Some Measurements of the Heat Capacity of Fish Muscle.—

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ABSTRACT.

The heat capacities of the muscle of various fishes were determined in an adiabatic calorimeter. From these results the specific heat, latent heat, and freezing point were obtained. The fish investigated were brook trout, burbot, cod, haddock, herring, mackerel and skate.

The heat capacities were found to be the same for all fishes above the freezing point with the exception of mackerel. Below the freezing point the heat capacities vary with the species. As the heat capacity curves are almost parallel the specific heats are almost the same.

The water and fat content of the fishes were also determined and they are believed to be an important factor in the latent heats.

In refrigeration problems it is important to have data on heat transfer. Accordingly values were obtained for the heat capacity of the muscle of various fish. From these values it is possible to find the specific heat, latent heat, and the freezing point. The fishes examined were brook trout, burbot, cod, haddock, herring, mackerel and skate.

Apparatus and Experimental Method.

The method consisted in keeping a weighed amount of the fish in an initial bath at a constant low temperature and then transferring it to an adiabatic calorimeter where the heat change could be measured.

The apparatus used was an adiabatic calorimeter of the Richard's type.[1] The calorimeter proper was a copper vessel holding about 800 grams of water stirred by an "up and down" stirrer. The outer container was an earthenware vessel of about six gallons capacity stirred by four two-bladed propellers.

The temperature change of the inner bath was read by a Beckmann thermometer placed in the outer bath. The temperature adjustment between the baths was obtained by means of a thermocouple system of such a sensitivity that a difference of 0.0008° C. between the two baths produced a deflection of one millimeter on the galvanometer scale. The absolute

[1] Maass and Waldbauer, Jour. Am. Chem. Soc. **47**. 1, (1925).

temperature of the outer bath was read by a tenth degree thermometer inserted directly into it.

The sample of fish was contained in a brass cylinder with a screw top. Its weight was about 13 grams and on the average about 11 grams of fish were used. The heat capacity of the empty container was determined over the same range of temperature as was used with the fish. It was found that the fish super-cooled very easily and to avoid this the fish were kept in the cold storage rooms at a temperature of about -18° C. By allowing the sample to warm up to the temperature of the initial bath instead of cooling down to it supercooling was avoided.

The bath in which the fish was brought to the required initial temperature consisted of a wide mouth thermos bottle carefully insulated with wool and placed close to the calorimeter to facilitate transfer. A copper tube into which it fitted tightly kept the container from actual contact with the cooling solution. This solution consisted of water for temperatures above 0° C.; salt and ice for temperatures beween 0° C. and -12° C.; and of ether and solid carbon dioxide for temperatures below -12° C.

The solution was stirred by a stream of dried air and the temperatures read by a toluol thermometer. The bath could be controlled to 0.1° C.

The sample was weighed in the container and allowed to remain in the initial bath for at least one hour, and, in cases where the initial temperature was near freezing point of the fish, for two hours. This time was found to be ample by preliminary experiments.

The calorimeter was then assembled, the water in the calorimeter being at such a temperature that it would be close to 20°C. at the end of the expeiiment, thus avoiding a large temperature correction, as 20° C. was taken as reference point. The baths were then balanced, being considered constant when the change in the Beckmann thermometer reading did not vary more than 0.002° over a period of ten minutes. The container was placed in the calorimeter and the heat changes followed by keeping the thermal balance between the two baths. The large initial temperature change could be followed to within 0.5°. After the initial change the two baths were kept to within 0.02°. When the temperature of the baths remained constant to 0.002° for ten minutes the run was considered as completed.

Since in the calculations the determined heat capacity of the container was subtracted from that of the container and fish, any heat loss in transfer was largely corrected. A rough value of the specific heat was calculated and the heat capacity was corrected to the required end temperature which was chosen as 20° C. The values were plotted against temperature and a smooth curve drawn through them. From this curve it was possible to obtain the freezing points, latent heats, and specific heats.

Results.

