome that insufficiency? ...

We have still to speak briefly of pain with tension of accommodation, which is probably combined also with spasm. I have already communicated a case of this nature. I may be allowed here shortly to relate two others.

Mrs. O., aged 29, called upon me in October, 1859, complaining of violent pain in the eye on any effort to see near objects, which had already existed in a greater or less degree for more than ten years. She had a flat face and shallow anterior chamber of the eye. The pupils were small, but movable. The nearest point lay at 11″, the farthest at ∞; upon artificial mydriasis, H appeared $= 1/16$. The acuteness of vision was normal. I gave her glasses of $1/16$, believing that after the return of the accommodation she would be able to work with them at a distance. Some time after she called upon me again. Her state had continued the same, and the spectacles had been of no use to her. Other glasses were tried, but with no better result. A derivative treatment was also adopted quite in vain. I determined then to have atropia dropped in for some time, in order to counteract all tension of accommodation, and I permitted her to wear light blue glasses of $1/16$, and to use $1/7$ for near objects. Repeatedly, after one month, two months, &c., it was tried whether the mydriatic could be omitted. The results of these trials were unfavorable. But at the end of six months, she observed with joy, that leaving off the use of atropia, with the return of accommodation, reading without glasses, she was free from pain. She now, moreover, occupied herself at close work with glasses of $1/16$. When after a year-and-half, a relapse occurred, the employment of atropia for three months was again sufficient to overcome the painful spasm.

In this case, the pain is much more prominent than spasmodic contraction. But what suggests the idea of the latter, is the whole latency of the hypermetropia, with comparatively slight range of accommodation. At the time of the relapse the patient was at Dresden, and she consulted me by letter. I should have been glad then to have examined her anew, particularly in order to satisfy myself still further respecting the relative range of accommodation.

A second case of this nature was that of a friend of mine, who had held an important office in the East Indies, in which he had to work hard and to make observations with optical instruments. During his observations, he for the first time felt pain, which made him cautious. His state was considered to be hyperæmia of the retina. On reading and in calculating his observations the pain increased. Examination now showed, that after the use of atropia, hypermetropia=1/24 existed. At first weak, afterwards strong convex glasses were given, quite in vain. Derivants, leeches, and Heurteloup's artificial leeches were tried, with equal want of success. Reading for a few minutes produced a degree of pain, which compelled him to desist. This state had already lasted for a year and a-half, and his return to his native country was spoken of. But it occurred to those about him, that they might first consult me by letter, for which purpose both the patient and his oculist, formerly a pupil of mine, sent me a very detailed report. My advice was:—for a time to employ sulphate of atropia (1 : 120) at least twice a-week, and meanwhile during the paralysis of accommodation thus obtained, to make vision at different distances possible by means of different convex glasses. Some months later I received the report, that the 'atropia treatment had instantly afforded the best results. Hope revives in me', thus wrote the patient, 'that we shall overcome the malady. In the morning I can already work tolerably steadily. In the evening, reading or writing inconveniences me less, but I do not yet venture upon it, in order not to retard the progress of my recovery. Your suspicion that my hypermetropia might be more than 1/24 is not confirmed; every time we get the same result. I now use 1/24 for distance, 1/16 when sitting at table, and 1/11 when at work'.

. . . .

This case scarcely needs any comment. It shows that in slight degrees of H a condition may be developed by continued tension, in which the least accommodation for near objects becomes very painful. Spectacles are then of no use, because with the convergence involuntary accommodation is combined, and this again excites the pain. The above-quoted observation of Liebreich has suggested to me the possibility, that in these cases, just as in Liebreich's, tension of accommodation too strong in proportion to the convergence sets in.

ADDRESS

by Professor

Dr. F. C. DONDERS

delivered at Utrecht
on May 28, 1888
on the occasion of the
Presentation of the Charter
of the

DONDERS FOUNDATION

Sent to all those who have contributed
to the said Foundation by the Committee

UTRECHT
P. W. van de Weijer
1889

COLLEAGUES AND STUDENTS! FRIENDS AND SYMPATHIZERS! GENTLE LADIES!

Whatever shall I say or answer to so many marks of appreciation and affection?

I have been overwhelmed.

I have not deserved such homage.

