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Magnetic properties of CrTe, $Cr_{23}Te_{24}$, Cr_7Te_8, Cr_5Te_6, and Cr_3Te_4 compounds

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The magnetic properties of different compounds of the Cr–Te system have been investigated. The magnetization of different specimens in the polycrystalline form has been measured as a function of field and temperature. The samples of the system Cr_xTe ($x > 0.75$) show ferromagnetic properties. The character of the $\sigma(H, T)$ curves is nearly the same for all these samples. Values of σ_s and T_c have been computed with the help of thermodynamic coefficients. In the case of Cr_2Te_3, however, spontaneous magnetization has been determined by extrapolation of isotherm $\sigma(H)$ to the magnitude $H = 0$.

1. Introduction

Compounds of the Cr–Te system possess interesting magnetic properties and have a great potential for application in modern technology [1]. These compounds are stable below 1200° C. The magnetic properties of different compounds of the Cr–Te system have been investigated by different authors. The results, are sometimes not in agreement because of the different conditions of either preparation or measurements [2–4]. The magnetic properties of these compounds depend upon the arrangement of vacancies in the unit-cell of their structure which is of the NiAs type. A large amount of effort has been spent on studying the magnetic and crystal structure properties of these materials and others which have the same structure with an admixture of some other element such as Se [5–10]. Some investigations on the pressure dependence of magnetic properties in these systems have also been made [11, 12].

In the present study we measured magnetization as a function of the magnetic field and temperature in CrTe, $Cr_{23}Te_{24}$, Cr_7Te_8, Cr_5Te_6, Cr_3Te_4 and Cr_2Te_3. The spontaneous magnetization, σ_s, and Curie temperature, T_c, have been determined for all these compounds.

2. Experimental techniques

Samples of the Cr–Te system used in the present investigations were prepared by the method of interdiffusion of components at 1100 to 1200° C. This technique was employed owing to the great difference in the melting points of the components which are 452° C for Te and 1890° C for Cr. For the preparation of samples, highly pure components were used: Cr 99.98% pure with the main admixture of O, N and I being approximately 0.02%; Te 99.998% pure with the main admixture of Cu, Fe, Mg and Si being nearly equal to 0.002%. The calculated amount of initial elements was placed in a cold quartz ampoule which was evacuated to 5×10^{-4} torr.

Heating was carried out at temperatures of 450, 600, 999 and 1000° C for 6 h at each step. The temperature was then increased to 1100 to 1200° C depending on composition. This temperature was maintained until complete melting of admixture was achieved and this time was usually about 30 min. After cooling the ampoule in air, the samples were placed in newly evacuated ampoules for further annealing at temperatures of 1200, 1100, 900, 600 and 400° C for durations of 30 min, 4 h, 24 h, 12 and 18 days, respectively, and they were then hardened in water at 0° C.

Metallographic and X-ray structural analysis of all samples under consideration showed that they were single-phased compounds. All studies were carried out on the polycrystalline samples powdered in a mortar made of BK-8 alloy. Measurement of

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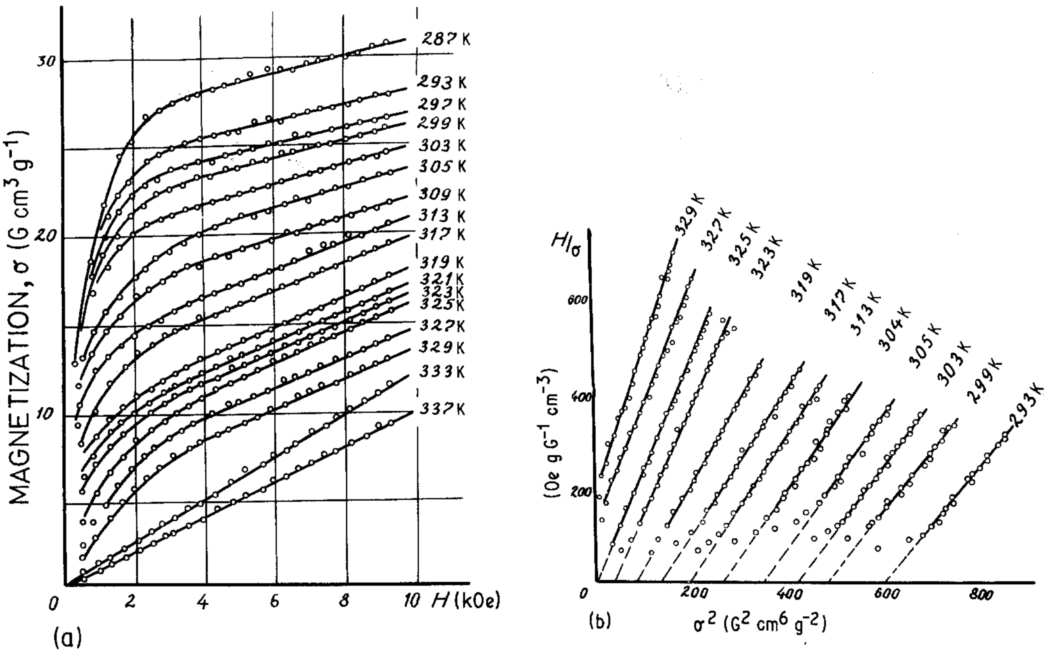


