A Manual of Underwater Photography

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1977

Academic Press
London New York San Francisco
A Subsidiary of Harcourt Brace Jovanovich, Publishers

ACADEMIC PRESS INC. (LONDON) LTD
24–28 Oval Road
LONDON NW 1

U.S. Edition published by
ACADEMIC PRESS INC.
111 Fifth Avenue,
New York, New York 10003

Library of Congress Catalog Card Number: 76–016967
ISBN: 0 12 286750 5

Text set in 11/12 pt Monotype Baskerville, printed by letterpress, in Great Britain at The Pitman Press, Bath

Preface

The search for oil and gas, the looming food shortage, treasure wrecks and almost daily television coverage all underline the fascination and importance of the sea. Despite this upsurge of interest, only a tiny proportion of the population has the capability, or indeed the inclination, to clamber into diving apparatus and enter the uncomfortable, treacherous but often beautiful underwater environment.

The minority of divers must somehow transfer the information they gain at first hand to the majority who keep themselves dry. More than that, a diver's memory and perception can be impaired by the physiological and psychological stresses of diving and he needs to be able to transfer information from himself as a rather stupid aquatic animal, to himself as a much more intelligent terrestrial one.

Photography is perhaps the most important method of information transfer. For the scientist and engineer it provides an immense amount of unbiased information. For the artistic photographer it allows his own vision of the underwater scene to be conveyed to others who may have never seen it for themselves.

The underwater photographer must have some basic competence in both photography and diving, but the beginner need possess neither to a very high order. Diving skills are important but they improve wonderfully after a few hours spent in the water with a camera. Photographic skills progress less swiftly because it is all too easy to blame poor results on the water conditions. A skilled surface photographer has a great advantage here because he can tell much more easily what results he should expect and how to change his techniques accordingly.

The main problems when taking underwater photographs come naturally enough from the physical and optical nature of the water itself. The first need is to keep the camera mechanism dry. Many methods to achieve this have been tried; some are reliable, some cumbersome and some result in a flooded camera. There is now enough accumulated experience to recognize the best methods and these are described in detail.

The most difficult problems come from the optical properties of the water itself. Water acts as a colour filter and steps may have to be taken to restore the colour balance. Most troublesome of all are the light-scattering properties of water which cause loss of definition and contrast in the negative. Techniques that improve matters are described, but these problems are likely to remain with us for a very long time.

The commercial sale of underwater equipment is not yet enough for the manufacturers to spend the time and money on development that the land photographer takes for granted. Technical problems have thus to be solved by the photographers themselves who must have an intelligent understanding of the problems he will meet. For this reason, Chapter 1 contains an account of the relevant optical characteristics of natural water. There is also a brief account of the human visual mechanisms which, being designed to function in air, can give severely misleading information underwater.

Underwater camera systems are generally less flexible than we have come to expect on land. Commercial cameras are available for most normal purposes, although often at a price that puts them beyond most budgets. In Chapter 2 we have described examples of the camera systems presently available and the type of task they can be expected to perform. There has been no attempt to describe all the types available for such a catalogue would be out of date even before it was published. Instead we have described some of the systems that have proved themselves in use or have important technical features.

As an alternative approach, Chapter 3 is concerned with building a waterproof case around an existing camera. The techniques have been described in considerable detail since the information is not available elsewhere. We also hope that this chapter will benefit those who want to use other kinds of apparatus under water and need a dry housing to put it in.

The other chapters need no explanation. We have tried to give a straightforward account of the equipment and techniques needed to take underwater photographs of a professional standard. This is not intended to be a textbook in physics or mechanics, and mathematics have been kept to the minimum. Equally, this book is not concerned with aesthetics; we have sometimes pointed to aesthetic questions that arise, but we have not burdened the text with our own artistic opinions.

November 1976

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1 Problems of Underwater Photography

INTRODUCTION

Much has been written about the difficulties of taking photographs underwater. This book is no exception. Nevertheless, we should say at the very outset that many of these problems have a solution. Indeed, the quality of a photograph actually taken underwater often excels that taken of the same subject in an aquarium.

Underwater scenery has no counterpart on land. The colour and distribution of the underwater light is quite different, whilst the delicate structure of many underwater plants and animals could not exist unless supported by the surrounding water.