The following results were obtained. In all the Tables the temperature is given in degrees Centigrade and the Heat Capacity in calories per gram.

The following values were obtained from three samples of brook trout received during the summer:

Table I.

HEAT CAPACITY OF BROOK TROUT.

Temperature	Heat Capacity	Temperature	Heat Capacity
60.8	36.1	− 3.1	− 65.5
50.3	26.8	− 6.3	− 72.4
40.5	18.0	− 6.4	− 72.8
0.0	− 22.0	− 9.8	− 78.8
0.0	− 20.7	− 11.7	− 80.2
− 0.7	− 26.2	− 13.0	− 81.4
− 1.4	− 43.3		

The following values were obtained from samples of burbot. Two fish were used and different results obtained. These fish were some of a lot which were sent to this Station from Ontario during the summer. The burbot is a fresh water fish.

TABLE II.

HEAT CAPACITY OF BURBOT.

First fish		Second fish	
Temperature	Heat Capacity	Temperature	Heat Capacity
51.5	28.2	- 1.3	- 43.8
0.0	- 18.1	- 5.5	- 77.2
- 1.1	- 41.1	- 10.8	- 83.7
- 1.1	- 43.0	- 12.4	- 84.8
- 1.7	- 53.7	- 12.8	- 85.9
- 4.9	- 75.0		
- 7.5	- 79.7		
- 10.0	- 82.1		
- 13.0	- 83.5		
- 13.5	- 84.3		
- 23.8	- 89.6		
- 38.5	- 98.1		

The following values were obtained from cod. Those marked * were from fish caught later in the summer, and it will be seen that they give a slightly different value.

TABLE III.

HEAT CAPACITY OF COD.

Temperature.	Heat Capacity.	Temperature.	Heat Capacity.
70.0	42.8	- 20.0	- 86.5
70.0	42.2	- 30.0	- 93.3
30.0	10.0	- 40.0	- 98.9
10.0	- 9.1	- 50.0	-103.0
10.0	- 9.7	- 60.0	-107.8
0.0	- 17.4	- 70.0	-110.7
0.0	- 18.3	- 70.0	-111.7
- 1.0	- 36.2	0.0	- 23.8*
- 2.0	- 60.0	0.0	- 24.4*
- 5.0	- 72.3	- 5.0	- 68.7*
- 5.0	- 70.5	- 5.0	- 69.7*
- 10.0	- 81.0	- 10.0	- 78.5*
- 10.0	- 80.5	- 10.0	- 78.3*
- 20.0	- 86.5		

The following values were obtained from haddock. Three fish caught during early summer were used. Those values marked * were from fish caught later in the summer and like cod a slightly different value was found.

TABLE IV.

HEAT CAPACITY OF HADDOCK.

Temperature.	Heat Capacity.	Temperature.	Heat Capacity.
60.7	36.4	− 4.5	− 71.0
50.2	26.8	− 4.6	− 69.9
40.2	17.9	− 4.6	− 69.5
0.0	− 16.9	− 6.4	− 75.9
0.0	− 16.9	− 6.8	− 77.1
0.0	− 18.1	− 10.5	− 80.2
− 0.5	− 20.2	− 10.5	− 80.0
− 1.0	− 41.3	− 12.8	− 82.6
− 1.3	− 41.3	− 14.2	− 82.5
− 2.0	− 50.9	− 43.2	− 94.0*
− 2.2	− 52.4	− 41.7	− 94.0*
− 4.2	− 69.5	− 11.2	− 78.5*
		− 11.8	− 78.5*

The following values were obtained from two samples of "fat" herring received duiing the middle of July.

TABLE V.

HEAT CAPACITY OF HERRING.

First fish		Second fish	
Temperature.	Heat Capacity.	Temperature.	Heat Capacity.
61.1	35.8	− 1.6	− 32.2
0.0	− 17.1	− 3.0	− 51.4
− 1.4	− 36.2	− 7.2	− 67.1
− 3.2	− 58.6	− 10.1	− 72.4
− 6.6	− 71.1	− 12.9	− 73.5
− 10.2	− 74.2		
− 12.7	− 77.8		
− 24.9	− 82.5		
− 42.5	− 87.9		
− 42.3	− 87.4		

The following values were obtained from two samples of "fat" mackerel received in the late fall.