Figure 1 (a) Magnetization isotherms for the CrTe sample. (b) Dependence of H/σ on σ^2 at different temperatures for CrTe.

magnetization of samples was made using a vibrational magnetometer. The details and working of the circuit have been described elsewhere [1].

The ampoule containing the sample could be placed either in an oven or a cryostat to obtain the temperature dependence of magnetization. Temperature was controlled with a copper–constantan thermocouple whose junction was fixed at the centre of the sample. With these arrangements, measurements could be made in the temperature range 77 to 800 K. The magnetometer was calibrated with the help of standard samples of electrolytic nickel.

3. Experimental results and discussion

In the samples of the compounds of the system Cr_xTe, the temperature below which ferromagnetic ordering appears, is obtained by the linear extrapolation to zero of the curve between the square of spontaneous magnetization and temperature. Magnetization isotherms, on the basis of which spontaneous magnetization at different temperatures is defined, taken in magnetic fields up to 8.5 kOe near the Curie temperature, T_c, are shown in Figs. 1a, 2a, 3a, 4a and 5a for different compositions of the Cr_xTe system. As is clear from the figures, the samples of the system Cr_xTe with $x > 0.75$, show ferromagnetic properties. For all these samples the character of the $\sigma(H, T)$ curves is nearly the same.

Crystal anisotropy in the region under consideration is not large; the magnitude of the residual magnetization in the zero magnetic field is not greater than 1.5 to 2.0 G cm³ g⁻¹ and the coercive force is not greater than 50 Oe.

In the investigations, the spontaneous magnetization, σ_s, is obtained by the method of thermodynamic coefficients [3]. The basis of this method is the presence of a linear relationship between the quantities H/σ and σ^2 for respective isotherms of magnetization near the Curie temperature. In fact, near the Curie temperature, T_c, the thermodynamic potential, ϕ, may be written as a series having an even degree of magnetization.

$$\phi = \phi_0 + a\sigma^2 + b\sigma^4 - \sigma H, \qquad (1)$$

considering the energy of interaction of magnetic moments having a field $-\sigma H$. The equilibrium magnitude of the parameter σ is defined by the condition $\partial\phi/\partial\sigma = 0$. This gives near the Curie temperature:

$$\alpha\sigma + \beta\sigma^3 = H. \qquad (2)$$

Here σ is the specific magnetization measured experimentally and is equal to $\sigma_s + \sigma_i$ where

σ_s is the spontaneous magnetization and σ_i is the true specific magnetization for field H. α and β are the thermodynamic coefficients depending on temperature and external pressure, P. Equation 2 may be written in a more simplified form as

$$\alpha + \beta\sigma^2 = H/\sigma. \qquad (3)$$

Equation 3 satisfies experimental data fairly well. Deviation from linearity has been observed only in weak fields where there is a possibility for diffusion and rotation which is not considered in obtaining the above relations. In this way, near to the Curie temperature, spontaneous magnetization, σ_s, at a given temperature, T, may be obtained by extrapolation to the x-axis of the H/σ–(σ^2) dependence.

Thermodynamically it is possible to show that near to the Curie temperature, the square of spontaneous magnetization must be proportional to the difference of temperature $(T_c - T)$. Therefore, the magnitude of T_c may be obtained with sufficient accuracy by the linear extrapolation of the curve σ_s^2 (T) to magnitude $\sigma_s^2 = 0$. The smaller the difference of temperature $(T_c - T)$ the more justified is the use of the above analysis. This method of obtaining the Curie temperature is one of the most simple and justified methods which are used to evaluate the experimental dependence of $\sigma(H, T)$.

