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THE TEMPERATURE - DEPENDENT PART OF THE IMPURITY RESISTIVITY IN DILUTE AlCu, AlMn AND AlCr ALLOYS

Hungarian Academy of Sciences

CENTRAL RESEARCH INSTITUTE FOR PHYSICS

BUDAPEST

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ABSTRACT

The total resistivity of some AlMn alloys shows a minimum, which is attributed to the localized spin fluctuation contribution. Separation of the effects of the different scattering mechanisms is discussed.There are indications that a similar phenomenon exists in AlCr alloys.

KIVONAT

Néhány AlMn ötvözet elektromos ellenállásának alacsony hőmérsékleten minimuma van, ami a lokális spin fluktuációknak tulajdonitható. Vizsgáljuk a különböző szórási mechanizmusok hatásának szétválaszthatóságát. Néhány tény arra utal, hogy hasonló jelenség létezik AlCr ötvözetekben is.

РЕЗЮМЕ

Измерен минимум электрического сопротивления у некоторых сплавов AlMn, который является следствием флуктуации локализованных спинов. Изучено разделение эффектов различных механизмов рассеяния. Есть указания, что подобные явления существуют и в сплавах AlCr.

Electric resistivity measurements were made in the temperature range from 12 to about 60°K on a number of dilute AlCu, AlMn and AlCr alloys containing the relatively high concentrations of about 200-1800, 50-5700, 50-4500 ppm impurity atom, respectively. These concentrations were determined by potentiometric titration. To check that the impurity atoms were individually distributed in the matrix the residual resistivity of the samples was measured as function of concentration after annealing at 620 K°for an hour following by rapid cooling in air. Quenching in water could not be applied because the ceramic sample holder used in the experiments would not have withstood the rapid temperature drop. The concentration dependence of resistivity at 4,2 K° is plotted in Fig. 1. Apart from the point belonging to the most concentrated AlCr alloy, the points lay on a straight line with a slope of 0,74 μΩ cm for 1 at% copper, 6,74 μΩ cm for 1 at% Mn, and 7,88 μΩ cm for 1 at% Cr in aluminium. In the calculation of $\frac{\Delta\rho}{c}$ for Cr the last value was omitted, because evidently only a part of its nominal concentration value can be considered as being in true solid solution. It appears, therefore, that the heat treatment and the speed of cooling were adequate and that with the exception of one sample the impurity atoms were homogeneously distributed.

A standard d.c. method was used for the electric resistivity measurements. The samples were wires of 0,8 mm diameter. Temperature was measured with a platinum resistance thermometer soft-soldered to a duplicate sample fixed on the holder in the same manner as the test samples. Four knife-edge contacts served as the current input and potential pick-up.

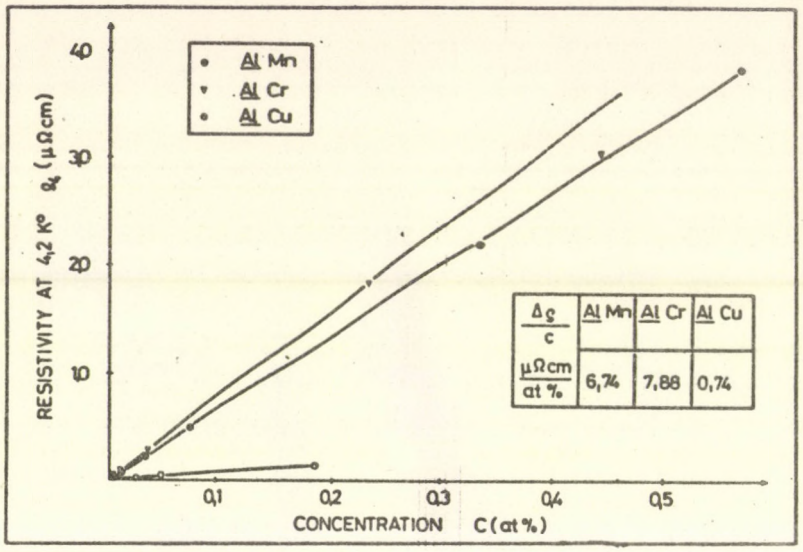

Fig. 1

Two test samples were mounted in the measuring equipment simultaneously.