I have cast my eyes backwards into the past, and have gratefully acknowledged that a rare concurrence of circumstances has made my life and my work fruitful.

Therefore, do not praise my merits; rather call me fortunate, that so much has been allotted to me!

Will you pause and listen to me, while I reveal the truth of that past?

You will then know what feelings must possess me.

When, in 1835, at the age of seventeen, I was enrolled as an undergraduate at the University of Utrecht, there was little I had learned thus far. Certainly there had never been any question of overburdening me. From the age of 7 to 13, I had been a boarder at the school of master Panken at Duizel, a moorland village in the Meierij district of Brabant. There I had been taught excellent arithmetic; to write Dutch fairly well; French, as much as master Panken and I could learn from Agron; and soon also music, for which there was an opportunity at Eersel, a quarter of an hour's distance from Duizel. For the last two years, from the age of 11 to 13, I also acted as an assistant master, and thus earned my keep. I was to continue my studies at Liège in Belgium, where my eldest sister lived with her husband. But the Belgians rose in revolt; and my good mother, as a result of her acquaintance with the undergraduates and officers from Utrecht who had been billeted on her, had developed a liking for the 'Hollanders' from the North. Thus it happened that at the age of 13 I was sent for awhile to the 'French School' at Tilburg. I did not learn any French there (for I knew my Agron), but fortunately I picked up some English from my schoolmate, Henry Collier, now well-known in the Netherlands as a merchant and banker, of Broad Street, London, E., who has remained my friend until this day.

I had a zest for learning and was therefore sent to Boxmeer 'to learn Latin', and did learn both to speak and to write Latin, and moreover some Greek from a book by Jacobs; but that was all. And that sufficed to promote me to the University within three years. Of Latin literature I knew little, of Greek literature nothing whatsoever, and about as much of the literature of Dutch or any other modern language.

It will be understood that I had had time to walk, shoot and fish along the banks of the River Meuse.

The young undergraduate's profound ignorance was equalled by his thirst for knowledge. It was a real joy for me to attend lectures. Chemistry, as taught by Nicolaas de Fremery, impressed me beyond words — really excellent lessons, illustrated by experiments. There I first got the idea that everything which existed, in all its endless variety, was made up of a relatively small number of elements, which combined and recombined in certain proportions — and it seemed to me that all Nature had been given, once the elements had been created, and in my own way I indulged in phantasies. Later I was particularly fascinated by physiology, which was taught by Schroeder van der Kolk, who was an enthusiastic lover of Nature, and knew, too, how to inspire love for it in others. When I had passed my preliminary examination in Physiology, he gave me a book and an advice. The book was: 'Bau und Entwicklung des Gehirns' (Structure and Development of the Brain), by Tiedemann, which certainly served to give some idea of descent, of which something may have lived in Schroeder van der Kolk's imagination, too, even though he was a convinced teleologist. His advice: Never fail to make post-mortem examinations, whenever you have the opportunity: 'they have been my school', he said.

Meanwhile I learned much by associating with my fellow undergraduates. We had entered the University with a great many medical students, among whom an excellent spirit prevailed: but I was interested in everything, and found my friends among students of all faculties. In the meantime I had to finish my studies quickly, for after four years I would have to leave Utrecht as a military surgeon. Consequently I passed my preliminary examination after Christmas of the second year, my B.A. after Easter in the third year, and wanted to graduate before the end of the fourth year. But the Faculty objected, as the law required two years' hospital practice. Now I had had two years in hospital, at any rate I had seen patients under Alexander, who was the clinician of the Army medical school, with the title of Honorary Professor. But the Faculty would not accept those two years, and so Alexander advised me to go to Leiden University to find out what they thought of it there; and — three days later I returned, with my degree. My Boxmeer version of Latin (in which I was as fluent as water) had impressed them. I had an all-round knowledge, which was, however, very superficial, and my general education was far from being complete.

In February, 1840, I was promoted military surgeon and sent to Flushing.