Water is many times heavier than air and, indeed, 10 metres of water exerts a pressure equal to that of the entire depth of atmosphere above our planet. As the diver goes deeper, so the pressure increases until at 30 or 40 metres, which is quite a moderate depth for a diver, the pressure inside him equals that in a fully inflated car tyre. This pressure by itself is not dangerous, but the change in gas volume that accompanies it can be. If the pressure inside and outside the diver is free to equalize itself there is no change in volume and no damage is done. However, if the pressure-relief route is blocked the isolated gas space will contract as the diver swims down or expand as he swims up, causing the body's tissues to rupture.

Techniques and schedules to make diving safe are well known and if they are observed diving is no more dangerous than driving a car. Nevertheless, underwater photography is a demanding skill and the diving photographer has to divert his attention away from his diving to his photography. In shallow water this causes no great risk, but at depths in excess of about 30 metres, and certainly at depths exceeding 60 metres, a dangerous situation can build up very suddenly.

Nitrogen narcosis begins to be measurable at about 30 metres and is well in evidence at 40 metres. A definite effort of will is needed to concentrate upon a particular task and all other thoughts are pushed to the back of the mind. A diver may feel that he is unaffected by narcosis because he is able to carry out instructions given him at the surface; but he does not realize that his judgment and his ability to make sensible decisions are much worse. The desire to take just one more picture of a wreck or a fish will override his awareness so that he has scarcely sufficient time to decompress on the air available. Indeed, he may attempt to recalculate his air reserves, reach a different conclusion each time, accept the most favourable, and carry on with his photography. In fact, diving photographers do not have a particularly high accident rate. We tend to attribute this more to the better photographic conditions at moderate depths than to any superior judgment, responsibility and diving skill.

Unlike the diver the camera does not suffer from narcosis and works as well at the bottom of the sea as at the surface. Provided the diver manages to set the camera correctly (it can be pre-set in shallower water) the resulting picture will yield comparable information at any depth. Once processed it can be examined at leisure and in comfort. The amount of information that it is possible for a single negative to store is surprising; details which are unnoticed or are dismissed as irrelevant by the diver may be vitally informative to an expert at the surface.

One would expect that a serious problem in case design would be that the high outside pressure tends to force water in through minute imperfections in the camera housing. Pressure does indeed create a problem in that the case has to be sufficiently strong to resist it—however, a properly constructed seal will only close more tightly when under pressure. In practice, cases almost never flood at depth and it is in the surface waters when seals are closed more loosely that accidents are most likely to occur.

Although the mechanical problems connected with pressure and waterproofing are not difficult to solve, those connected with the optical nature of the water itself are less easy. One class of optical problem deriving from the different refractive power of air and water could be largely solved if the market in underwater cameras was large enough to make research and development economically worthwhile for the photographic equipment manufacturers. The problem of degradation of colour and contrast by the water itself are more difficult. Because so little basic work has been done by the manufacturer, the underwater photographer must do much of his own research and development. It is to enable this to be done most effectively that the following sections on the optics of natural water have been written.

BEHAVIOUR OF LIGHT UNDERWATER

The land photographer may benefit from knowing something about the light entering his camera lens; but in truth the benefit is not great. The underwater photographer cannot afford the luxury of ignorance because the behaviour of the light underwater fundamentally affects the appearance of his work. The problems are made worse because he cannot believe the evidence of his own eyes which are designed to function on land and may give him misleading information in the different light climate underwater.

Attenuation of Light

Eventually most divers swim in water so dark that the only light is from a torch. The torch beam is usually clearly visible in exactly the same way as a torch beam is visible on a foggy night on land.

The path of the beam is made visible by the light scattered out of its path by the tiny suspended particles in the water and, indeed, by the water molecules themselves. The brightness of the beam decreases as it penetrates the water, partly because light is lost by scattering (Fig. 1.2). An important further loss is due to absorption by the water when the light is converted into other forms of energy, principally heat.

After the torch beam has penetrated a certain distance through the water (e.g. 1 m) it will be reduced to 10% of its original value. In the next metre that remaining 10% will itself be reduced to 10% so that after 2 m only 1% of the original light will remain; after 3 m only 0·1% will remain, and so on.

