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# Light Transmission through Snow and Ice

R. James Maguire



**TECHNICAL BULLETIN NO. 91**  
*(Résumé en français)*

INLAND WATERS DIRECTORATE,  
C C I W BRANCH,  
BURLINGTON, ONTARIO, 1975.

J. C. ANDERSON



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## **Abstract**

The transmission of photosynthetically active radiation (400–700 nm) by snow and ice has been examined and extinction coefficients have been determined for clear ice, cloudy ice, soft new snow and hard powder snow. These values have been used to predict, to a satisfactory degree, the transmission of light by snow-ice systems of varying composition and thickness.

## **Résumé**

L'auteur a étudié la transmission, à travers la neige et la glace, des radiations photosynthétiques (de 400 à 700 nm) et a déterminé les coefficients d'absorption de la glace transparente, de la glace translucide, de la neige légère récemment tombée, et de la neige dure et poudreuse. Il a utilisé ces données pour prévoir, de façon satisfaisante, la transmission de la lumière à travers des complexes neige-glace de composition et d'épaisseur variables.

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## INTRODUCTION

One of the first important observations made with regard to ice-covered lakes was that they occasionally suffered a drastic decrease in the concentration of dissolved oxygen, so that the water was foul and fish-kills were reported. Drown (1892) noted that ice cover prevents the wind from supplying oxygen to the water and that in general the exclusion of air from the water is followed by a diminution of the concentration of dissolved oxygen in direct proportion to the amount of decomposable organic matter present. This problem is only one of the general considerations of winter photosynthetic and respiration rates for entire lake communities, about which relatively little is known. Croxton, Thurman and Shiffer (1937) were among the first to investigate the suggestion that the decrease in oxygen concentrations may be in part due to an attenuation of light by the ice and snow cover, with a resulting reduction in the extent of photosynthesis. Their light measurements under ice indicated that sufficient light penetrates ice to permit photosynthetic activities of most water plants, but where the ice is covered by a layer of snow, it is doubtful whether the illumination would be adequate. Support for this conclusion is given by the figures of Greenbank (1945) for the amount of penetration of light through snow and ice cover; these figures are such small fractions of the amounts proposed as general aquatic plant compensation intensities that it seems almost certain that such small amounts of light could not maintain a favourable balance of photosynthesis over respiration and decay. On the other hand, it appears that the amount of light which penetrates even 0.5-1 m of moderately clear ice, with no snow cover, is enough to satisfy the requirement for photosynthesis (Wright, 1964; Halsey, 1968; Schindler, 1971, 1972; Maeda and Ichimura, 1973).

In general it appears from the literature that most photosynthetic activity would stop with more than 20 cm of snow on clear ice, or less snow if the ice is cloudy. Many articles on this subject report only the effects of a combined ice and snow cover on light transmission, so that it is sometimes difficult to differentiate the effects of ice alone from those of snow alone; many results are based on only two points: the initial intensity of light penetrating a medium and the intensity at a certain thickness. This has

led to a wide range in values of extinction coefficients; indeed, the validity of the application of the Lambert-Beer law to media such as snow and ice has been questioned (Shishokin, 1969). The objective of this study was to separate the contributions to the overall light extinction coefficient of media such as soft new snow, hard powder snow, cloudy ice (numerous air bubbles), and clear ice (no air bubbles). The extinction coefficients were determined for photosynthetically active radiation (400-700 nm), which is a more suitable parameter in photosynthetic considerations than determinations based on total radiation. The validity of the Lambert-Beer law was confirmed and individual values for the extinction coefficients for various media were used with success in predicting the transmission of photosynthetically active radiation (PAR) through snow-ice systems of varying composition and thickness. This work is a first step toward developing a relationship between the amount and kind of ice and snow cover on a lake and the oxygen concentration; such a relationship requires knowledge of winter photosynthetic and respiration rates for entire lake communities.

## METHODS

From December 1974 to April 1975, experiments were performed on the ice of the Ottawa River at Shirleys Bay, Ontario, and Dunrobin, Ontario, and on the ice of some artificial ponds filled with river water.

Light meters and sensors were obtained from Lambda Instruments, Lincoln, Nebraska, calibrated against a standard light source traceable to United States National Bureau of Standards sources, and corrected for a cosine error of less than 2% from 0° to 82° angle of incidence. The temperature dependence of the signal from the sensors was negligible ( $\pm 0.15\%$ /°C maximum). Although experiments were performed both with pyranometers and quantum (400-700 nm) sensors, the results reported here are only in terms of PAR. The quantum sensors have a wavelength of average energy of 510 nm; Figure 1 shows the spectral response of one of the underwater quantum sensors. Sun plus sky quantum flux measurements at solar noon are typically 230-350 watt m<sup>-2</sup>. It is of course realized that the photosynthetic apparatus is in general more sensitive to two spectral bands within the range of

400-700 nm rather than the whole spectral region; the use of sensors of this type, however, represents an improvement over the use of broad spectrum sensors.

