History of Science. — *The Amici-microscopes about 1850 in possession of the University of Utrecht.* By P. H. VAN CITTERT and J. G. VAN CITTERT–EYMERS. (Communicated by Prof. A. J. KLUYVER.)

(Communicated at the meeting of March 29, 1947.)

When about 1800 achromatic microscope objectives were constructed, only relatively weak objectives could be made, so that an important improvement was only attained for the lower magnifications. Indeed, the achromatic objective must necessarily consist of a convex crown lens and a concave flint lens. Now, in order to obtain high magnifications the convex lens must be very much more powerful than in the case of a single monochromatic lens and this leads to practical difficulties in their construction. SELLIGUE and CHEVALIER, soon followed by others, were the first to obtain high magnifications by combining into a system a number of small lenses, each of which had been separately achromatized as well as possible. The advantage of this method was that by simply adding or removing one or more of the lenses, the magnification could be altered very easily. The drawback, however, was the accumulation of the separate spherical aberrations, which in the case of higher magnifications spoiled the resolving power. This explains why the resolving power of the compound microscope, though increased considerably by achromatizing, still remained below that of the simple microscope. It is due to the ingenious AMICI (1786—1863), among others, that these difficulties were overcome. He showed that in order to arrive at a high resolving power the objective must be composed of different parts, each of which separately still can give rise to aberrations, but which are so computed that they neutralize each other's impairing influence. He was also the first to draw attention to the part played by the cover glass and to the great advantage of having at one's disposal a number of eyepieces of different powers, as well as a number of different objectives. He pointed out, moreover, the influence of a larger aperture and the great advantage of immersion.

About 1850 the University of Utrecht was, as far as can be traced, in the possession of three original AMICI-microscopes:

A. the microscope bought in 1835 for *f* 750.—, described by HARTING [1]) in his famous book entitled: Het Mikroskoop, part II, page 85, 1848;

B. the microscope bought in 1836 for *f* 500.— by Prof. VORSSELMAN DE HEER for Prof. G. MOLL on behalf of the Physical Society (Natuurkundig Gezelschap) of Utrecht;

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[1]) Prof. P. HARTING was professor at the University of Utrecht from 1843 to 1882. He was succeeded in 1882 by Prof. A. A. W. HUBRECHT and died in 1885.

