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ST. ANDREWS, N.B.

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G. O. LANGSTROTH

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MANUSCRIPT REPORTS OF THE EXPERIMENTAL STATIONS

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On the Rate of Freezing of Fish Muscle. II

By G.O. Langstroth

Abstract.

The time of freezing of various thicknesses of Haddock ranging from 0.78 cm. to 2.31 cm. with bath temperatures of from -7.1 to -15.3°C. is determined. The values of the conductivity calculated from an equation developed in a previous paper are found to be constant within the limit of experimental error, thus indicating that the theoretical equation gives correct results under experimental conditions. The values of the constants in the freezing equation are also given for several other species of fish.

The problem of the rate of freezing of fish muscle has been treated by means of a one dimensional Fourier analysis* with the assumption that the muscle while not in the actual process of freezing is a homogeneous medium. A first approximation equation is of the form

$$t = \epsilon^2 L \rho / 2k \, (T-\theta)$$

where t is the time of freezing, ϵ is the thickness frozen, ρ is the density, T is the temperature of the bath, θ is the freezing point of the fish, and L and k are the latent heat and the conductivity respectively. All constants refer to the fish in the frozen state. It was the purpose of this work to investigate whether this analysis could be applied to actual experimental conditions with sufficient accuracy to warrant its use, and if so, to determine the necessary constants so that knowing the thickness of the fish to be frozen and the bath temperature the time of freezing could be calculated.

The method of measurement of the time of freezing consisted in determining the temperature of a small plate in thermal contact with the fish muscle, which in turn was in contact with a plate at a constant low temperature. By taking the temperature at intervals it was possible to follow the history of the layer of fish farthest from the freezing plate and hence to determine the time of freezing of the whole thickness of fish.

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* Langstroth.....Trans. N.S. Inst. Sci. - 1929.

The apparatus was as shown in Fig.1. The constant temperature bath A was of six gallon capacity. The cooling agent was a water-ice-NaCl or a water-ice-CaCl solution. Stirring was accomplished by means of two motor driven propellors. The cylindrical container B whose bottom served as a cold temperature plate, was removable from the bath. It was about ten centimetres in diameter. The thermocouple plate C was about two centimetres square and the constantin-copper thermocouple was soldered directly to the back of it. A sample of fish about six centimetres square was placed on the cold plate so that it did not touch the sides of the container. The thermocouple plate was placed on top of this and was held in place at constant pressure by the spring D. The top of the container was then packed loosely with wool so that the sample was surrounded by a dead air space on all sides excepting that against the freezing plate. The temperature of the bath was read from a thermometer inserted directly in it.

The sample was kept in the container in a crushed ice bath to insure a standard initial condition of the fish. At a noted time the container was introduced to the freezing bath and the temperature of the thermocouple plate was read at intervals of two minutes. The thickness of the fish was measured with a centimetre rule directly on its removal from the bath.

The readings of the temperature of the thermocouple plate in terms of microvolts were plotted against the time and gave curves such as that in Fig.2. The ordinate of the point at which the sample began to act as a homogenous medium ---i.e., where the curve becomes nearly a straight line----was taken as the time of freezing. The assumption that the time taken for the fish to cool down to its freezing point is negligible with respect to the time taken to freeze it seems a sound one. Since with the exception of k, the values of the constants in the equation are known**, the value of k can be calculated. This was done for Haddock over a fairly wide range of thicknesses and bath temperatures and the results show k to be constant within the limit of experimental error, although some variation might be expected in consideration of the type of material under investigation. The constancy of k within these limits denotes that the equation may be applied under conditions approximating one dimensional freezing. Such types of freezing as used by the Atlantic Coast Fisheries, Kolbe, and to a lesser extent the Experimental Station at Halifax fall in this class.

** Chipman and Langstroth....Trans. N.S. Inst. Sci...1929.

The results for the work done on Haddock are given in the following table.

Table 1.

Thickness	Bath Temp.	Conductivity	Exp. Time	Cal.Time
1.30	- 7.1	.0023	66.	63.
2.31	- 7.4	.0025	184.	191.
0.78	- 9.1	.0022	20.	18.
1.20	- 9.2	.0023	41.	39.
1.38	-10.5	.0027	40.	45.
1.44	-10.8	.0023	50.	48.
1.18	-10.9	.0025	31.	32.
1.49	-11.9	.0023	50.	48.
1.33	-12.4	.0023	33.	32.
1.72	-14.1	.0025	49.	51.
1.69	-14.8	.0025	46.	48.
1.42	-15.3	.0022	36.	33.

