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NOTES ON A THERMAL PROBE FOR MEASURING THE TEMPERATURE OF ICE LAYERS

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NOTICE

NOTES ON A THERMAL PROBE FOR MEASURING THE TEMPERATURE OF ICE LAYERS

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Karl Philberth

SUMMARY

When a thermal probe is thrust down into ice, it disturbs the ambient temperature. In order to measure the original temperature only 1 hour after such heating, a special device is suggested: the thermometer is placed in the point of a bar below the head of the probe [see ref. (1)].

A number of scientific and technical reasons [2,3] make it necessary for us to know the temperatures of the Greenland or Antarctic glacier caps. Cores, however, have penetrated only to a depth of 400 meters [4,5,6]. This is why I have already suggested a special method for such measurements [1]. We shall be concerned here with a probe built according to that concept, which can be thrust to the very bottom of a glacier cap to a depth of several kilometers [1].

To measure the virgin temperature of ice by means of a thermometer set in a thermal probe, you have to cut off the heat to the probe. After this interruption, you have to wait for a certain length of time, whose actual length depends upon the energy transferred to the ice by the probe during the heating period [1]. In cold ice this energy also includes the heating needed to protect the lateral walls of the probe against freeze-fixation.

The energy transferred to the ice will depend on the way the probe is built. Suitable design for the heated head of the probe may be achieved by using a piece of solid copper in the shape of a paraboloid, which is in good contact for purposes of heat-transfer with the heating coil. If you are using alternating current, you can heat the head by setting up Foucault currents in its walls. To do this, you set up an alternating magnetic field in the ferromagnetic walls of the head, which is enclosed in the ferromagnetic axial core of the coil.

Even if conditions are favorable, you have to wait several days after the heating cutoff, until the temperature of the probe has almost reached the virgin temperature. This is not practical when you want to find the temperatures at different depths.

In the following we present a method which will make it possible to measure the original temperature only 1 hour after heating cutoff. The basic idea behind this method is the following: while a probe is going in, there is in its immediate vicinity a temperature field which is stationary in relation to the probe. When the head of the moving probe rests on ice, you get the equation shown here for the vertical axis:

$$T_C - T_0 = (T_F - T_0)f(d)e^{-(Cvd/Y)}$$

in which T_C = temperature in the stationary field

T_0 = virgin temperature

T_F = melting temperature

$f(d)$ = equal to or less than 1, a function which depends on the form of the probe

d = greater than or equal to 0, the distance to the base from the head of the probe

C = heating capacity (for example: 0.45 cal/'C.s.cm)

Y = heat conductibility (for example: 0.004 cal/'C.s.cm)

v = the speed of the probe while in operation (for example: 0.03 cm/s).

For the values of the examples shown in parentheses, $T_C - T_0$ is negligible for d equal to or greater than 3 cm; in other words, the temperature is disturbed only in the space of a few centimeters below the moving probe.

In order to get the temperature below the probe, a vertical bar is attached to the head of the probe. The thermometer is set at the tip of that bar. You can use a movable bar, which is deployed only while the temperature is being measured. The arrangement with a fixed bar is simpler, though. Now, while the probe is moving, the fixed bar must steadily penetrate the ice, and it must be protected against freezing. This can be done by rotation or vibration or -- and this is particularly simple -- by heating. Even a very slight degree of heating will suffice. If, for example, C, Y, and v have the values shown in the examples above, if T_0 = -25'C and if the diameter of the fixed bar is 0.4 cm, 1.3W will be enough to melt the ice at the top of the bar and a dozen watts will be enough to protect the lower part of the bar up to a length of 10 cm against freezing; even smaller power levels are adequate to protect the higher parts of the bar.