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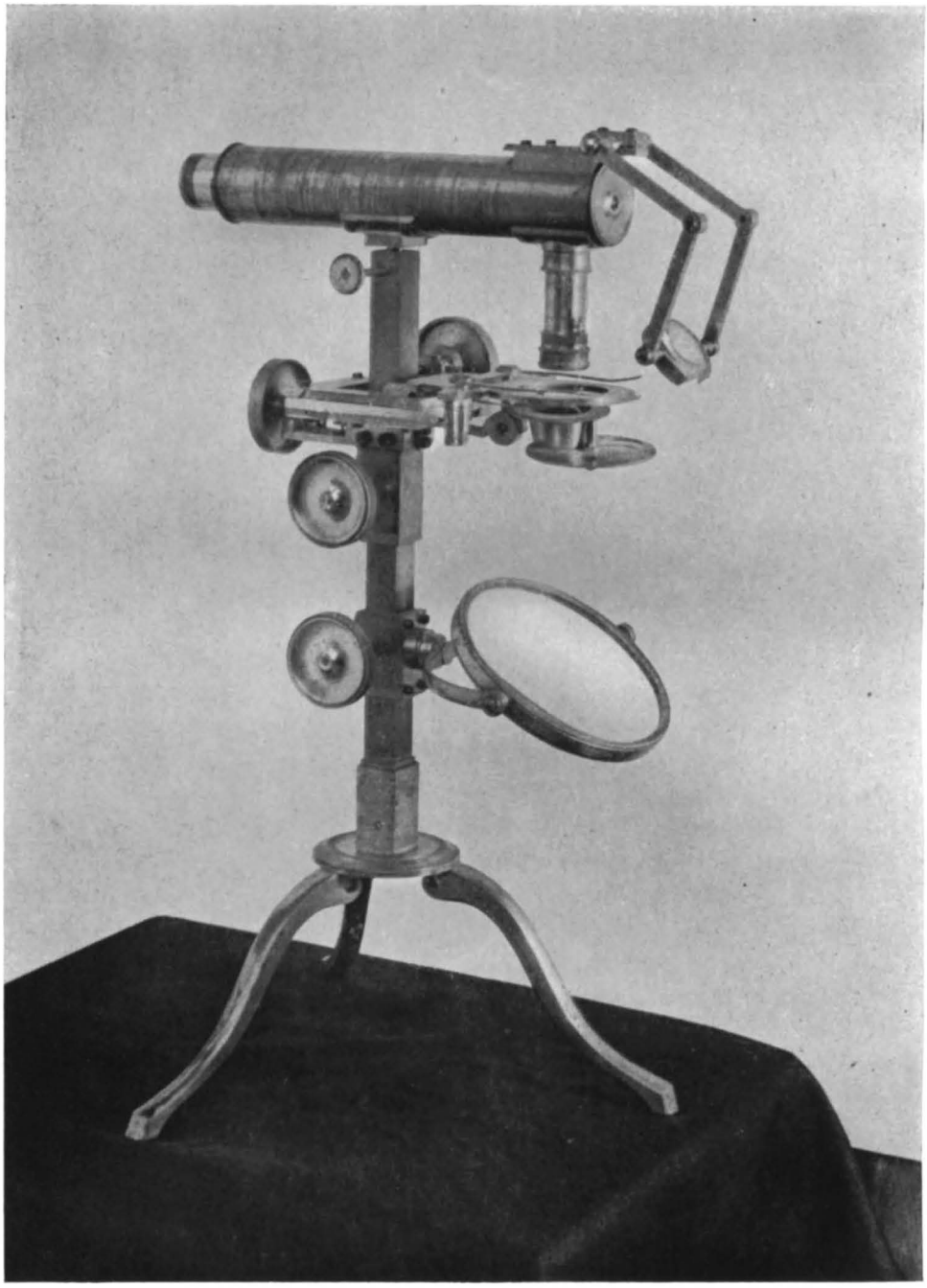

Fig. 1. AMICI microscope, bought in 1836 by the Physical Society of Utrecht.

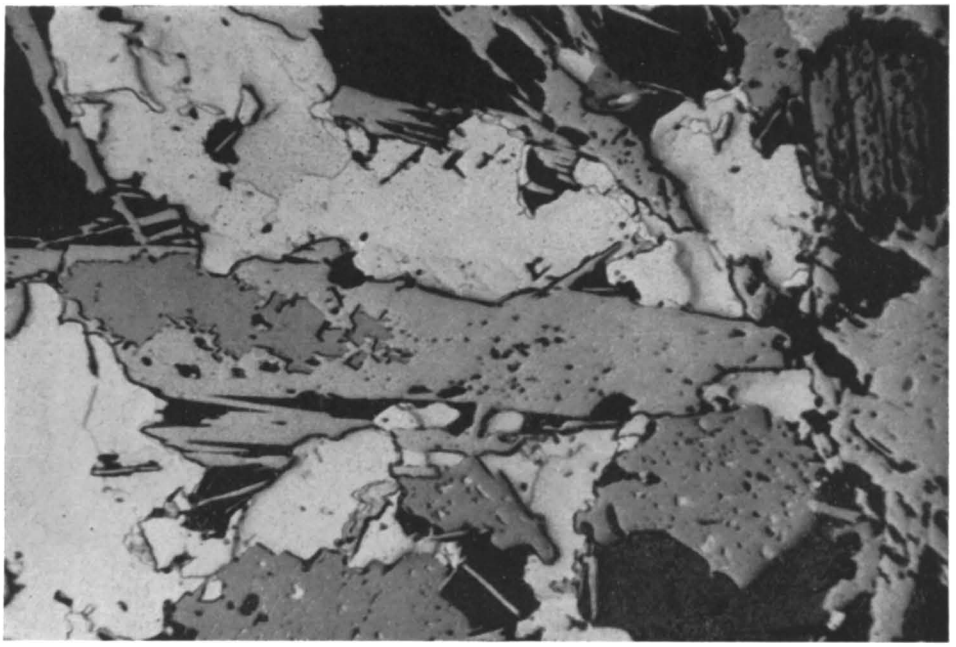

Fig. 7.