Figs. 1b, 2b, 3b, 4b and 5b illustrate the method of obtaining σ_s and T_c with the help of thermodynamic coefficients. The magnitudes of T_c obtained from the condition $\sigma_s^2 = 0$ are given in Table I.

The experimentally determined magnitudes of T_c, with the help of the thermodynamic coeffic-

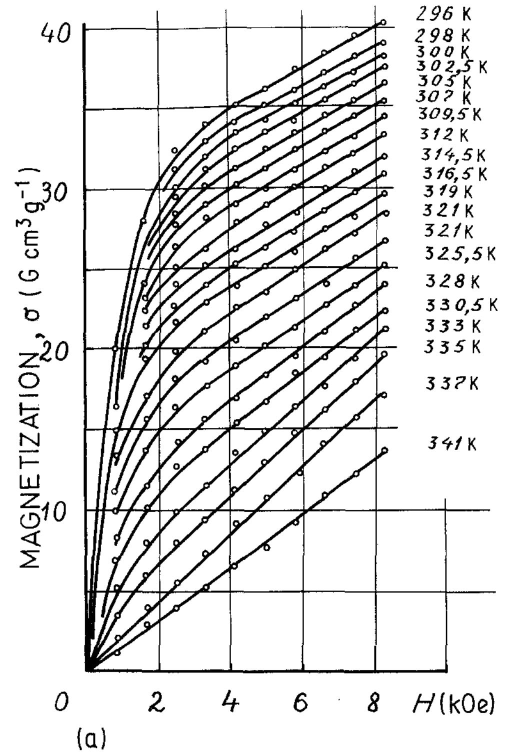


Figure 2 (a) Magnetization isotherms for the $Cr_{23}Te_{24}$ sample. (b) Dependence of H/σ on σ^2 at different temperatures and the temperature dependence of σ_s^2 for $Cr_{23}Te_{24}$.