Treatment of the results of resistivity measurement is usually accomplished in the following way: The total resistivity of an alloy with a single "a"-type impurity is

$$\rho_T^a = \rho_o^a + \rho_T^o + \Delta_T^a \qquad /1/$$

The lower index denotes the temperature, the upper one refers to the concentration, ρ_o^a is the residual resistivity of the alloy, and ρ_T^o the resistivity of the pure metal.

In this case Δ_T may be termed as "the deviation from the Matthiessen rule". In general this deviation consists of more than one term; however separation of the contributions of different scattering mechanisms is hard to

achieve experimentally, because at higher temperatures the electron-phonon term is several orders of magnitude greater than the deviation term. In dilute nonmagnetic alloys experiment generally shows that $\Delta T > 0$ and is proportional to the third power of temperature. The magnitude of the proportionality coefficient B is independent of the impurity species. Deviations for different copper concentrations are plotted in Fig. 2. The proportionality to T^3 is well obeyed, but at higher temperatures it not only flattens off but starts to decrease, which is more characteristic for the smaller concentrations. The picture is quite similar in the AlMn case, displayed in Fig.3. A cubic dependence can be established with this, too, but in the most dilute alloy the strong decrease bends the otherwise linear log-log plot. The "measured" Δ_T for two more dense alloys of 0,32 and 0,57 at% M concentration are plotted in Fig.4.

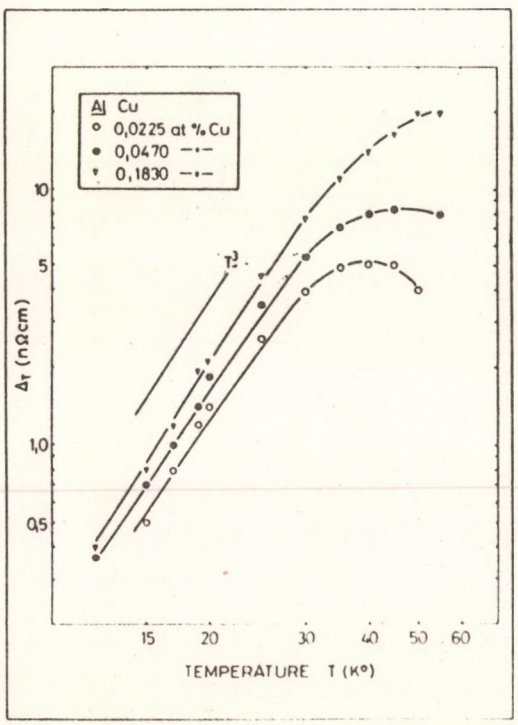

Fig.2

For the sake of comparison the deviation from two lower concentration is also plotted here /triangles/. On the basis of Fig.3 one would expect that a larger deviation corresponds to a larger concentration, but here the situation is opposite: above 30°K the deviation decreases with concentration.

The total resistivity of most concentrated AlMn alloys passes through a minimum. This behaviour is a basic feature of Kondo systems, where the impurity atom has a constant magnetic moment, the susceptibility obeys the Curie-Weiss law, there is a maximum in the specific heat, and a minimum

is observed in the electrical resistivity. In AlMn alloys Aoki and Ohtsuka [1] measured significantly enhanced Pauli susceptibility compared to the susceptibility calculated from the density of states in one-electron approximation and also observed enhanced electron specific heats. For the /Al-0,046 at% Mn/ alloy Caplin and Rizutto [2] found that the temperature dependence of the electrical resistivity in the range 1,5-4,2 K^o could be described by the formula