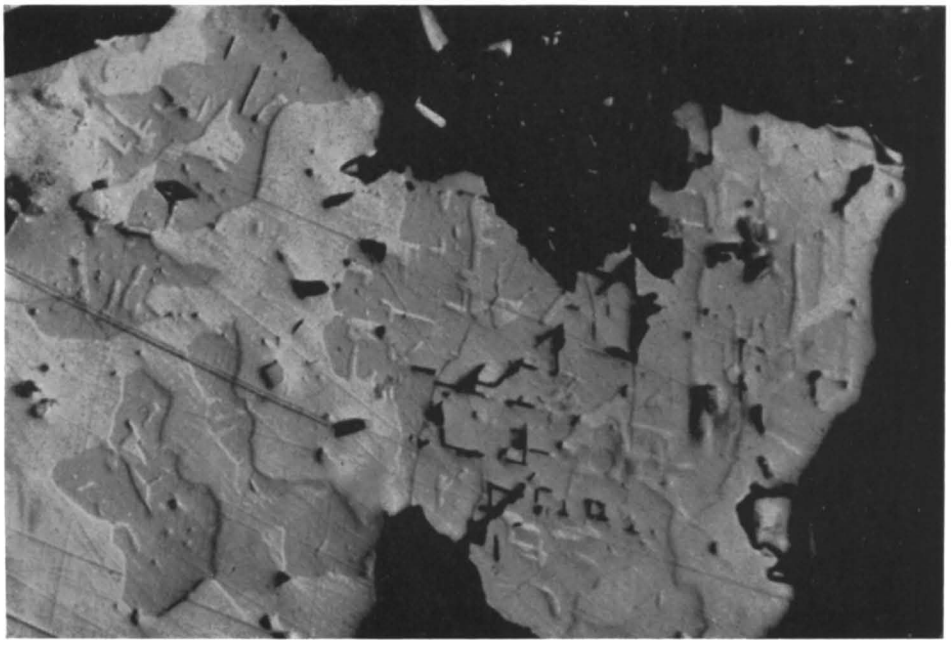

Fig. 8.

C. the microscope bought in 1849 for *f* 250. — by Prof. HARTING personally and presented by him to the Zoological Laboratory of Utrecht. This microscope is amply described in the above mentioned book by HARTING, part III, page 205, 1850.

As regards microscope A, HARTING informs us that ten achromatic double lenses belonged to it, out of which various combinations could be formed. Only four of them, called by him 1, 2, 3 and 4, are mentioned in his book. Further, five eyepieces belonged to this microscope, the strongest of which was not used by HARTING, as its magnification was unnecessarily large. Besides, a weak eyepiece of DOLLOND was used, designated by HARTING as no. 1. The AMICI-eyepieces used by him were numbered 2, 3, 4 and 5. From HARTING's description we may conclude that in mechanical respect this microscope probably strongly resembled microscope B, described below. Whether microscope A has been in the possession of the Zoological Laboratory or in that of Prof. HARTING personally cannot be ascertained. It has disappeared without leaving any traces. One of the eyepieces (no. 4), however, has recently been found again (see below).

