A Note on Nelson’s term ‘Optical Index’

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In the last issue of the Proceedings, Cyclops (1998) mentioned an objective with an initial magnification of 40 and a numerical aperture of 1.0 and said “The high value of what old E. M. Nelson called ‘optical index’ is of the utmost value in fluorescence work, where every single ray of light is valuable ….” When the term was introduced at the end of the last century, it was not regarded as relevant to the context of maximum available light but as an important factor in the evaluation of objectives intended for the exploration of fine detail in objects such as diatom frustules. To many microscopists today, however, used to considering objective resolution solely in terms of numerical aperture, the term optical index is not familiar.

What, then, is optical index, a term introduced by E. M. Nelson in 1893? He defined it as “the N.A. of the objective multiplied by 1000 and divided by the initial magnifying power of the objective”. This shows the efficiency of the objective solely from an optical standpoint; it can therefore be called the ‘Optical Index’, or ‘O.I.’. Nelson intended the O.I. to be used as an aid to the comparison of objectives in terms of their ratio of aperture to magnifying power. In other optical systems such as camera lenses and telescopes it is common for this comparison to be made in terms of the ratio of aperture to focal length. Nelson did not adopt this for microscope objectives, however, because although the foci of telescope and camera lenses are easily and accurately measured, this is not so for microscope objectives, where it is the power and not the focus which can be easily determined. The magnification of an objective may be measured directly but it is of course also given by the expression

\[
\text{tube length} \\
\text{focal length}
\]

both being measured in the same units. In his original article Nelson goes on:

If a Microscope is required to show all that a keen eye is able to appreciate then .26 N.A. must be given to it for every 100 diameters of magnification. If we limit the power of the eyepiece of such a Microscope to 10 then the objective must have .26 N.A. for each 10 diameters of initial magnifying power. The optical index therefore for a theoretically perfect Microscope objective will be 26.0.

In his book Critical Microscopy, A. C. Coles (1921) lists the O.I.s of some objectives then current. He mentions the Zeiss 24mm apochromatic of N.A. 0.3 and magnifying power of 10, which had an O.I. of 30, whilst the Zeiss 12mm apo with a N.A. of 0.65 and a power of 21 had an optical index of 31. Coles contrasts these figures with those for an old unnamed water immersion objective which had a N.A. of 1.1 and a focal length of \(\frac{1}{50}\)th inch. Calculation shows that the magnification of this objective would be about 550, so its optical index worked out at 21! Coles goes on to say:

The value of these figures will be apparent when we remember that any lens used with a 10-power eyepiece must have an O.I. of 26 to resolve all the detail visible to a keen eye. The optical index, therefore, tells us that the \(\frac{1}{50}\)th water immersion of 1.1 N.A. had a vast amount of empty magnifying power, while on the other hand, the 24 and 12mm will both stand a higher power eyepiece than 10, may even require it before the detail resolved by them is made visible to the eye.

Coles concludes

As it is more difficult to put aperture into a lens than power, the O.I. becomes also an index of the money value of a lens.

Cyclops is, as usual, absolutely right when he comments that the “40/1.0 is a worthy successor to the legendary 12mm 0.65 NA dry apo of classic memory”. A quick survey of some of my modern objectives (admittedly none specifically designed for fluorescence work) reveals that most have values for their O.I. of between 12 and 16, with two notable exceptions, one English, one Russian. These have rather higher figures, although neither reaches the values attributed by Coles to the two Zeiss apochromatic objectives mentioned above.

References