TABLE VI.

HEAT CAPACITY OF MACKEREL.

Temperature.	Heat Capacity.
36.0	12.6
0.0	-14.7
0.0	-15.6
-1.0	-29.9
-2.0	-42.5
-5.0	-54.5
-10.0	-64.1
-10.0	-64.5

The following were obtained from one sample of Skate.

TABLE VII.

HEAT CAPACITY OF SKATE.

Temperature.	Heat Capacity.	Temperature.	Heat Capacity.
61.0	36.4	-8.0	-70.9
0.0	-16.9	-11.0	-76.4
0.0	-17.5	-11.6	-78.0
-2.0	-25.3	-12.7	-79.7
-2.8	-36.2	-20.0	-84.2
-4.8	-59.7	-23.3	-83.8
-6.0	-64.5	-41.7	-96.4

The results given in Tables I-VII are shown in Fig. 1.

LATENT HEAT, SPECIFIC HEAT, AND FREEZING POINTS.

The latent heat, specific heat, and the freezing point may be obtained from the curves which are shown in Fig. 1. The freezing point is obtained by extrapolating the curve and is good only to about 0.2° C. The Latent Heat is the difference between the heat capacity at the freezing point and the point where the curve begins to straighten out. The specific heat is obtained in the usual manner.

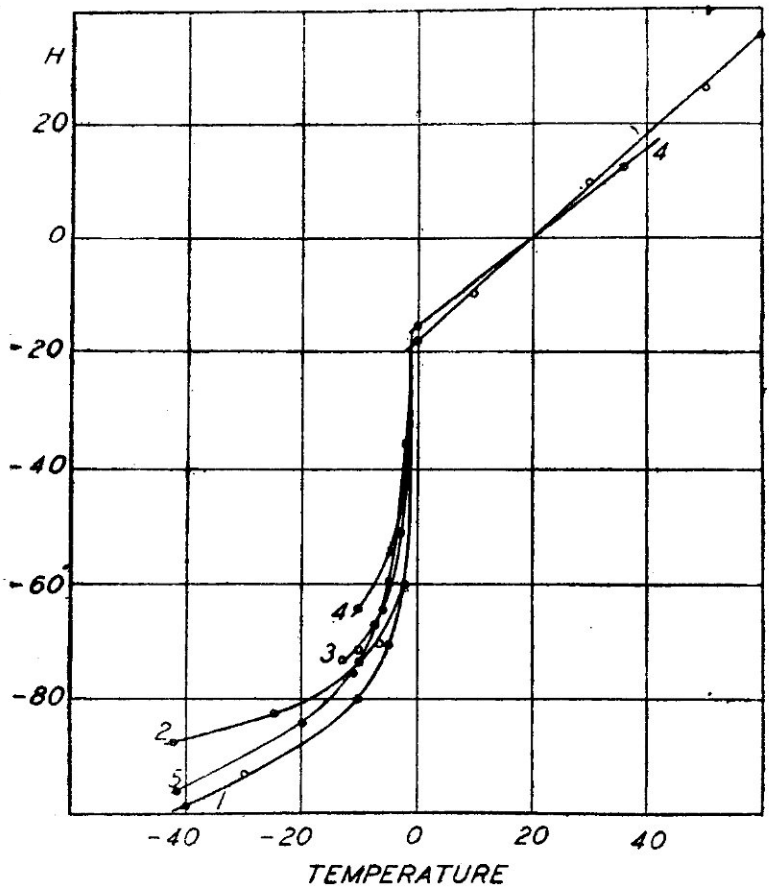

Figure 1.

HEAT CAPACITIES OF FISH MUSCLE.

TABLE VIII.

LATENT HEATS, SPECIFIC HEATS, AND FREEZING POINTS.