Three kinds of experiments were performed. In one kind, holes were cut in the ice, the sensors were placed under the ice in a vertical ( $\pm 5^\circ$ ) position by means of twine and a harness of foam rubber, and the ice in the holes was allowed to form again over a period of two to three weeks prior to making light measurements. No algal growth on the sensors was observed, even after they had been in the water for two months. In the second kind of experiment, holes were cut in the ice and light measurements were taken immediately, with a large black cloth over the hole employed to eliminate the possibility of sunlight entering the water through the hole. In both kinds of experiments the results were compatible, indicating that within experimental error the black cloth was effective in preventing light penetration of the hole and that the refrozen ice in the hole was substantially the same as the

surrounding ice. For work with snow, the sensors were placed in a vertical ( $\pm 5^\circ$ ) position during periods of snowfall. Placing snow on the sensors by hand results in lower light intensities, presumably on account of packing of the snow. Values for  $I_0$ , the intensity of light initially penetrating a medium, were obtained by measuring the intensity of light which passed through a thin section of the medium in question, usually with another light sensor which was calibrated against the sensors used to determine the light intensity,  $I$ , as a function of thickness of the medium.

Light measurements were made in many different places at the locations mentioned and under a variety of conditions of medium composition and thickness. In these experiments, results are reported for Ottawa River water, clear ice, cloudy ice, soft new snow and hard powder snow (the media were free of soot and dirt). Particularly in the cases of the latter three media, it is realized that the adjectives used in the descriptions are only qualitative. No

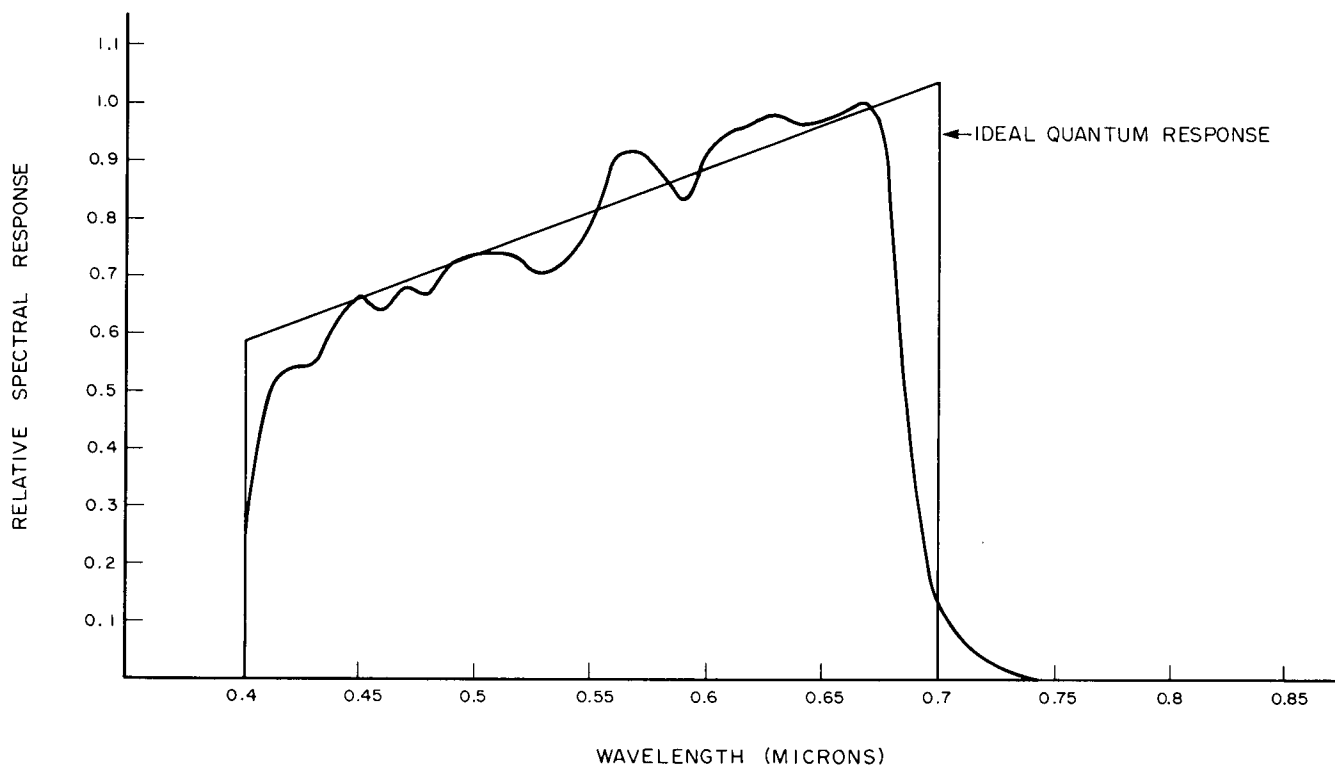
LAMBDA INSTRUMENTS CORP.