The mechanical construction of microscope B (and also probably of microscope A) can be seen in fig. 1. It is constructed as follows: on a folding tripod is mounted a brass stand along which a very large concave illuminating mirror and the stage as well, can be made to slide by rack and pinion. The horizontal microscope is attached to the upper end of the stand. AMICI constructed the tube horizontally, convinced that this facilitated the observations: he attained this by placing a rectangular prism above the objective. The stage can be moved in two directions at right angles to each other. These displacements can be measured with the aid of two micrometer screws of which the divisions correspond to 0.0031 mm and to 0.00246 mm (= 0.0001 inch) respectively. Directly under the stage is fitted a cone with a diaphragm-wheel with three apertures. This cone can be rotated out of the optical axis. There is, further, a small ground glass plate capable of the same rotation. A plano-convex condensing lens for the illuminating of opaque objects is attached to the microscope tube, and one of the objectives is fitted with a LIEBERKUEHN mirror [2]). Three different camera lucida belonged to this microscope [3]). Originally five eyepieces and ten objectives belonged to it. The objectives were numbered from 1—8, 10 and 12 and could be combined by two small cylindrical tubes no. 0 and 11 in the following ways:

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[2]) A. LIEBERKUEHN mirror is a small concave mirror fixed to the objective for the purpose of converging light from above onto opaque objects.

[3]) A detailed description can be found in: Descriptive Catalogue of the collection of microscopes in charge of the Utrecht University Museum with an introductory historical survey of the resolving power of the microscope by P. H. VAN CITTERT, pages 68—71, 1934. Edition P. Noordhoff N.V., Groningen.

U 1	U 2	U 3	U 4	U 5	U 6	U 7	U 8
10	10						
	11	0	0	0	0	0	0
	12	1	1	1	1	4	6
			2	2	2	5	7
				2	3	6	8

The only difference between *U* 4 and *U* 5 was that the LIEBERKUEHN mirror (also marked 2) was attached to the lower end of the combination 0—1—2.

According to AMICI the thickness of the cover glass was of no importance when using the combination *U* 1 to *U* 5, *U* 6 required a definite clearly determined thickness, *U* 7 should be used without a cover glass, while with *U* 8 it was necessary to cover the object with a thin plate of mica.

AMICI gives the following magnifications for a distance from the eyepiece to the surface of the table = 33 cm:

TABLE I.

Eyep. / Object.	1 (Am 1)	2	3 (Am 3)	4[4] (Am 4)	5
U 1	38				
U 2	61				
U 3	120				
U 4	247	480	636	1039	
U 6	348	676	896	1464	4685
U 7	305	591	784	1306	4100
U 8	585	1137	1507	2463	7881

At the time when the Descriptive Catalogue, quoted above, was composed, all that was left of these various optical accessories, were only tube 0, objective 1, fitted with the LIEBERKUEHN mirror and the eyepieces 1, 3, 4 and 5. Lately, however, 5 objectives of this microscope viz. 4, 5, 6, 7 and 8, from which can be formed the systems *U* 7 and *U* 8 have been found again in the Zoological Laboratory of Utrecht, together with a large number of objectives belonging to the microscope C, described below.

Of the eyepieces, no. 1 is a very long one: it consists of a plano-convex field-lens and a ditto eyeglass; the plane surfaces of both are turned toward the eye. No. 3 is an Huygenian eyepiece, also fitted with two plano-convex lenses; no. 4 is composed of two plano-convex lenses, one immediately on top of the other, whereas no. 5 consists of a single spherical lens. AMICI

[4]) The Desc. Cat. gave for eyepiece Am 4 the magnifications 1039, 1264, 1406 and 2263, instead of 1039, 1464, 1306 and 2463. This is partly due to the fact that in AMICI's letter the figures 4 of 1464 and 2463 were written so illegibly that they looked like figures 2 and partly to the fact that AMICI gives the number 1406 instead of 1306.

remarks, with some truth, that this eyepiece is practically never used: the magnification is unduly large and the image formed is not sharp. As even the weakest eyepiece (no. 1) is relatively strong, we have added a weaker one belonging to a microscope of HARTNACK [5] [6], in order to check the optical power of the various optical combinations. HARTING did the same thing when examining microscope *A* by adding an eyepiece of DOLLOND. We should have liked to use that same eyepiece of DOLLOND, in order to make a direct comparison possible, but the DOLLOND-microscope, to which this eyepiece belonged, is lost to the Utrecht collection (see below). Table II gives the magnification and the resolving power [7] of the various combinations, eyepiece no. 5 not being used:

TABLE II.