	Latent heat.	Specific heat		Freezing point.
Haddock	63 cals/gm	0.0° to 60°	0.89	– 0.8° C
and		–10° to –20°	0.70	
Cod		–20° to –30°	0.63	
		–30° to –40°	0.56	
Skate	60 cals/gm	0° to 60°	0.89	– 1.8°
		–20° to –30°	0.63	
		–30° to –40°	0.56	
Herring	57 cals/gm	0° to 60°	0.89	– 1.0°
	54 "	–10° to –20°	0.63	
		–20° to –30°	0.40	
		–30° to –40°	0.26	
Burbot	64 cals/gm	0° to 60°	0.89	– 0.8°
		–10° to –20°	0.68	
		–20° to –30°	0.63	
		–30° to –40°	0.56	
Brook Trout	62 cals/gm	0° to 60°	0.95	– 0.8°
Mackerel	48 cals/gm	0° to 36°	0.78	– 0.8°

WATER AND FAT ANALYSIS.

Since it was thought that the water content of the fish muscle affected largely the value of the heat capacity, it was determined in two ways; one by means of a vacuum desiccator and the other by passing dry air over the sample heated to about 105° C. The first was probably the better method since in the latter there may be some volatile material carried off in the air stream.

The vacuum desiccator was of the usual type, sulphuric acid being used as a drier. About eight grams of fish, finely sliced, were used in each determination. The fish was allowed to dry for a day and a half and the weighings were made every hour and a half. When the weighings were constant to 0.004 gm. the determination was finished.

When dried by the air stream, the fish was placed in a small flask which was immersed in a salt solution at 105° C. Air, dried by passage over concentrated sulphuric acid, was passed over it and then through some more sulphuric acid to detect the presence of organic material which had been volatilized. Organic material would discolour the acid. It was found there was a very slight discoloration denoting only a very small amount of organic material being given off.

Samples from the same fish as used in the heat capacity determinations were not always available; but the analysis was made from fish caught at the same time and which had passed through the same handling.

The following results were obtained.

TABLE IX.

WATER CONTENT OF FISH MUSCLE.

Muscle	Percentage water	Average
Burbot	82.8	
	83.5	83
Cod	79.9	
	80.4	80
Haddock	80.3	
	79.1	80
Herring	64.5	
	64.0	
	65.7	65
Mackerel	58.0	
	58.2	58
Skate	78.6	
	80.6	80

The water analyses were carried out on samples from the same fish as was used in the heat capacity determinations except in the case of cod and haddock.

The fat content of the fish muscle was determined by extraction with naptha. The same fish as were used for the water analyses were used. The following results were obtained.

TABLE X.

FAT CONTENT OF MUSCLE.

Muscle.	Percentage fat.
Burbot	0.3
Cod	0.3
Haddock	0.3
Herring	13.3
Mackerel	25.2
Skate	1.8

With the exception of the analyses of the mackerel all of the fat analyses were carried out by Miss Anna M. Wilson, Technical Assistant at the Experimental Station. At the time of analysis there were no longer any samples of trout available.

DISCUSSION.

The heat capacity curves are shown in Figure 1. Above 0°C. with one exception, the heat capacity curves correspond within the limit of experimental error. This exception is in the case of mackerel, which the analyses show to contain considerably more fat and less water than any of the other fish examined.

Below 0° C. there is a very marked difference in the heat capacity curves. Both the magnitude and the direction of these differences lead to the conclusion that the water content is the important factor in the latent heat.

Slight differences in the latent heat for two fish of the same species were noted, but the specific heat was always the same for the same kind of fish, as shown by the parallelism of the herring and of the burbot curves.

The results are good to about 1% for the samples examined. The latent heats do not apply that closely for all fish of the same species because of such variations as are to be noted in the case of the two investigated samples of herring and burbot. The specific heat does not vary by more than the experimental error for different fish of the same species. It is good to about 1.5% between 0° and 60° and to about 1% for the various points below -10° C.