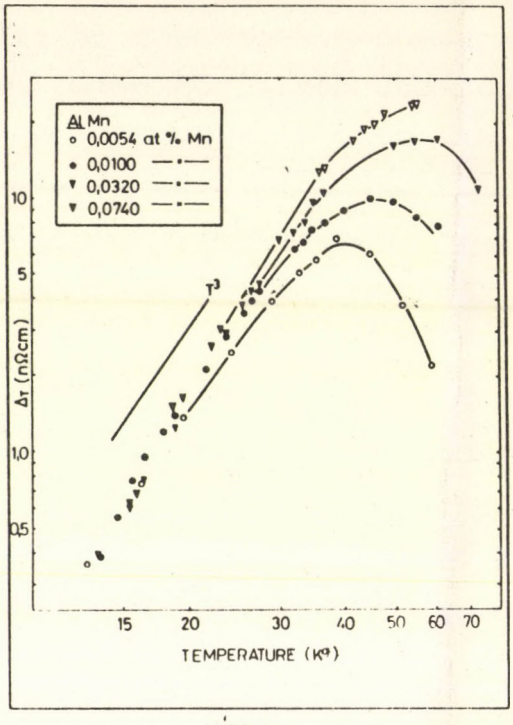

Fig. 3

$$\rho_T = \rho_o \left(1 - \frac{T^2}{\Theta^2}\right) \qquad /2/$$

where ρ_o denotes the residual resistivity for 1 at% impurity concentration and $\Theta = 530 \pm 30$ K^o.
The authors explained their results on the basis of the localized spin fluctuation concept as shown by Rivier and Zuckerman. [3] This theory predicts an increase of the density of state and a reduction of the resistivity contribution with temperature. Putting the empirical result /2/ into /1/ it can be seen that the measured deviation is

$$\Delta_{T\text{measured}} = BT^3 - \rho_o \frac{T^2}{\Theta^2}$$

The minimum is determined by the competition of these two terms. The calculated values of the spin fluctuation contribution are plotted in Fig. 4. with thin dashed curves. Around 12 K^o the first term can be neglected /it is about one order of magnitude smaller than the spin fluctuation term/, and thus the measured data for the spin fluctuation

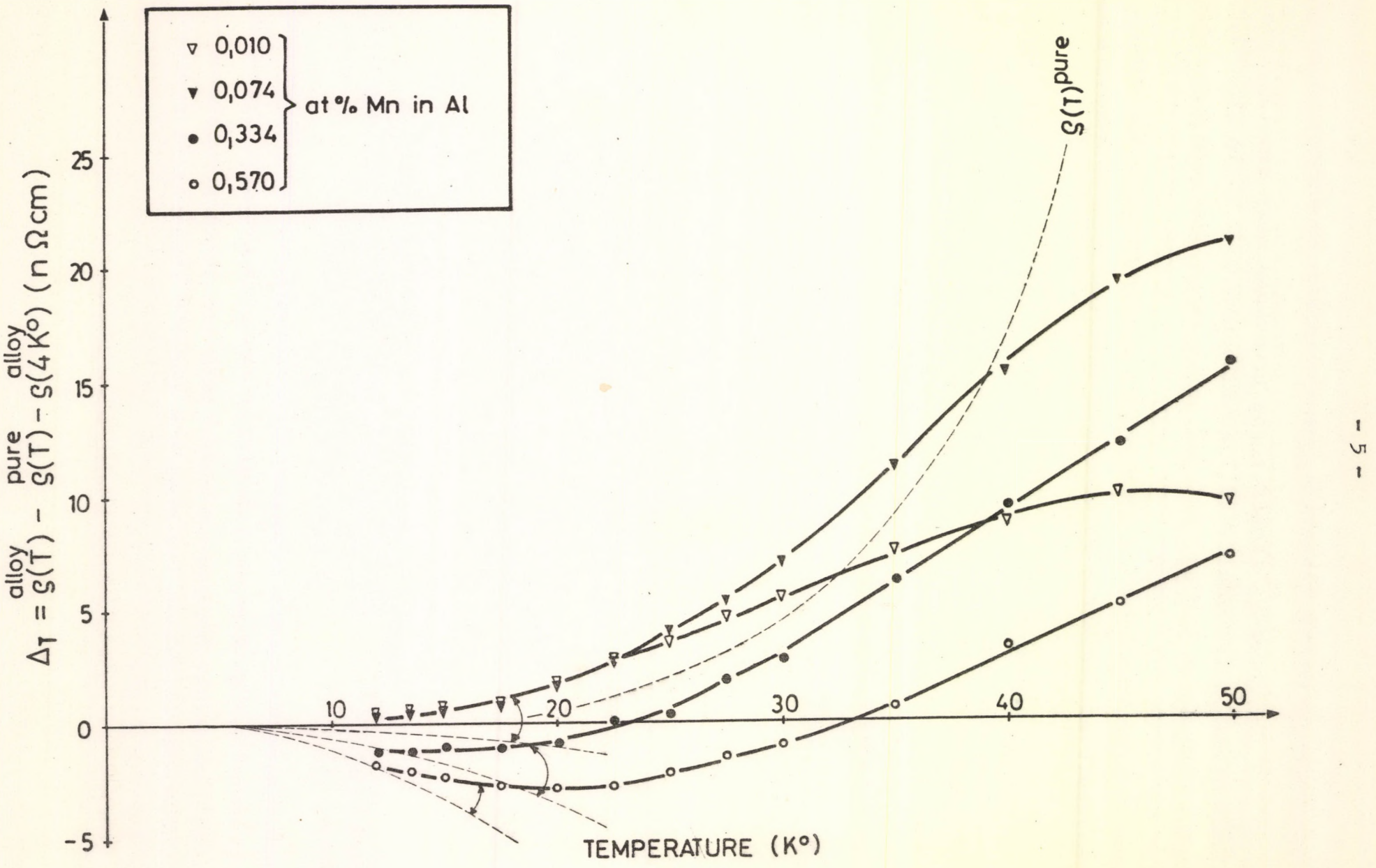
0,010
0,074
0,334
0,570
at % Mn in Al
$\rho(T)^{pure}$
$\Delta_T = \rho^{alloy}(T) - \rho^{pure}(T) - \rho^{alloy}(4\,K^\circ)$ (n Ω cm)
25
20
15
10
5
0
-5
10
20
30
40
50
TEMPERATURE (K°)