Eyep. / Object.	Magnification at 25 cm distance				Resolving power in mm
	Hck	Am 1	Am 3	Am 4	
U 3	45	100	250	400	1/ 400 [1]
U 7	115	255	640	1020	1/ 800
U 8	210	465	1165	1865	1/1000

[1] with eyepiece Hck only 1/200 mm.

Microscopes A and B dating practically from the same year, their optical properties could be expected to be very much the same. Indeed, from a comparison of the data of HARTING, those of AMICI and of our measurements it appears that the objective systems no. 1, 2 and 4 of the lost HARTING microscope A and identical with the combinations *U* 5, *U* 6 and *U* 8 of microscope B, which is still in Utrecht; combination no. 3 of microscope A, however, does not fit in with any of the combinations *U* 1—*U* 8 of microscope B. The eyepieces no. 3, 4 and 5, mentioned by HARTING, are identical with the eyepieces 2, 3 and 4 of microscope B, while HARTING states that the eyepiece, called by him no. 6, is impracticable, just as is the case with no. 5 of microscope B.

HARTING gives on page 91 of part II of his book the resolving powers of some combinations of the objectives and the eyepieces. Since, for their determination he used as a criterium their capacity of resolving the meshes of a network, his measurements cannot be compared immediately with ours in which the GRAYSON ruling was used. HARTING's data lead to a resolving power of 1/400 mm for his objective no. 1 and 1/1400 mm for no. 4, whereas the corresponding combinations *U* 3 and *U* 8 give at present a resolving power of 1/400 and 1/1000 mm respectively.

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[5] Desc. Cat., page 81, Q 3.

[6] Denoted by us by Hck, as distinctive from the AMICI eyepieces, which we shall call Am 1 ... Am 5.

[7] All measurements are done with the aid of a "GRAYSON ruling" (Desc. Cat. page 7), with pencils of rays of very slight divergence.

Concerning microscope C HARTING (loc. cit.) informs us that he regarded this microscope, though surpassed by several microscopes in mechanical respect, at the most perfect microscope in optical respect he ever examined. The mechanical design can be seen immediately in fig. 2, to be found on plate 6 of part III of HARTING's book. We mention here that besides a coarse adjustment with rack and pinion, a fine adjustment by means of the screw *l* is possible, that the mirror admits of a sideways motion in order to make oblique illumination possible and that the tube, in contradistinction to microscope A and B is not provided with a rectangular prism immediately above the objective, but is the usual vertical tube, and can be drawn out from 29 to 57 cm; for those observers, however, who prefer to observe horizontally a prism *A* can be mounted between the parts *n* and *f* of the tube. A small tube is mounted under the object table for the screwing in of one of the objective systems to be used as a condensor. According to HARTING no less than 21 achromatic double-lenses belonged to this microscope with which 13 different systems could be formed. Several of these combinations had about equal focal distances and consequently also equal magnifications, but were intended to be used with cover glasses of different thickness (from 0—1.5 mm). Four of these systems gave for instance, when used with the weakest eyepiece, the magnifications × 664, 672, 644 and 650, resp., but should be used with cover glasses of thickness 0, 0.2, 0.25 and 0.33 mm resp. In all, there were three eyepieces, all of a peculiar construction: they consisted of two small sliding tubes *x* and *y* (see fig. 2), each provided with a plano-convex lens, while a diaphragm *z* was mounted in the inner tube. When the tubes were completely pushed in, the system formed a RAMSDEN eyepiece, it could, however, be altered immediately into a Huygenian eyepiece by drawing out the tube. HARTING describes the optical power of this microscope in detail. He compares the resolving power with among others that of an OBERHÄUSER microscope [8]), and concludes that the AMICI microscope surpasses the latter.

