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A Correcting Lens for Use in Underwater Photography

by

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INTRODUCTION

Most underwater cameras employ a conventional lens intended for use in air placed behind a plane glass window. The passage of light from water through the window into air refracts the ray away from the normal to the surface. Thus, a lens with a given angular field in air will image a considerably smaller field in water. In addition, the dispersion of water requires that red light be refracted by a smaller angle than blue. The lateral chromatic aberration in the final image resulting from this is small in the center of the field but becomes large enough to cause appreciable loss in definition in the outer parts of the field for lenses having moderately large angular fields of view. Obviously, the image quality can be improved by using color filters to restrict the band of wavelengths reaching the film. Some such filtering is, in fact, accomplished by the water itself. The image quality can also be improved by adding a correcting lens which will compensate for the dispersion of water. There are various optical systems designed to do this.[1, 2] A very simple correcting lens is described in the next section.

DESIGN OF CORRECTING LENS

The correcting lens consists of a plano-concave flint-glass lens with its concave side cemented to the convex side of a plano-convex crown-glass

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1. A. Ivanoff, Compt. Rend. 232, 1193 (1951); J. Opt. Soc. Am. 41, 645 (1951)

2. W. R. Stamp, Sci. Am. 189, 32 (1953)

lens. The two glasses are chosen to have approximately the same mean index of refraction but markedly different dispersions. This arrangement provides a lens of essentially zero power which does not affect the focus of the main camera lens but which does provide dispersion to balance that of water. The amount of dispersion introduced by a given correcting lens for light passing through the entrance pupil of the camera lens at a particular angle increases as the correcting lens is moved away from the camera lens making the light pass through regions of the corrector which are further from its center. Thus, the position of the correcting lens can be chosen to give an exact correction for rays at one particular angle. With this done for a ray near the edge of the field, the correction for all other rays is found to be entirely satisfactory.

The dispersion at a water-to-air surface, calculated with the formula

$$\Delta \phi_a \cong \tan \phi_a \frac{\Delta n}{n} \quad \text{(radians)}$$

where ϕ_a is the angle in air, $\Delta \phi_a$ is the difference in angle for two wavelengths having a difference in refractive index in water, Δn, and n is the refractive index of water for an intermediate wavelength, is tabulated below. The numerical values used are: $n = n_D = 1.3330$ and

$\Delta n = n_F - n_C = 0.00599$

ϕ_a	$\Delta \phi_a$
10°	0.8×10^{-3} radians
20	1.6
30	2.6

The dispersion produced by the correcting lens can be calculated by tracing rays through its three surfaces for two wavelenghs and taking the difference or by calculating the approximate difference directly with the formula

$$\Delta\phi' \cong \left[\cos\phi_3 \tan\phi_2' - \sin\phi_3\right]\left(\frac{\Delta n_1 - \Delta n_3}{\cos\phi_3'}\right) \text{ radians}$$

where the light is considered to come from the water side and pass through the surfaces 1, 2, and 3 with the ray making angles with the surface normals indicated by the ϕ's, each unprimed angle being in the object space and each primed angle being in the image space. Δn_1 is $n_F - n_C$ for the first element of the lens and Δn_3 the corresponding quantity for the second element. Using Jena glass F-6 with n_C = 1.63090, n_D = 1.63616, and n_F = 1.64882 and SK-18 with n_C = 1.63582, n_D = 1.63929, and n_F = 1.64729 one obtains with suitable dimensions:

ϕ_3'	$\Delta\phi_3'$	
10°	0.8×10^{-3}	radians
20	1.6	
30	2.6	

It is apparent that the values obtained here are very close to those calculated for the water-to-air surface. As the directions are reversed, one can be used to balance the other.

It can be seen from the optical data for the glasses that the lens will have zero power for the central part of the spectrum and positive and negative powers at the ends. The radius of the surface between the two elements of the lens is chosen sufficiently large to make these powers small enough to avoid the introduction of appreciable longitudinal chromatic aberration in the final image. With a lens having a large radius for the surface between the elements, the distance from the correcting lens to the entrance pupil of the main camera lens and the diameter of the correcting lens both become large. As a large window in the camera housing is undesirable for cameras to be used at great depths, it has been found wise to mount the correcting lens in water in front of the window rather than in air behind it.

EXPERIMENTAL RESULTS

Visual examination of the images of a resolving power chart formed with the correcting lens in front of a good camera lens showed great improvement in the region from 10° to 23° from the axis in water. Photographic tests in the laboratory showed less striking but definite improvement in this region. Tests at sea remain to be made.