The period of measurement begins with the simultaneous cutoff of head from the probe proper and the fixed bar. If you assume that the diameter of the probe and the bar are reduced to zero and that the properties of the ice are independent of the temperature, you find:

$$T_p - T_0 = \Delta T = \frac{C^{1/2}}{(4\pi Y)^{3/2}} \int_{z=0}^{\infty} q \int_{\tau=0}^{\infty} \frac{1}{(t+\tau)^{3/2}}\, e^{\frac{C(z+v\tau^2)}{4Y(t+\tau)}}\, d\tau\, dz$$

in which T_p = temperature reading in the tip of the fixed bar

t = time after heat cutoff

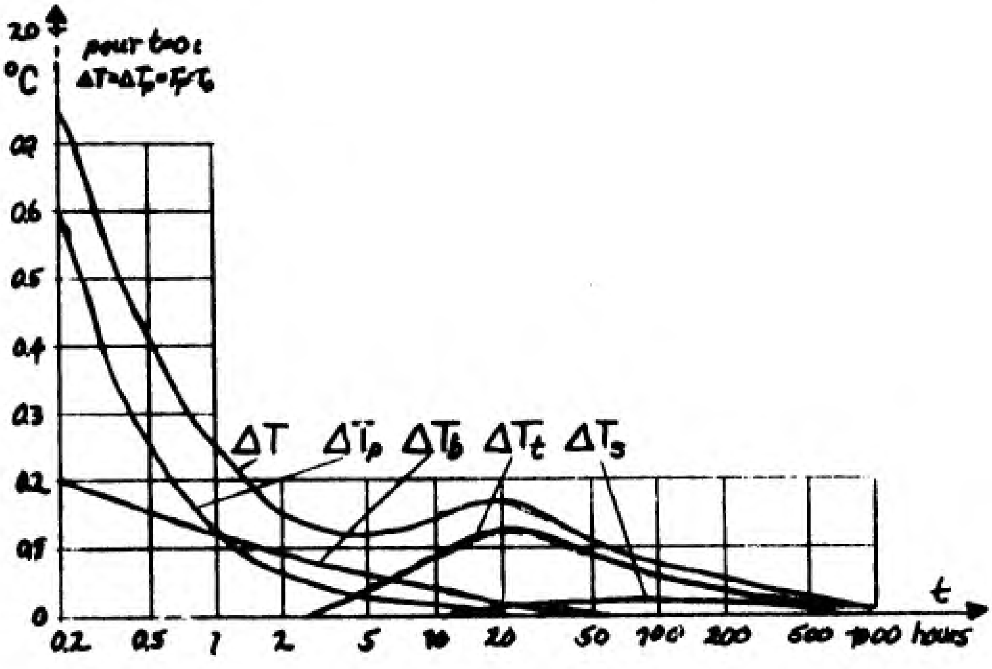
z = distance upward from the tip of the bar

T_0, C, Y, v = explanations and sample values given above

$q(z)$ = the power per unit of length, for a real bar diameter of 0.4 cm and for $-30'C \leq T_0 \leq -10'C$, for example:

6W/cm for 0 cm $\leq z \leq$ 1 cm (tip of the bar)
1W/cm for 1 cm $< z \leq$ 40 cm (lateral walls of the bar)
50W/cm for 40 cm $< z \leq$ 50 (head of the probe)
3W/cm for 50 cm $< z \leq$ 190 (lateral walls of the probe)

For sample values, Delta T is shown in the figure.



ΔT is the difference between the temperature at the top of the bar and the virgin temperature; t is the time since heat cutoff; $\Delta T = \Delta T_p + \Delta T_b + \Delta T_t + \Delta T_s$, with the latter values representing, respectively, the effect of the tip and lateral walls of the bar and the tip and lateral walls of the probe.

The temperature T can be measured by means of a resistance thermometer which is found in the tip of the bar. If T_0 is close to the melting point of the ice, you get very accurate readings by measuring the difference between T_P and the temperature of the probe head, since the head remains at the melting point for some time after the heat has been cut off. This measurement of the temperature difference is simple to do since the bar is made up of layers of different metals which act as thermoelectric elements.

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