In those days Flushing was certainly no place of exile. Nowadays there are fine harbours without ships; then there were fine ships without harbours. Prince Henry had just put into port with a squadron, and the place was swarming with naval officers and midshipmen. To this add the flourishing dockyard with its Commandant, its designers and officials, generally men from whom you could learn something; moreover a Directorate and Staff of the Royal Engineers, the entire Marine Corps, the requisite garrison artillery and some batallions of infantry. Everywhere I looked for, and found, contacts. I performed my duties in military barracks and in a few hospital wards; did all the autopsies; wrote my thesis there, and went to Leiden to get my doctor's degree; practised medicine; made music; and found opportunities for a many-sided training of mind and character by associating with excellent men and charming women. Therefore I was reluctant to leave out-of-the-way Flushing the next year, in August 1841, when the Surgeon-General called me to the Royal Residence, The Hague. Yet I had every reason to be pleased with my posting, as it afforded every opportunity for acquiring knowledge in many fields. My superior officer, Surgeon Major Rodi de Loo, a man of knowledge and culture, went out of his way to meet the wishes of those under his command. Remembering Schroeder van der Kolk's advice, I again performed all autopsies here, and my reports in the medical journal *Boerhaave* brought me into contact with the editor, Dr. Van de Kasteele, a man who had brains and a heart, but was, alas! snatched away by an all too early death. He gave me an introduction to the library, 'Leesmuseum', where I became a member and spent all my available hours, almost over-indulging in reading literary, as well as medical and scientific pamphlets and magazines.

My college friend Schroeder, afterwards Parliamentary Under-secretary at the Home Office, then introduced me into a circle of young lawyers, most instructive acquaintances for me; one of whom, the former minister Wintgens, became my lifelong friend. It seems almost incredible how chance brought the flower of manhood to our table of 'officers without arms'. Not only was there a *convivere* at the dinner table; we also spent the evenings together, either at the Opera, which had an excellent troupe in those days, or in our respective lodgings, with conversation and music, and a cup of cocoa. Could anyone wish for better companionship? It goes without saying that I had a taste of Court life, that I did not remain a complete stranger to State affairs, heard something of politics, and saw something of art.

It was delightful life indeed. Moreover I had Beckers', our Inspector- General's, ear. He wished to reorganize the Army Medical School, asked my advice, desired me to suggest teaching staff, and finally told me that I was to teach anatomy and physiology there. I had hoped for the position, and readily assented, although leaving the Royal Residence meant loss of the special allowance, and consequently a reduction of my income from 1000 to 800 guilders.

In September, 1842, I entered upon my new duties, relinquishing all the joys of life in the Royal Residence without regret; for teaching, I felt, was my vocation.

Realizing that, and finding myself, at the age of twenty-four, charged with the teaching of anatomy, histology and physiology — 18 lectures a week, 46 weeks of the year, side by side with friends like Van Hasselt, Jansen and Ellerman—what more could I desire?

Thus I came back to Utrecht, never to leave it again. And, lo! just in those days Gerrit Jan Mulder had taken the chair of chemistry there, and with the magic wand of his genius he had conjured up new life and rallied the old and the young around him.

He received me with great courtesy. I worked in his laboratory as often and as long as time would allow, and soon won his friendship. I greatly valued that friendship, and had every reason to do so. In his house I met Heije, the physician and popular poet, a singular and no less remarkable man, whom one valued the more, the deeper one managed to penetrate into the heart of his personality; and his intimate friend, Voorhelm Schneevoogt, medicus humanus, a man of tact and erudition and a most lovable character, who soon became my close friend. And besides them, Jac. Moleschott, the warm-hearted friend —who even then was thoroughly versed in German philosophy and physiology, and invaluable to me by reason of his stimulating power. And shortly after there was Opzoomer, with his brilliant talent and unrivalled knowledge, and Robert Fruin, the college friend who had followed him to Utrecht; soon both of them were my daily companions. Under the influence of such men all seeds which lie dormant within us will develop and burgeon.

Then there were in the Faculty of Science, that training ground of the physiologist, besides Mulder, men like Van Rees and Wenckebach, Miquel and Harting, and with a number of younger friends they formed a circle in which we regularly reported to each other on the latest scientific progress, each in our own particular field. How could a physiologist fail to be stimulated again and again to further research in his own province?

And what interesting times they were! Never before had the science of life known such a period. Great discoveries in all fields! Life and movement everywhere!