The column headed calculated time is given for comparison with the experimental time. The values are calculated from the theoretical equation using the mean value of the conductivity from column three. The following values were used for Haddock,** L=63 cal/gm., θ = -0.9°C., ρ = 1.06 gm/cc., k = .0024 cal/cm.C°, sec.

Since the evidence indicates that the theoretical equation gives correct results under experimental conditions, the values of the constants were obtained for Cod, Herring, Salmon, Skate and Mackerel. The results are given in the following tables.

Table 2. (Cod)

ϵa	T	k	Exp.Time	Cal.Time
I.28	-10.5	.0023	38.	38.
0.95	-10.2	.0023	23.	23.

The following values for the constants were used,** L=63 cal/gm., θ=-0.9°C., ρ=1.06 gm/cc.

Table 3. (Herring)

ϵ	T	k	Exp.Time	Cal.Time
1.07	-10.2	.0017	29.	29.
0.96	- 9.2	.0018	38.	39.

The following values were used,** L=56 cal/gm., θ=-1.0°C., ρ=1.06 gm/cc.

Table 4. (Skate)

ϵ	T	k	Exp.Time	Cal.Time
0.95	-12.0	.0020	25.	25.
1.13	-10.2	.0021	41.	42.

The following values were used, ** L=60 cal/gm., θ=-1.8°C., ρ=1.10 gm/cc.

Table 5. (Salmon)

ϵ	T	k/L	Exp.Time	Cal.Time
1.32	-12.2	32×10^{-6}	43.	43.
1.70	-15.4	34×10^{-6}	51.	54.
0.87	-11.6	31×10^{-6}	20.	19.

The following constants were used, θ=-0.8°C., ρ=1.06 gm/cc.

Table 6. (Mackerel)

$\epsilon\alpha$	T	k/L	Exp.Time	Cal.Time
0.81	-13.4	26×10^{-6}	18	19
1.08	-12.9	24×10^{-6}	24	25

The following values were used, $\theta = 0.9°C.$, $\rho = 1.07$ gm/cc.

The experimental error of observation causes an error of less than eight percent in the above values of the conductivity. The values check to this degree of accuracy - with one exception - a fact which may seem rather surprising in view of the nature of the material. It is probable that the constants differ for fish caught at different times of the year, but such variations should not be large enough to materially affect the approximate value of the results. The samples used for Haddock were taken from different fish which had passed through widely different handling.

The values given for the conductivity may vary by quite a large amount from the "absolute" conductivity, due to the fact that the initial conditions are only approximately those of the ideal case, and to the large experimental error involved. The value obtained cannot be said to be closer than twelve percent to the value of the absolute conductivity for a single run, although the results allow the time of freezing to be calculated to less than eight percent. It must also be noted that these values are for the conductivity taken as an average value between -7° and -16°C., and that while they can probably be extrapolated to a fairly low temperature they will not hold so accurately at very low temperatures.

It was thought that the conductivity of the dark layer of muscle along the lateral line was less than that of the white muscle, since several runs in which this layer formed part of the sample indicated this fact. Subsequent measurement of the conductivity of the dark muscle however showed that in Haddock there was no detectable difference, and that in Herring the value was only very slightly lower, being two or three percent below the limit of experimental error.

The times for freezing for different thicknesses of Haddock have been plotted in Fig. 3. This has been done for two bath temperatures (-10° and -18°C.) and for freezing from one side and from both sides. The curves are drawn from values calculated from the theoretical equation using the constants which have been given in the first part of this report. The time of freezing under other conditions of temperature and thickness can readily be calculated from the equation itself.

Fig.4 is also given as an illustration of the use of this analysis. Here the additional thickness of fish which is frozen on removal of the sample from the bath before freezing is complete, is plotted against the thickness of fish which has frozen before removal. With high bath temperatures the effect is small but it increases with lowering of the temperature. At a temperature of -78.5°C (solid carbon dioxide) it contributes approximately twenty five percent of the whole effect.

Summary.

The time of freezing of different thicknesses of Haddock muscle with different bath temperatures has been determined, and the values for the conductivity have been calculated from a previously developed equation. These values are constant within the limit of experimental error indicating that the theoretical equation may be applied to experimental freezing to give correct results.

2. The constants in the equation have been determined for several different species of fish.

3. Graphs are given which show the relation between the time of freezing and the thickness for a few cases. Curves are also given for the residual freezing effect investigated in the former analysis.

