Experimental Investigation of the Inhibition of Convection by a Magnetic Field

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The theory of stability of a layer of fluid heated below has been developed by RAYLEIGH (1916), JEFFREYS (1926, 1928) and PELLEW and SOUTHWELL (1940). According to this theory the layer of fluid first becomes unstable when the Rayleigh number

$$R = \frac{g\,\alpha\,\beta}{\varkappa\,\nu} \cdot d^4$$

exceeds a certain determinate value R_0. In this formula g denotes the acceleration due to gravity, d the depth of the layer, β is the temperature gradient which is maintained and α, $\varkappa$ and ν are the coefficients of volume expansion, thermometric conductivity and kinematic viscosity, respectively.

The theory has been extended by CHANDRASEKHAR (1952) to the case when the fluid is an electrical conductor and an external magnetic field is introduced into the fluid. According to Chandrasekhar the magnetic field delays the onset of convection, i.e., the critical Rayleigh number at which instability sets in is $R_c > R_0$. R_c depends on the strength of the magnetic field, B, through the dimensionless parameter

$$Q = \frac{B^2\,\sigma}{p_0\,\nu} \cdot d^2,$$

where σ denotes the electrical conductivity and p_0 the density of the fluid. Chandrasekhar has tabulated R_c as function of Q. In order to confirm this theory experiments with a constant magnetic field and a layer of mercury of different depths have recently been performed by NAKAGAWA (1955). The values of R_c, obtained are in good agreement with the theoretical values given by CHANDRASEKHAR (1952).

Investigations along similar lines as in Nakagawa's experiment were started some time before the publication of Nakagawa's results, but the experiments were performed in a different manner. An external magnetic field was produced by an electromagnet and could be varied in the range 0 to 10,000 gauss. Mercury was used as electrically conducting liquid. A layer of mercury was enclosed between two plates of plexiglas (both of 0.5 cm thickness) situated within a plexiglass cylinder 20 cm of diameter. The depth of the mercury layer was 1.0 cm. The magnetic field and gravity acted in the same direction along the axis of the cylinder perpendicular to the layer of mercury. The temperature gradient in the fluid was obtained in the following way.

Hot water of temperature T and cold water of temperature T_0 was circulating beneath the lower and above the upper plexiglass plates respectively. The total temperature difference $T - T_0 = \triangle T$ was measured by means of a molybdenum-constantan thermopile. The temperature difference $\triangle\Theta$ between the top and the bottom of the mercury layer was measured by means of a mercury-constantan thermopile. As long as the liquid is at rest the relation between $\triangle\Theta$ and $\triangle T$ is given directly by the thermal conductivities of plexiglass and mercury. When convection sets in, however, heat is transported through the mercury layer by the convective motions also. This implies that the "effective thermal conductivity" of the mercury is increased. Thus the distribution of temperature over the plexiglass plates and the layer of mercury, i.e., the relation between $\triangle\Theta$ and $\triangle T$, is changed when convection in the fluid sets in.

The temperature difference $\triangle\Theta$, corresponding to the temperature gradient β, was plotted against the temperature difference $\triangle T$ for different values of the magnetic field strength, B. The critical temperature difference $\triangle\Theta$ erit, when convection sets in, was determined from the discontinuity of the slope of the curve. Fig. 1 shows the experimental results for magnetic field strengths of 600 and 10 000 gauss. (See table 1). From the values in the transition points the critical values, R_c, have been determined. The curves clearly show the suppressing action of a magnetic field on the convective motion of an electrically conductive liquid. For a field strength of 10,000 gauss the motion was suppressed within the whole region of observation. Theoretically the curves should have been linear. The theory applies to a layer of mercury of infinite extensions in the horizontal directions and the slight deviation from linearity is probably due to the effects of the boundaries.

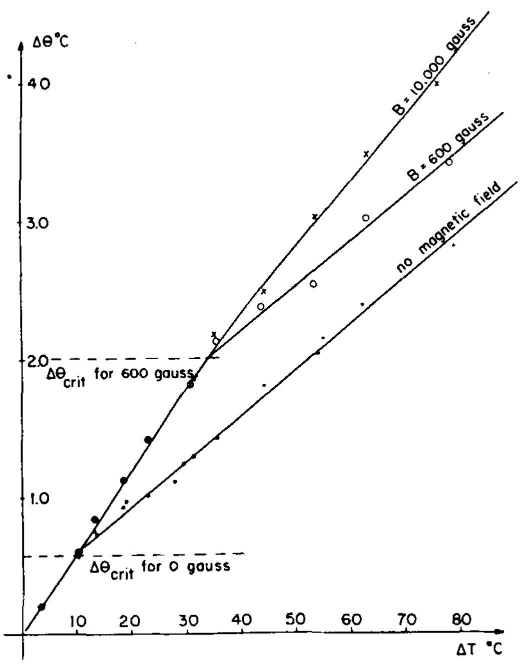

Fig. 1. Temperature difference $\triangle\Theta$ across a layer of mercury as a function of the total temperature difference $\triangle T$ across the layer and its boundaries. Curves are given for three different values of a magnetic field, B, perpendicular to the layer.

Table I

Magnetic field strength B (gauss)	R_c, theoretically calculated according to Chandrasekhar	R_c, experimentally determined
0	1708	1900
600	6600	6800
10000	$R_c > 100000$	$R_c > 14000$

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