Karl Ernst von Baer had discovered the mammalian egg; Bischoff had studied yolk cleavage, also in mammals, and discovered that the embryo consists entirely of cleavage cells. Theodor Schwann had demonstrated that the cell was the ultimate unit of life, from which all living forms had sprung; Henle had provided an Organon of histology with his 'Handbuch der allgemeinen Anatomie' (Handbook of General Anatomy). The life of the tissues — their form and development in connection with their structure and function — had become the basis of general physiology, to which now the study of the lower forms of life was made subservient as well.

In the field of neurology, Charles Bell's discovery had provided the impetus, which we saw at work in the experiments of Magendie, of Johannes Müller, of our Van Deen, my kind guide in this field, and of so many others. At the same time Johannes Müller, in his 'Handbuch der Physiologie', gave physical science its due, and his school of thought produced the immortal trio, Helmholtz, Du Bois-Reymond and Brücke as its representatives; there were also Claude Bernard, who surprised us with unexpected discoveries on many occasions, and Karl Ludwig, who founded a school of experimental research, which even now is unrivalled. Such was the world, gentlemen, in which I had the privilege to move.

In those same years Liebig and Dumas, as well as Mulder, continued to build on the foundations of physiologic chemistry laid by Berzelius. Right here, ladies and gentlemen, in the laboratory of our great Mulder, we beheld the genesis of physiologic chemistry. I was a daily witness. Then we exchanged views on all sorts of subjects. We particularly discussed the relationship between form and composition of animal tissues. Mulder was perhaps the first man to see clearly that chemistry can start successfully only at the point where morphology comes to an end. The composition of all distinguishable forms, rather than of complex tissues, should be investigated. This view caused him to suggest that I should make microchemical studies of animal tissues, just as he had studied vegetable tissues with Harting. I eagerly accepted his proposal. During the day I treated preparations with all sorts of agents; every evening the great man, wearing his student's cap, arrived at my lodgings over De Lang's smithy on the Steenweg, to inspect the preparations together, to note what was to be seen and take it down immediately in a few brief words. Those notes, with explanatory drawings, may be found literally in his 'Proeve ener algemene physiologische scheikunde' (General Physiologic Chemistry) (1843/50, pp. 539 seqq.). They contained a wealth of new facts, also in respect of morphology (see my adaptation in the 'Holländische Beiträge zu den anatomischen und physiologischen Wissenschaften').

What a privilege, again, to have a man like Mulder for a guide in venturing into the field of experiments!

Meanwhile I had been appointed Extraordinary Professor in the Faculty of Medicine, although there was no vacancy — supernumerary, as we said then. But in a faculty of no more than four members there must be something left to do, and I felt sure I could find a sphere of activities without colliding with my colleagues. And I had not been mistaken. Moreover I knew the lacunae. I could take forensic medicine, which was not taught in the medical faculty. The Royal Decree which regulated higher education required public health and sanitation as well; I taught it in connection with hygiene. Anthropology (by which term I comprehended popular anatomy and physiology, with psychology on a physiological basis) seemed to me necessary for law students by way of introduction to forensic medicine, and even quite helpful to students of divinity, and apparently the undergraduates were of the same opinion. They came, encouraged, I gratefully acknowledge, by the professors of their various faculties. There was a great deal of interest for those lectures then. Once I wanted to pass over one year, but was dissuaded by a petition from the theological students; seeing my friend

Allard Pierson before me has just reminded me, for his name headed the petition. I combined histology and general metabolism under the name of general *biology*, preferring to avoid the word *physiology* (which was mentioned in the Royal Decree) to avoid all semblance of rivalry. Further I taught under the name of ophthalmology, physiology of the organ of sight, with reference to pathology. I also undertook to perform autopsies in the hospital, which were faithfully attended by the students. Whatever time was left was devoted to practical exercises and laboratory studies. In those early years I lived with the students — with some of them nearly all day long.

Thus I continued until unexpectedly my lectures on ophthalmology gave a new turn to my life. I had suggested certain methods for studying diseases of the eye. For this reason my friends sometimes wanted my advice in obscure cases. The result was that very soon patients found their way by themselves. I was interested in many cases as physiological problems. But I had no desire to be an ophthalmologist, so I sent most of them away. But now some of my friends began to argue that I should not try to avoid practising. There was not a single ophthalmologist in the Netherlands who enjoyed general confidence, and there was need of one. On my part I considered that an extraordinary professor, in order to live, with his wife and child, on an income of 1600 guilders minus a 20 per cent. reduction, still had to spend several hours a day translating; and that a few ophthalmic patients would yield the same revenue in less time. I wavered.