When the "Descriptive Catalogue" was composed, microscope C was missing in the Utrecht collection, so that it was not described in the catalogue. What had become of it was totally unknown. When visiting the Science Museum in London one of us, however, was very astonished to find the missing microscope C exhibited there with the inscription: "purchased of the Zoological Laboratory of the Utrecht University through Dr. C. W. HUBRECHT in 1886, presented by Prof. P. HARTING to the University". On making inquiries we learned that a number of microscopes, belonging to the Utrecht University, were sold to the late Mr. CRISP, these microscopes being bought after Mr. CRISP's death by Mr. COURT. Some of these instruments are exhibited in the Science Museum, but are still owned by Mr. COURT. Mr. COURT very kindly gave us some further informations: Among these microscopes of the Zoological Laboratory in Utrecht in

[8]) Desc. Cat, page 80, Q 2.

charge of Prof. HARTING, which were sold after his death, was a microscope, made by DOLLOND which actually belonged to the Physical Laboratory but happened to be under his care at the time of his death; it was

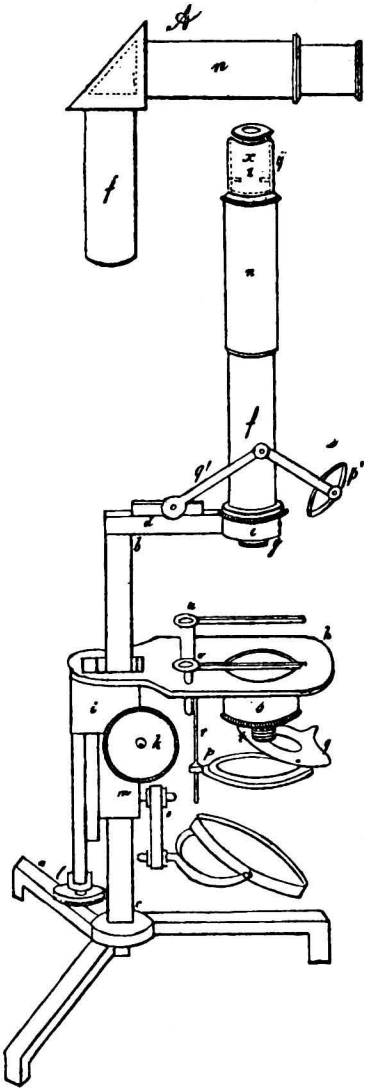

Fig. 2. AMICI microscope, bought by Prof. HARTING for his own use in 1849.

to this microscope that the eyepiece belonged, used by HARTING when examining microscope A. A second microscope bought was the above mentioned AMICI microscope C, which is provided with one system of 3 objectives, marked *A, B, C,* one adjustable eyepiece, a binocular fitting, a double body fitting, a quadriocular fitting and an experimental prism for use with the quadriocular body, which had been found by HARTING to be unsuitable [9]). A third microscope, made by KIPP, was bought, thrown in instead

[9]) These accessories are described in P. HARTING: "De nieuwste verbeteringen van het microscoop", 1858, page 74—112.

of a WOLLASTON microscope, made by HARTING himself (Desc. Cat. page 31, *E* 2), which was the original offer. Even the VAN LEEUWENHOEK microscope (Desc. Cat. page 14, *A* 1), the VAN MUSSCHENBROEK microscope (Desc. Cat. page 17, B 1) and the achromatic objective of BEELDSNIJDER (Desc. Cat. page 63, *L*) were offered for sale, but were fortunately saved for the Utrecht collection and for the Netherlands.

As practically all objectives of the above described AMICI microscope B were missing, it seemed likely that these were all sold to Mr. CRISP with the AMICI microscope C. It was, however, impossible to trace any of these, as Mr. CRISP used to combine all separate objectives and eyepieces to form a special collection, instead of leaving them with the instruments to which they originally belonged.

Recently, however, through the kind intermediation of Dr. BRETSCHNEIDER a small box containing a large number of achromatic lenses and eyepieces was found again in the Utrecht Zoological Laboratory. An accompanying letter from AMICI made it clear that the lenses, contained in the box, were all the missing lenses from the AMICI microscope C, except of course the system *A*—*B*—*C*, which is actually in London. Moreover, however, this box also contained the objectives 4, 5, 6, 7 and 8 from the microscope B and also an eyepiece, which was nearly identical to eyepiece no. 3 of microscope B and must therefore in all probability be identified as the eyepiece no. 4 from microscope A (see above).