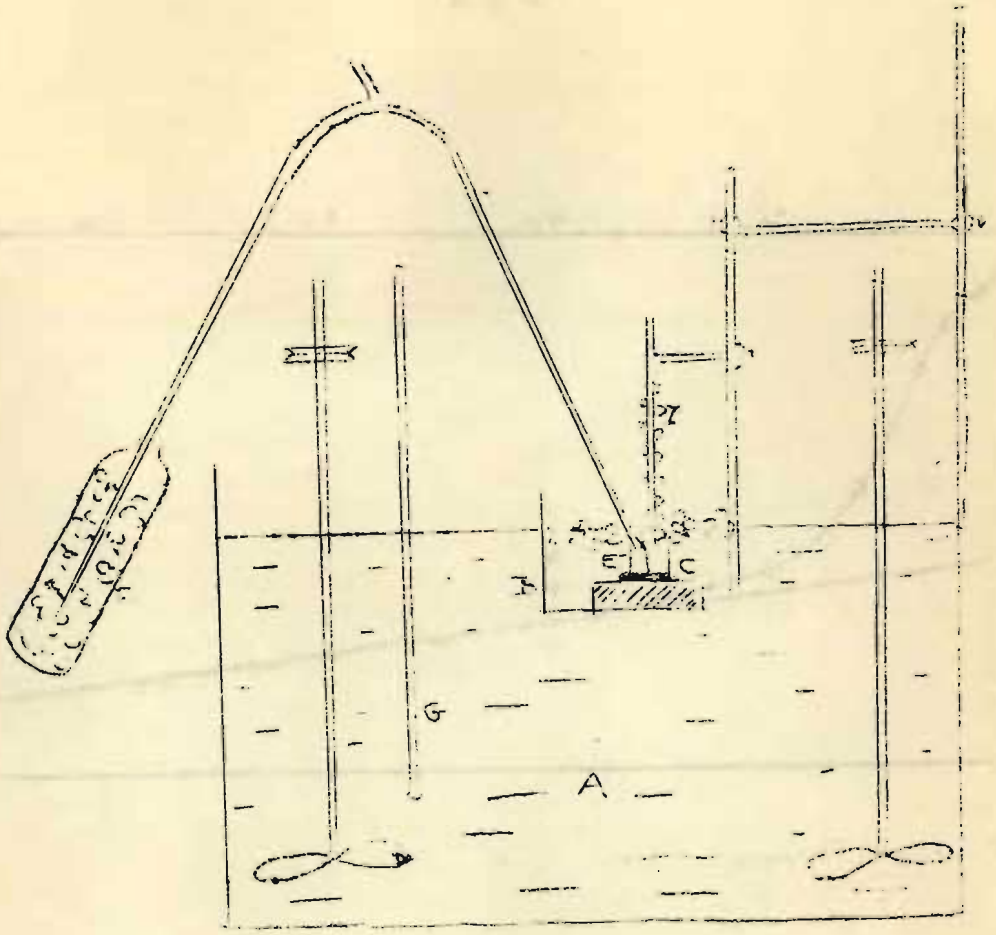


Fig. 1.

The letters in the illustration have the following significance;

A Freezing Bath.
B Container.
C Thermocouple plate.
D Constant pressure spring.
E Cork.
F Cold Temperature junction.
G Thermometer.