And then what happened?

My lectures on anthropology were faithfully attended by a number of South Africans, most of them theological students. One day my eye discovered, among the Cape students, a distinguished middle-aged man with a fine head and imposing features. After the lecture he was introduced to me as Simpson, the famous Edinburgh gynaecologist (who had discovered chloroform as an anaesthetic), accompanied by Dr. Van der Bijl, from Cape Town, who had taken his doctor's degree at Edinburgh. Simpson departed a few days later; but Van der Bijl, who spoke Dutch, stayed for several months. He saw me examine ophthalmic patients and urged me to go to London to visit the great clinics. It was the year of the first Great Exhibition, 1851; I was then 33 years old. Very tempting indeed! The extraordinary professor examined his cash box and shrugged his shoulders; but Van der Bijl was going to take a room in a private house, and knew the way; it could be managed.

That journey, Ladies and Gentlemen, was to be of the utmost importance for my life to come. I saw the physiologists there, and had the good fortune to make friends with Sharpey and with James Paget. But of even greater importance for my future was my meeting with William Bowman, then already known everywhere for his classical studies on the structure and function of the kidneys and on muscular tissue; moreover he was an excellent ophthalmologist, scientifically excelling all others, with an operating technique which may never have been equalled either before or after him. He had heard my name mentioned, and that was enough for him to get in touch with me. After a few days we were friends. After that all at Moorfields, where he was held in high esteem, vied with each other in their willingness to be of use to me. Was not I fortunate?

The Great Exhibition had also brought Friedrich von Jaeger, Professor of Ophthalmology in Vienna and especially famous as a great surgeon, to London. I was introduced to him by his host, White Cooper, and now went to attend his operations at Guthrie's Ophthalmic Hospital. I had just watched him, sitting on a chair and alternately using his right and his left hand, remove the cataractous lenses from the left and right eye of the same man, when a young man rushed in and threw himself into the arms of his teacher and his father's friend. It was Albrecht von Graefe, who was passing through London for the second time during his scientific tour. Von Jaeger thought we would suit each other, and Von Graefe and I soon agreed with him. The days which followed were unforgettable! In everything we saw and heard in the practical field, Von Graefe was my guide; in matters of science he was willing to listen and eagerly enquired after the smallest detail. For a month we lived together, and then parted as brothers. To have won the friendship of William Bowman and Albrecht von Graefe was to be an invaluable treasure in my future life. Again, was I not fortunate?

With letters of introduction by Von Graefe, who had left an indelible impression everywhere, I arrived in Paris, and visited the great ophthalmologists and the clinics of Sichel and Desmarres. My reception was similar to that in London: everyone was extremely obliging, and willing to instruct me and to show me everything.

In different surroundings, in the Société de Biologie, I heard myself proclaimed an honorary member. And when I took the liberty to present myself to the President Rayer, he bowed kindly and said: 'Prenez donc place parmi les membres'. The members—physiologists, Cl. Bernard, Ch. Robin, Brown-Séquard, Lebert, and others, came to greet me, invited me to dine with them, and were amazed that I spoke French and played whist, and—I was one of the circle of young physiologists of Paris.

Thus Fortune favoured me again and again.

Back in the Netherlands, I intimated that I was now willing to see patients, and they came — soon even from all our provinces. You are astonished, perhaps? Know, then, that only a few months ago Von Helmholtz had enriched ophthalmology with the ophthalmoscope, and all the world was talking about it. They wanted to see the ophthalmoscope, to be examined with the ophthalmoscope, which had aroused a flicker of long-lost hope. And I offered them the opportunity. What a coincidence, was it not?

I had opened a policlinic for needy patients, at my own expense. But there were no facilities for nursing them. One word — and the cholera hospital with its equipment, with the caretaker and his wife as staff, was put at my disposal; the Governors of the City Hospital supplied food at most reasonable terms. Thus I could continue for the time being. But lo! a big house next door to the cholera hospital was offered for sale. I cast covetous eyes on it; I knocked at a door at the corner of the Drift and Janskerkhof, and came back with the certainty that the house would be an ophthalmic hospital. Five months later the Committee which had warmly taken up the cause, had a fund of 40,000 guilders, enough to buy and fit up the house. That blessed result, gentlemen, had been obtained under the influence of the invention of the ophthalmoscope, and Von Graefe's practice in Berlin, two facts which kept all the world talking.