RELATIVE SPECTRAL RESPONSE

CALIBRATION DATE 6-26-74

SENSOR TYPE LI-192S-A

SERIAL No. UWQ262-0674



PEAK ABSOLUTE SENSITIVITY =  $0.032 \mu\text{A} / \text{WATT M}^{-2}$  @ 0.670 MICRONS

Figure 1. Spectral response of Lambda underwater quantum sensor.



Table 1. Extinction Coefficients for Ice and Snow

Medium	k (cm <sup>-1</sup> )	Radiation (nm)	Reference
Ottawa River water	0.015	400-700	this work
Clear ice	0.02 ± 0.003	400-700	this work
Clear ice	0.025	total	I.N. Sokolov, in Shishokin (1969)
Cloudy ice	0.20 ± 0.03	400-700	this work
Cloudy ice	0.15	total	I.N. Sokolov, in Shishokin (1969)
Soft new snow	0.10 ± 0.02	400-700	this work
Soft new snow	0.11	total	Gerdel (1948)
Hard powder snow	0.50 ± 0.05	400-700	this work
Hard powder snow	0.27 - 0.45	total	Thomas (1962-63)

attempt was made to describe these media in more quantitative fashion, e.g., percentage of bubbles of a certain size in cloudy ice or snow density or snow grain size, and although they represent the most common conditions found on the Ottawa River at that time, these are not the only snow or ice conditions found in lakes and rivers. The results of the light penetration experiments, however, do establish definite differences in the extinction coefficients for the various media.

## RESULTS AND DISCUSSION

Plots of  $\log(I/I_0)$  vs thickness for all media were linear to 1% transmittance or less, confirming the validity of the Lambert-Beer law for the transmission of PAR through snow and ice. Values for the extinction coefficient were obtained either by experiments on the pure medium or on a system in which the extinction coefficients of the other components were known. In such cases there was good agreement between the values obtained both ways. This indicates that within experimental error the following relationship holds:

$$k_t I_t = \sum_i k_i I_i$$

where  $k_t$  and  $I_t$  are the overall extinction coefficient and overall thickness of a composite medium, respectively, and the  $i$ 's represent the individual states, such as clear ice

and powder snow, etc. Also it appears that any effects of back-reflection at interfaces between different media are not significant, within experimental error. Every extinction coefficient is the average of 10 values, each of which is obtained from a plot of  $\log(I/I_0)$  for about 15-20 thicknesses or depths. The values of the extinction coefficients obtained using the quantum sensors in the range of 400-700 nm are listed in Table 1 with some comparative values from the literature which were obtained by pyranometer. Powder snow and cloudy ice are most effective in absorbing PAR. There appears to be no substantial difference between values of  $k$  determined for PAR and those determined for total radiation. Other observations made are that dirt, soot, granular condition, and wetness are all factors that tend to diminish PAR transmission through snow. Granular snow permitted the least transmission of PAR, clean, but wet, snow allowed a greater transmission, and clean and fresh snow the greatest.

The values of the extinction coefficients were tested for their accuracy in predictions of the amount of PAR transmitted through various snow-ice compositions and thicknesses, on the Ottawa River and on artificial ponds containing river water. The agreement between predicted values of PAR intensity and observed values was in general good. For example, under 30 cm soft new snow, 5 cm powder snow, 15 cm cloudy ice, 20 cm clear ice, and 41 cm water in one of the ponds, the predicted and observed PAR intensities were  $4.7 \times 10^{-3}$  and

$7.0 \times 10^{-3}$  watt  $m^{-2}$ , respectively, and under river ice of composition 10 cm soft new snow, 5 cm cloudy ice, and 30 cm clear ice, the predicted and observed PAR intensities were  $3.81 \times 10^{-1}$  and  $4.30 \times 10^{-1}$  watt  $m^{-2}$ , respectively.

Table 2. Compensation Depth and Thicknesses<sup>1</sup>

Medium	Compensation thickness (cm)
Ottawa River water	300
Clear ice	250
Cloudy ice	25
Soft new snow	50
Hard powder snow	10

<sup>1</sup> Assumed  $I_0 = 70$  and  $I$  (compensation intensity) =  $4.45 \times 10^{-1}$  watt  $m^{-2}$

Gibbs (1962) has given a value for the compensation intensity of *Chlorella pyrenoidosa* of  $4.45 \times 10^{-1}$  watt  $m^{-2}$ . That this value is a reasonable assumption for a compensation intensity in our systems is borne out by primary productivity studies on the ponds which indicate a substantial increase in the uptake of  $H^{14}CO_3$  when the PAR exceeds this amount (D. Shindler, personal communication). Using this value as a lower limit, and making the reasonable assumption that  $I_0 = 70$  watt  $m^{-2}$ , we obtain the values for the compensation depth or thickness shown in Table 2. It appears that as little as 10 cm of powder snow on clear ice, or less snow if the ice is cloudy, effectively inhibits net photosynthesis.

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