Fig. 4

contribution agree well with the calculated values.

In order to separate the processes more exactly, the present measurements will be extended to 2 K^o in the next future. As far as the consideration of the term BT^3 is concerned the situation is made more difficult by the uncertain extrapolation of B values towards higher concentrations, and secondly by the fact that the high-temperature limit of exact cubic dependence - at least according to the present measurements - is not greater than 30 K^o. Some calculated values of coefficient B are plotted as a function of logarithm of residual resistivity /$\sim$ log concentration/ for this temperature interval in Fig. 5. The errors denoting the maximal and minimal slope of the lines in the Δ_T versus T^3 plot were determined from the scattering of the data.

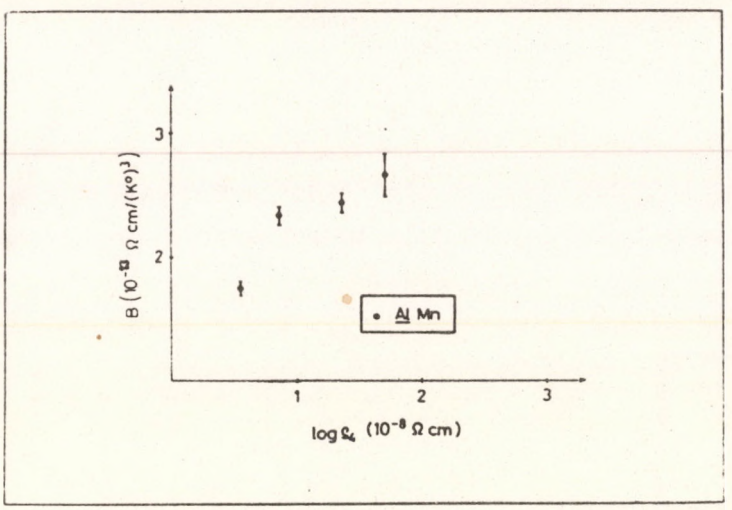

Fig. 5

Fig. 6 shows the result for AlCr alloys. The initial cubic dependence holds well and it is possible to draw the deviation for even the largest concentration on a log-log plot.

Owing to the higher Θ of this system there is a smaller quadratic term in resistivity, although this is noticeable only where the monotonous increase of deviation ceases at 0,23 at% Cr concentration; almost the same deviation is found at about twice this concentration, around 0,4 at% Cr. The solubility limit is smaller for Cr in Al than for Mn, and it is very likely that the minimum can only be observed at much lower temperatures. A plot of the B values for AlCr and AlCu can be seen in Fig. 7. With Cr there is a small deviation from the predicted linear dependence on the logarithm of concentration, while for the AlCu system the aggreement is good.