Those who are used to the photographic stop scale may prefer to think in terms over which the brightness is reduced to 50% (equals 1 stop), then to 25%, then to 12·5%, etc. Of course, this beam will be reduced by 50% in only 0·3 m compared to the 1 m it must travel to be reduced to 10%.

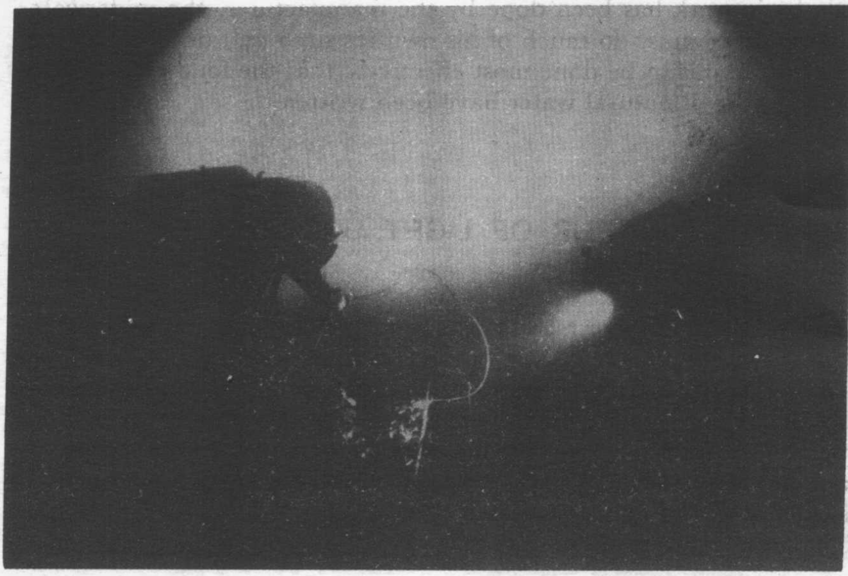

Fig. 1.1 Light scattered out of a light beam by suspended particles in the water. Depth 10 m Ektachrome X 1/16; *f* 5·6; Nikonos with Vizmaster fish-eye lens.

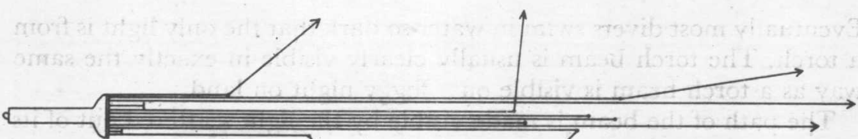

Fig. 1.2 Light from a torch beam is reduced in intensity partly by absorption and partly by light being scattered out of its path by particles in the water.

Scales such as 100, 10, 1, 1/10, 1/100 (or $10^2, 10^1, 10^0, 10^{-1}, 10^{-2}$) and 8, 4, 2, 1, 1/2, 1/4, 1/8 (or $2^3, 2^2, 2^1, 2^0, 2^{-1}, 2^{-2}$) are called logarithmic. When light is reduced to 1/10 its value by some means it is said to have been reduced by one log unit. A filter reducing light by this amount (i.e. by 90%) is said to have an optical density of 1. A filter reducing light by 2 log units has an optical density of 2, and reduces the light by 99% of its original value. It is interesting to note that what appears to be an equal brightness interval scale is, in fact, a logarithmic scale. This can be demonstrated by taking several glasses of water and mixing one drop of ink into the first, two in the second, four in the third, eight in