In those days — here I may surely be permitted to tell what I have hitherto kept silent — I received a request from the Faculty of Medicine at Bonn to become Helmholtz's successor. It was the unanimous desire of all members of the Faculty, wrote the Dean, and also of Helmholtz himself, who was about to leave Bonn. The offer might have been a temptation. With a gift of 40,000 guilders put at my disposal for a definite purpose, there was no need to consider it. Another blessing!

The Foundation was to be an ophthalmic hospital for needy patients, and also a teaching hospital, completely free and independent, but intended to serve first and foremost the needs of the University. Everything required by science and practice was collected here for purposes of teaching and research. Thus we had at our disposal much that could not be found elsewhere; the result was that not only our medical students availed themselves of the opportunity, but colleagues from abroad, too, came to visit our institution and take part in our research work, especially that concerning the study of anomalies in refraction and accommodation. Much work was done on this subject for ten years. The view one obtains of a new territory depends on the point at which it is first entered. I came from the physiologists' camp, and thus the gaps in our knowledge of the said anomalies perforce caught my attention. The remedy was obvious. If the Utrecht school has acquired the merit of providing a better grounding for this subject, the reason was that I was a physiologist before I became an ophthalmologist, and had the co-operation of our students and of many visitors from abroad.

In those years I was rather overtaxing my strength. An ophthalmic hospital and a physiology laboratory, an extensive practice and lectures on many subjects, in addition to laboratory research and work for the press. I was in danger of collapsing under the burden. In 1862, Professor Schroeder van der Kolk's death gave a new turn to my life, as well as providing some relief. I had to decide whether I would assume the task of teaching physiology to its full extent. Physiology, my first love! I had not been unfaithful to her! In addition to ophthalmology I still taught histology and physiologic chemistry under the name of general biology, and I had constantly kept in touch with special physiology as well. I could therefore consider myself qualified, and my decision was made when the Trustees of the University held out the prospect of a new laboratory, and Dr. Snellen declared himself willing to assist me in ophthalmology. First one of my students, then my assistant, he would now be my colleague, to be my successor afterwards. Thus I have wished it to be, and thus it has happened. I knew that Snellen would not only follow up my line of work—which was brilliantly proved by the work which he published together with Landolt: 'Ophthalmometrologie'- Vol. III of Graefe-Saemisch's Handbuch der gesamten Augenheilkunde, Leipsic, 1874;—but his brilliant insight and practical talent promised to do justice to a new side, for which I had no particular vocation; the results have proved that my views were correct.

Meanwhile the new physiology laboratory was realized, and became a new source of joy and happiness. I have most pleasant memories of the old laboratory; it was small and its equipment poor, but sufficient for the small number of students.

In the new laboratory I soon had the privilege of seeing Engelmann by my side. Albert von Bezold, his beloved brother-in-law, who, alas! has been torn away from us all too early, had recommended us to each other. Thus Engelmann came to Holland. I need not tell you here what he has been to our University, to science. What he has to been me — what memories he arouses! I lack the courage to turn to him, for I feel that the sight of him would prevent me from going on . . . I *cannot* tell you.

I turn to Kagenaar, my chief technician for nearly 30 years. As a boy he was apprenticed to my colleague Harting's technician. I liked the boy from the moment I saw him, and asked if he would let me have him. 'I will think it over', he replied. The next day he said: 'Professor, I will let you have the boy; but you must look after him, for he is worth it'. I gave that conscientious man my promise, and—I have kept it, have I not, Kagenaar? But you, my friend, you have done more. Gentlemen, I want you to meet our Kagenaar, a skilled mechanic, who has made every instrument designed by us, and improved nearly all of them; who ships them all over the world; who has been my right-hand man at all my lectures, and without whom my teaching would have failed in more than one respect. If I have been able to pursue many and manifold activities simultaneously — I owe it to Kagenaar. Kagenaar had taken care of everything; I only had to mention what was required. In the laboratory he is always everywhere, is at everyone's service and has time for everything. He never raises his voice, and yet he is obeyed by those under him as no one else is. And do you wish to see a scene of homely peace and happiness? then enter his living room, and behold him sitting among his wife and eight children.