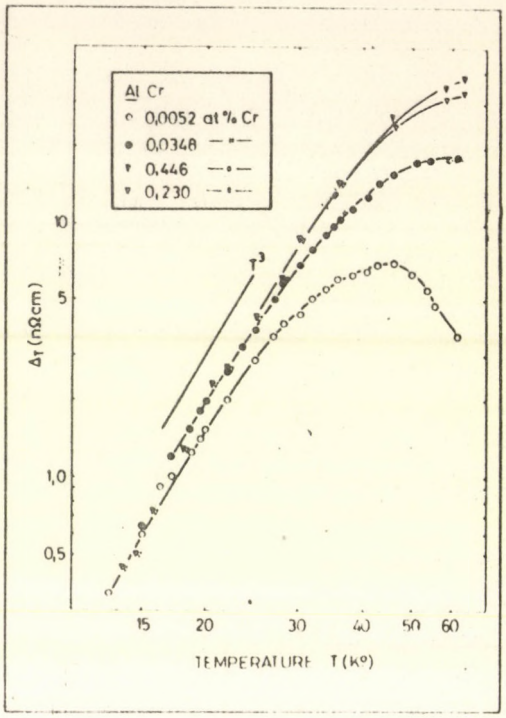

Fig. 6

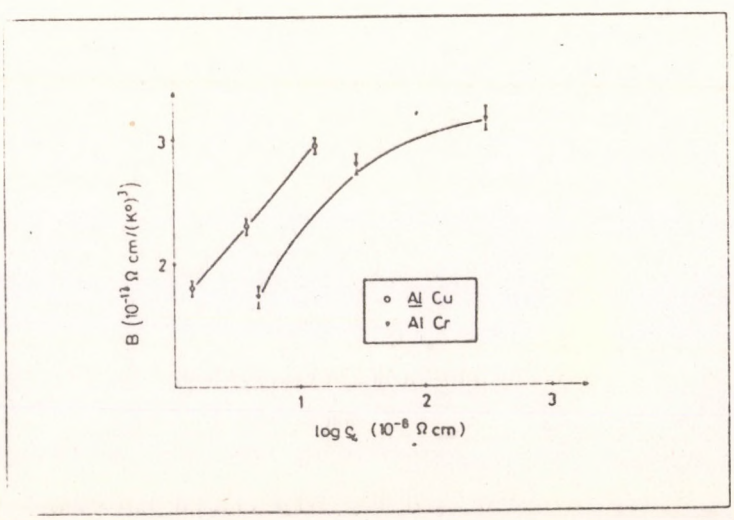

Fig. 7

REFERENCES

[1] R. Aoki and T. Ohtsuka, J.Phys.Soc. Japan 26 651 /1969/

[2] D. Caplin and C. Rizutto, Phys.Rev.Lett. 21 746 /1968/

[3] N. Rivier and M. Zuckerman, Phys.Rev.Lett. 21 904 /1968/

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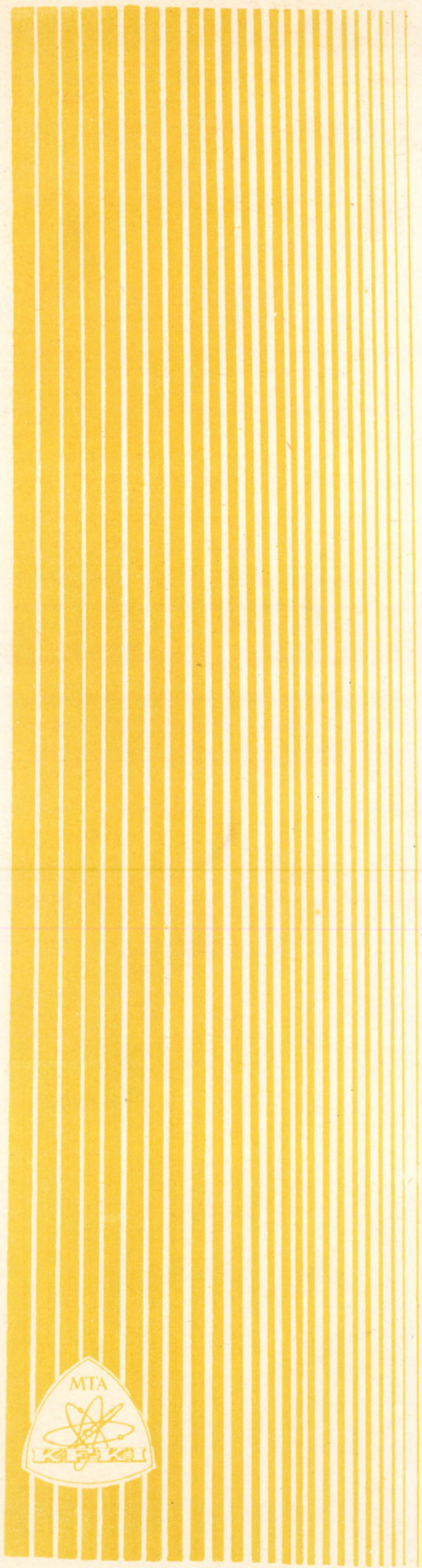

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