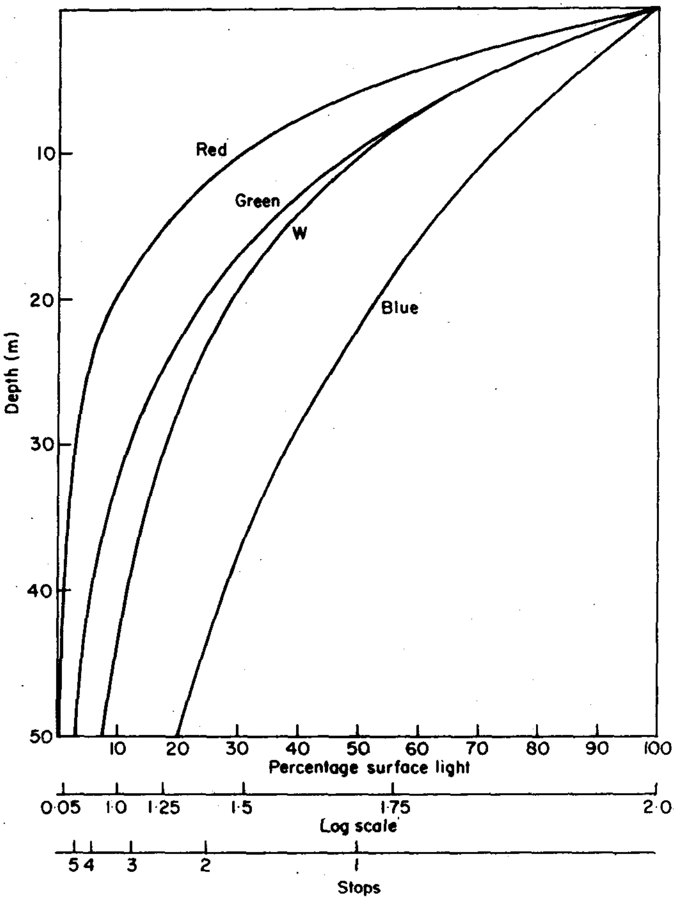

Fig. 1.3a The reduction in intensity of daylight as it penetrates into clear blue (Gulf Stream) water. Three wavelengths are considered 435 nm (blue), 532 nm (green) and 576 nm (red). The curve, W, is the calculated reduction of white light (mean of blue, green and red). This figure is calculated in equal steps in the reduction of light energy. 100% is the light energy just beneath the surface. Also shown for comparison are scales calculated in photographic stops and in log units (log scale).

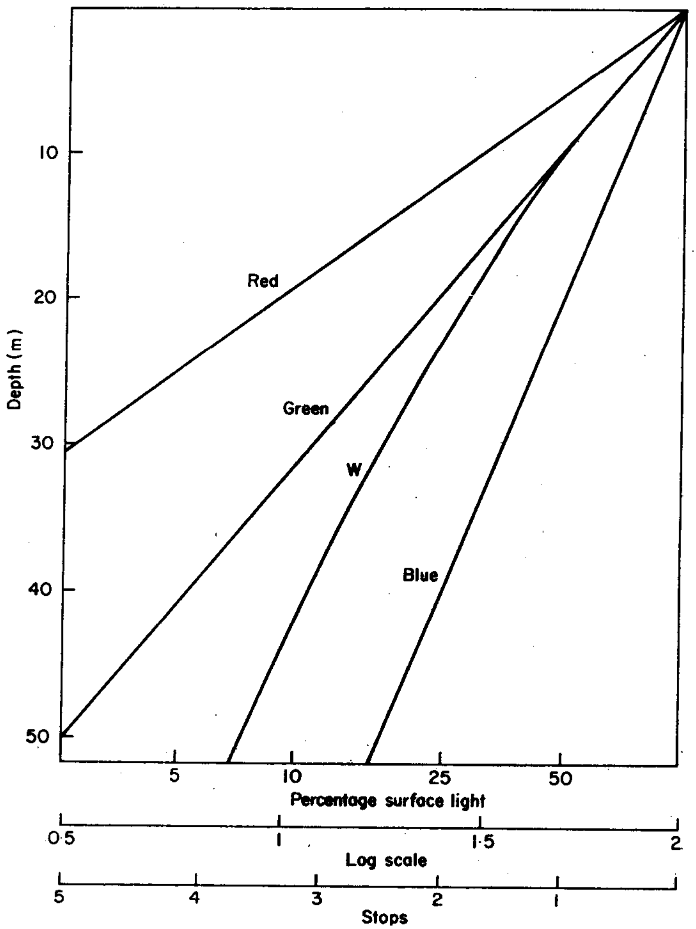

Fig. 1.3b Contains the same information as Fig. 3a but the reduction in light intensity is in equally-spaced photographic stops. Note that the log scale is also in equal steps, but the percentage surface light scale is not. The reduction of red, green and blue light are straight lines in this type of plot but the reduction of white light is not. This is because at the surface red light contributes one third of the "white" light, but below about 30 m its contribution is negligible. In about the surface 10 m daylight reduces at about 1 stop for each 10 m; below about 30 m it reduces at 1 stop for each 20 m—see p. 14 for a comparison with coastal water. (Data from Tyler & Smith, 1970.)

the fourth, etc. The concentration of ink in the glasses will increase logarithmically but each glass will seem to make an equal step scale.