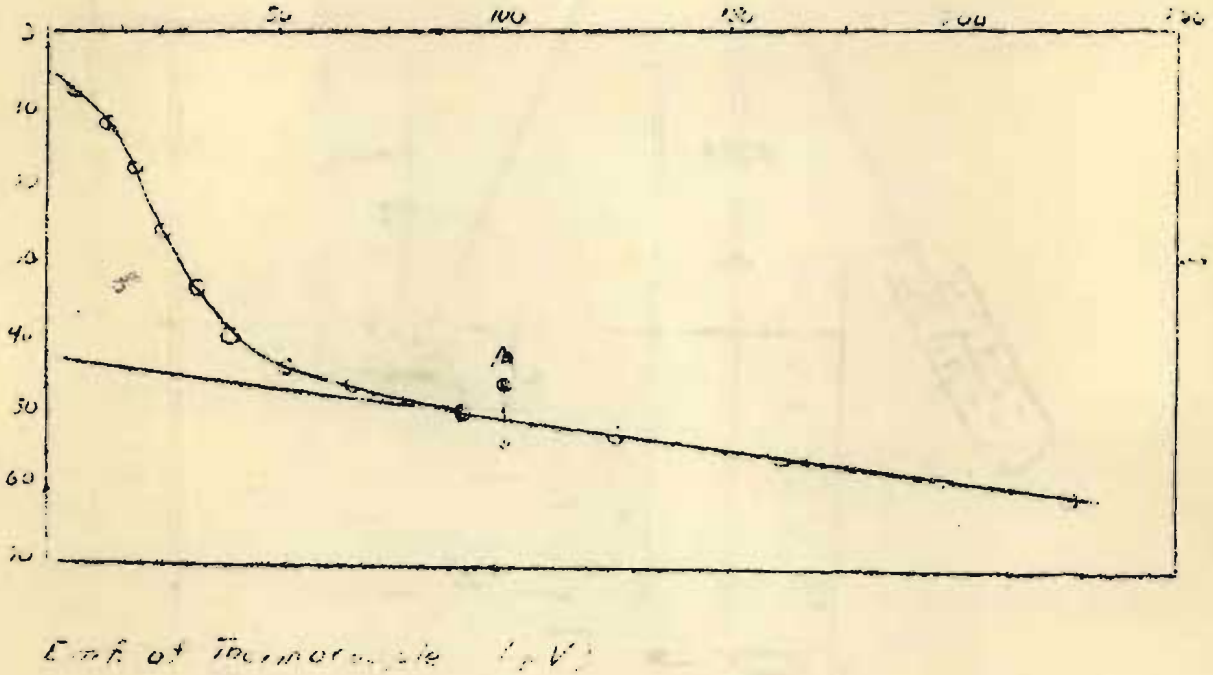
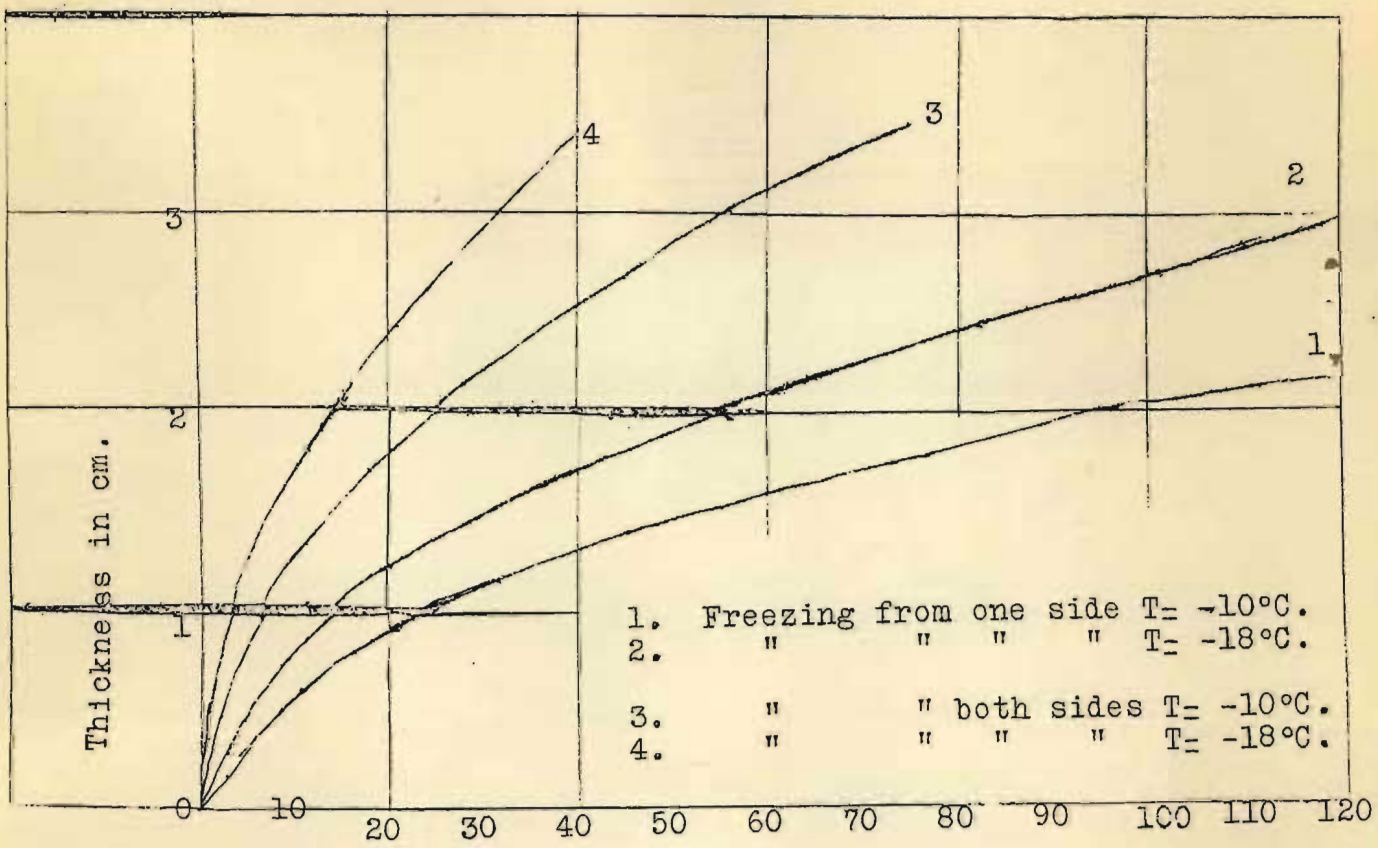
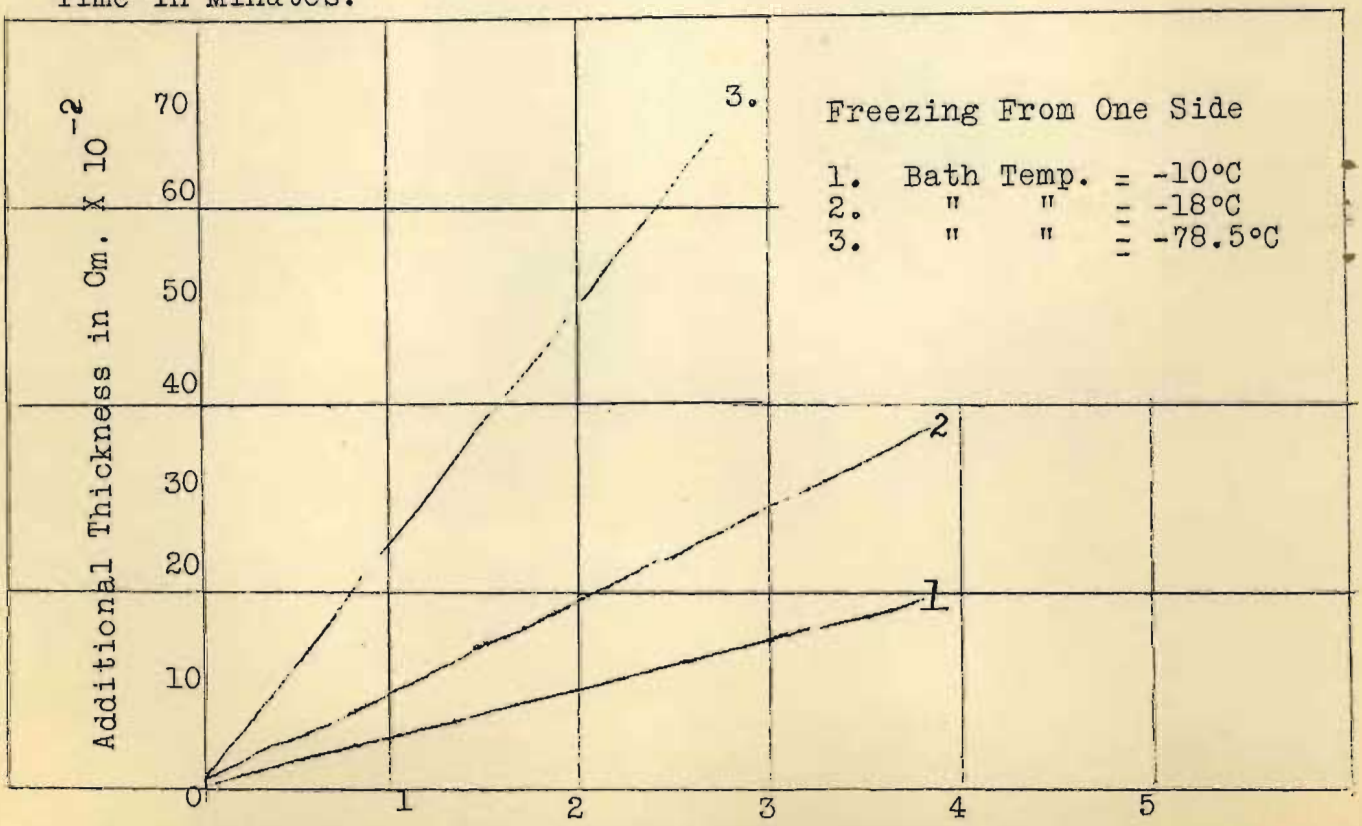


Fig. 2.

The curve shown in Fig. 2 is typical of the data obtained. The point A was taken as the point at which the fish was frozen. Points below 0°C. only are plotted. The sample was generally slightly above the zero point in temperature when introduced to the bath.



Time in Minutes.



Thickness Frozen on Removal from Bath (in Cm.).