According to AMICI's letter the following 20 objectives: *A, B, C, M, N, P, Q, R, Y, Z,* 0, 1, 2, 3, 5, ., . .., ..., ..., ..., belonged to the microscope C, further there were three cylindrical tubes, marked 3′, 4′ and *X*. All these objectives (of coarse except *A, B* and *C*) and the three tubes were found again. The lenses could be combined in the following ways:

	L 1[1]	L 2	L 3	L 4	L 5[2]	L 6	L 7
	A	N	N	N	M	4′	3′
	B	P	P	P	N	2	3
	C	Q		R	P	1	1
					R	0	0
thickness of cover glass in mm		0	0	1 =	1 1/2	1	0—1/4

	L 8	L 9	L 10	L 11	L 12	L 13
	5	5	X	X	Y	Z
	3′	4′	. . . .	. . . . .	X	X
	3	2	. . .	. . .	. . .	. . .
	1	1	. .	. .	. .	. .
	0	0	.	.	.	.
thickness of cover glass in mm	1/4—1/2	1	0—1/7	1/5	1/4	1/3

[1] Can also be used without lens A.

[2] M is a correcting negative lens.

The adjustable eyepieces mentioned above are unfortunately missing. According to AMICI the variable distance between the two eyepiece lenses was necessary because the various objectives were not all achromatized in the same way and the adjustment allowed to a certain extent the correction of the differences left. A few testobjects, enclosed between two glass plates, one having a thickness of 1 mm and the other being very thin, belonged originally to the microscope.

As the original microscope and one of its eyepieces were in London and the other eyepieces were missing, we combined the objectives with the HARTNACK eyepiece and with the eyepieces *Am* 1, *Am* 3 and *Am* 4 of the AMICI microscope B in order to be able to measure the magnifications and the resolving powers of the different objective systems. We mounted the lenses in an arbitrary microscope tube, taking as the length of the tube that of the tube of microscope B. The magnifications and the resolving powers measured by us are given in table III. All measurements are done with

TABLE III.

Eyep. / Object.	Magnification for a distance of 25 cm				Resolving power in mm.
	Hck	Am 1	Am 3	Am 4	
L 2	90	200	500	800	1/ 800
L 3	60	130	335	535	1/ 400
L 4	100	220	555	890	1/1000 [1]
L 5	85	190	470	760	1/ 600
L 6	180	400	1000	1600	1/1000 [2]
L 7	180	400	1000	1600	1/1000
L 8	190	420	1055	1690	1/1000
L 9	200	445	1110	1780	1/ 800
L 10	280	620	1555	2490	1/1200
L 11	290	645	1610	2580	1/1200
L 12	270	600	1500	2400	1/1000
L 13	280	620	1555	2485	1/1000

[1] With Hck and Am 1 only 1/800 mm; with an extra cover glass of 1 mm thickness for all magnifications only 1/800 mm.

[2] With Hck only 1/800 mm; with an extra cover glass of 1 mm thickness, however, also 1/1000 mm.

a thickness of the cover glass equal to 0.17 mm, viz. the cover glass of the GRAYSON rulings (refractive index 2,549), but sometimes an extra cover glass was added in order to approximate the thickness mentioned by AMICI.

HARTING states that he was able to resolve with system *L* 2 the 7th group of a NOBERT plate, which corresponds to 1/1100 mm, with *L* 4 and *L* 6 the 8th group (1/1300 mm) and with *L* 11 the 9th group (1/1560 mm); these measurements, however, cannot be compared directly with our measurements, as HARTING used widely diverging beams instead of beams of very

slight divergence as were those, used by us. Therefore our measurements gave results for the resolving power, which were about 1,3 times as low as HARTING's results [10]), and taking this into account the agreements must be considered as striking, especially as about a century lies between these two sets of measurements.