Is it not excessive happiness, to be surrounded by such people?

I spent many happy days in that laboratory. If learning is generally a pleasure, her knowledge is obtained from the very source, from Nature itself, and I know no greater delight.

And besides studying, there was teaching. That has always been a joy to me, never a burden. If learning may be called a delight, the knowledge acquired will be like a treasure that has been hidden away. It is dormant. But teaching will arouse it. It is interesting to trace that process in oneself. It will start with a certain amount of doubt, so little conscious one is of one's own knowlegde; but the first thought will beget others, the routes of association are prepared, and under that influence of mostly unconscious inner and outer impulses, a whole series will be evolved, and new combinations may be made, new ideas may be born.

It is said, no doubt truly, that the delight is in the acquisition of knowledge, not in its possession; but that delight may be even greater in awakening one's latent knowledge, and forming it, like a plastic mass, into something better.

You will observe how teaching brings its own reward. Never in any year have I failed to thank my audience for it; it has been the gratitude of the collector, who opens his portfolio to his friends, and thus once more has the joy of seeing his drawing and finding fresh beauty in them. And I am happy also to be able to thank them for their interest. It provides a stimulus which a teacher cannot do without, and also a considerable satisfaction, for it is a guarantee that the seed which was scattered has fallen on good ground. For myself I have never wished for any form of gratitude other than this *act*. Yet I have not lacked expressions of gratitude. I found them everywhere on my way. They have strengthened my conviction that I could not have chosen a better career. A teacher needs to *know*, and to know exactly. But that is not enough. He must also be able to *feel* how to express himself so that his audience may understand him. That is the art of teaching. If I was born with any talent, then surely this is the one.

You see, Ladies and Gentlemen, how much gratitude has constantly been my share. Now that my official activities are fast coming to an end, all this has been crowned by the honour granted to me, that my name is to be linked with a fund, collected after the appeal by a Committee of students, friends and distinguished fellow countrymen, by Dutchmen and foreigners alike. I am deeply moved by this touching evidence of appreciation and trust. I have given much and careful thought to the appropriation of these monies.

The intention surely has been that the sum which has been collected should be earmarked for an independent purpose, which it was left to me to name. This has suggested to me that it should be devoted to ensuring a proper training in ophthalmology and physiology, the two subjects to which I have chosen to devote my life. When a vacancy arises, the usual complaint is that there is no choice of men who will warrant an appropriate filling of the post. We need not look far for the cause. In this country there is little chance of pursuing a so-called scholarly career, especially in medical subjects. Expectations are uncertain because of the small number of our universities, and if only for that reason the system of external University lecturers cannot flourish as it does elsewhere. Well, I wish to see suitable candidates for the chair of physiology and ophthalmology in the Netherlands. I have estimated that once every eight years the proceeds accruing from the fund will allow two young men to be trained for two years in the best schools. Thus the Netherlands will acquire an ophthalmologist and a physiologist once every eight years. That will be enough.

This Foundation, Ladies and Gentlemen,will no doubt help to safeguard the flourishing of ophthalmology and physiology in the Netherlands for all times.

I cannot imagine a greater satisfaction from my work, and wish to express my deep gratitude to all those who have helped by sending their donations to this fund.

CONVERSION TABLES

	cm/*line*	*cm*/*inch*	*cm*/*foot*
1	0·212	2·54	30·48
2	0·4	5·1	61
3	0·6	7·6	91
4	0·8	10·2	122
5	1·1	12·7	152
6	1·3	15·2	183
7	1·5	17·8	213
8	1·7	20·3	244
9	1·9	22·9	274
10	2·1	25·4	305
11	2·3	27·9	335
12	2·5	30·5	366

Focal distance in Parisian inches	*Dioptres*
2	18·5
2·25	16·5
2·5	14·9
3	12·3
3·5	10·6
4	9·25
4·5	8·2
5	7·4
5·5	6·7
6	6·2
7	5·3
8	4·6
9	4·1
10	3·7
12	3·1
14	2·6
16	2·3
18	2·1
20	1·85
22	1·7
24	1·5
28	1·3
36	1·0
40	0·9
48	0·8
60	0·6
72	0·5
100	0·4
120	0·3