As the beam travels through the water it assumes a blue colour. Although pure water absorbs all wavelengths of light, short wavelength (blue) light is not absorbed as rapidly as other wavelengths. Long wavelength (red) light is absorbed particularly swiftly and a 25 m thickness of water will have absorbed virtually all the red light. In practice, water is never pure and the effect of the impurities on the colour of the water will be considered on p. 15.

Refraction

Anyone who has dived with a torch will have noticed that the torch beam is different in shape underwater than in air. If the torch is constructed to make a divergent beam in air and the glass is flat, that beam will become much more condensed underwater.

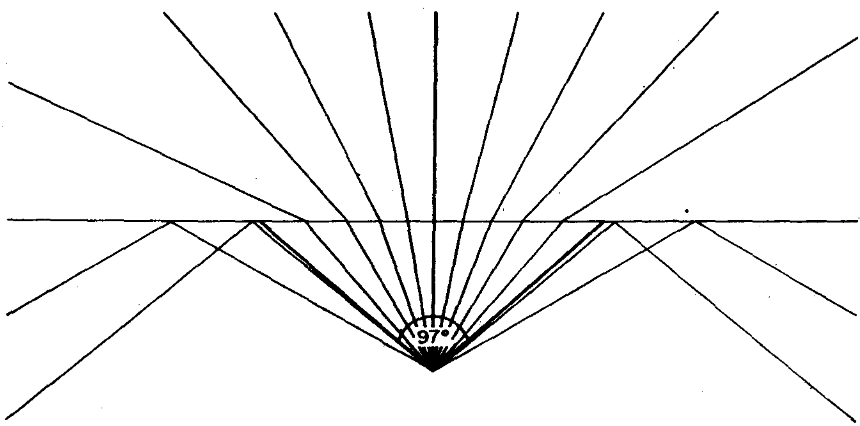

Fig. 1.4 Snell's window. A diver sees the entire hemisphere above the water compressed into a cone that subtends a solid angle of 97°.

When light passes from a medium of low refractive index (air) into one of higher refractive index (water) its velocity is retarded. If the light passes at right angles through the air–water boundary, it does not change in direction; but if it strikes the boundary at an angle, there is change (Fig. 1.4). The refractive index n represents the ratio of the velocity of light in a vacuum to the velocity of light in the medium. For all practical purposes the velocity of light in air is the same as that in a vacuum and so the refractive index of air is 1. The refractive index of water does vary according to its density but is usually taken as 1·33.

The relationship between the angle of incidence θ in the one medium of refractive index n and the angle of refraction θ' in the second medium of refractive index n' is

$$n \sin \theta = n' \sin \theta' \quad (1)$$

This is known as Snell's law and has considerable practical consequences in the distribution of underwater light, the design of lens systems and underwater vision (see Chapter 4).

The amount of light scattered also depends upon its wavelength provided that the scattering particles are very small (of the order of the wavelength of light). In this case, the scattering is proportional to the frequency (1/wavelength) of the light. Thus blue light is the most strongly scattered, red light the least. This explains the blueness of sky, and in part the blueness of water. When the particles are the size of plankton or sand grains all wavelengths of light are scattered about equally.

From the underwater photographer's point of view, molecular scattering is somewhat less important than scattering from larger particles since it is only in very clear water that it becomes important. Scattering from larger particles is, however, of crucial importance and will be discussed in later sections.

Polarized Light

Light behaves as though it is a hail of energy particles (called photons) that are carried along a wave motion. The energy particles travel through space at the speed of light but the light wave that carries them vibrates at right angles to the direction of travel. This vibration can be divided into two components. One is known as the electric vector and the other, which vibrates at right angles to it, is the magnetic vector and corresponds to the plane of polarized light. In unpolarized light there is no preferred plane of vibration, but when the light is plane polarized, there is an overall oscillation in one plane for the electric vectors and in a plane at 90° to it for the magnetic vector.

Light reflected from very small particles, of the order of the wavelength of light in size, is plane polarized as well as being coloured blue. Thus the light from the torch beam will be plane polarized, the plane being at right angles to the direction of the beam. Plane-polarized light is only a special case of elliptically-polarized light. Another extreme case