In fig. 3 our results are plotted in the graphs published in the Desc. Cat. page 8 [11]). In these graphs the horizontal line gives the theoretical limit

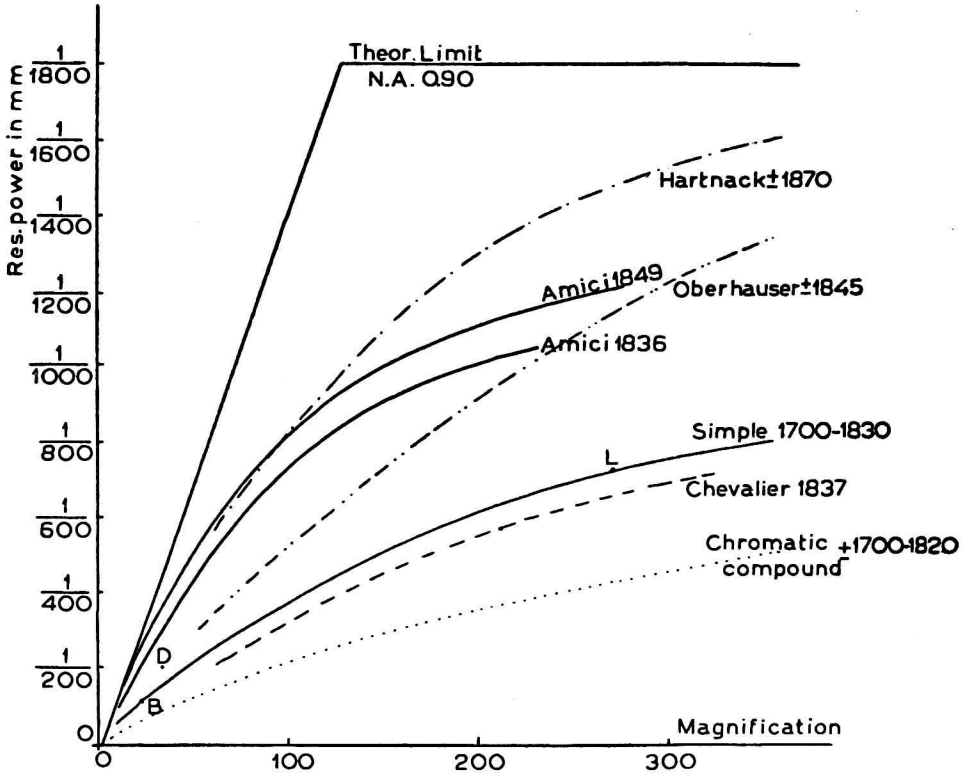

Fig. 3.

for $N.A. = 0{,}9$ and $\lambda = 5000$ Å. The construction of the slanting line is based on the experimental fact that the angular distance of two points must be at least $1'$ in order to be seen separately. How in the course of time these limits have been more and more approximated is clearly to be seen. The single microscopes and also the chromatic compound microscopes have been considered as a group. The points L for the VAN LEEUWENHOEK microscope and D for the VAN DEYL microscopes have been indicated separately (see Desc. Cat. l.c.). This figure shows very clearly how till about 1830 the resolving powers of the compound microscopes fall short by a long way of those of the single microscopes. This was no longer the

[10]) P. H. VAN CITTERT, Proc. Kon. Akad. v. Wetensch., Amsterdam, **39**, 182 (1936).
[11]) See also Ned. Tijds. v. Nat. 2, 51 (1935).

case when achromatic objectives were made successfully. Yet it is a fact that the VAN LEEUWENHOEK microscope, dated about 1700, is superior to an achromatic microscope made by CHEVALIER in 1837. The lines AMICI 1836 (microscope B) and AMICI 1849 (microscope C) indicate the very large progress, due to AMICI. Whereas HARTING remarks that the AMICI microscope 1849 (C) surpasses the OBERHÄUSER microscope (1845), our measurements show that this is, at least for the lesser magnifications, even the case with the AMICI microscope 1836.

To be sure the work of AMICI has indeed improved the optical power of the microscope by leaps and bounds!