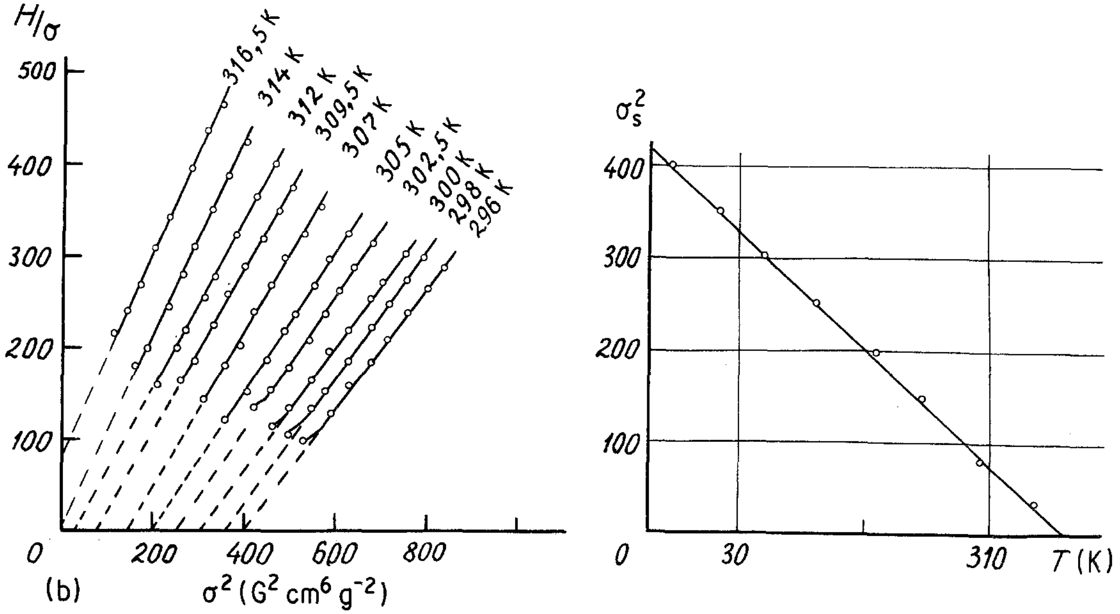


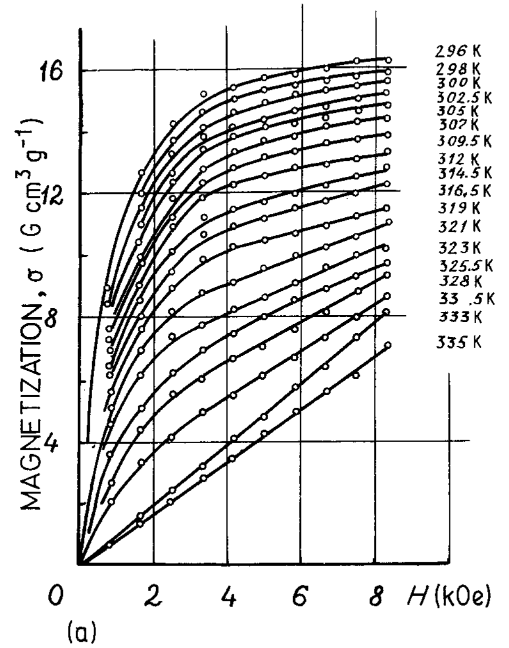
TABLE I

Serial no.	Composition	T_c (K)
1	Cr Te	328
2	$Cr_{23}Te_{24}$	327
3	Cr_7Te_8	326
4	Cr_5Te_6	320
5	Cr_3Te_4	317

ients, are near to the known magnitudes. The difference may be due to different conditions of preparation or the presence of local inhomogeneity due to disordered distribution of vacancies which leads to the breaking of the regions of magnetic phase transition.

For the determination of T_c for Cr_2Te_3 alloy, the thermodynamic coefficient method could not be used. This may be due to the appearance of antiferromagnetic interaction between the neighbouring surfaces at temperatures $180 < T < 270$ K. This leads to the possibility of a tendency towards antiparallel ordering of magnetic moments of the neighbouring bottom layer. It must be so weak that a comparatively small field (1/100 Oe) may disturb this state. It may also be due to the fact that the magnetization is a complex function of the external magnetic field. On the other hand, in agreement with the known neutronographic data, the magnetic moments of the neighbouring bottom layers are quite different. In other words, at complete antiparallel orientations of spinning electrons, there remain uncompensated magnetic moments.

In the case of Cr_2Te_3, spontaneous magnetization has been obtained by extrapolation of the isotherm $\sigma(H)$ to the magnitude $H = 0$. According to these data spontaneous magnetization tends



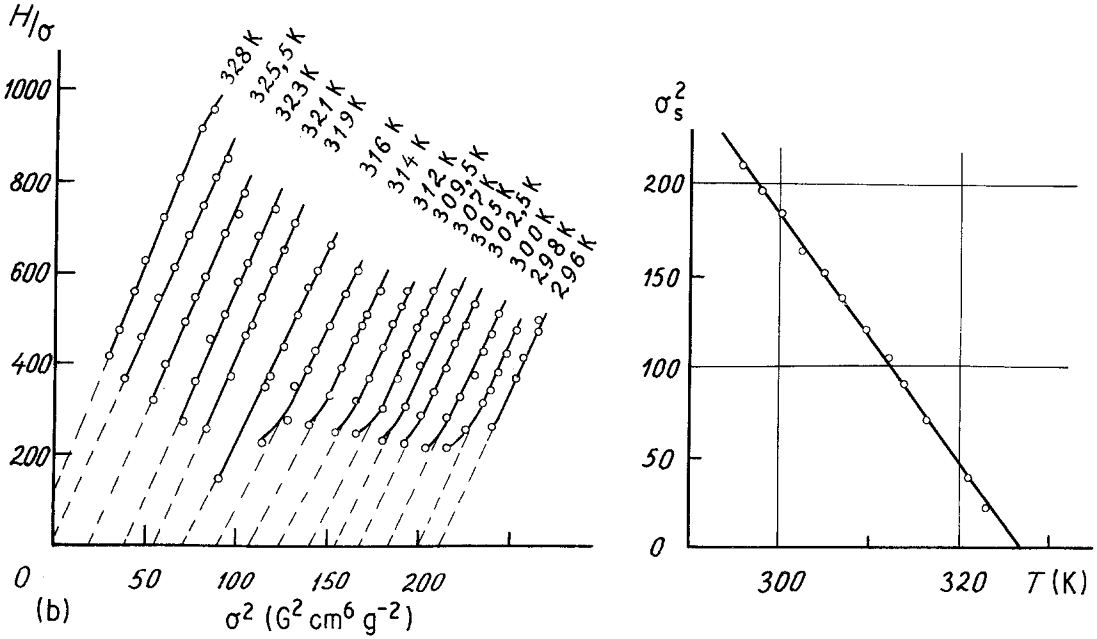


Figure 3 (a) Magnetization isotherms for Cr_7Te_8. (b) Dependence of H/σ on σ^2 at different temperatures and the temperature dependence of σ_s^2 for Cr_7Te_8.

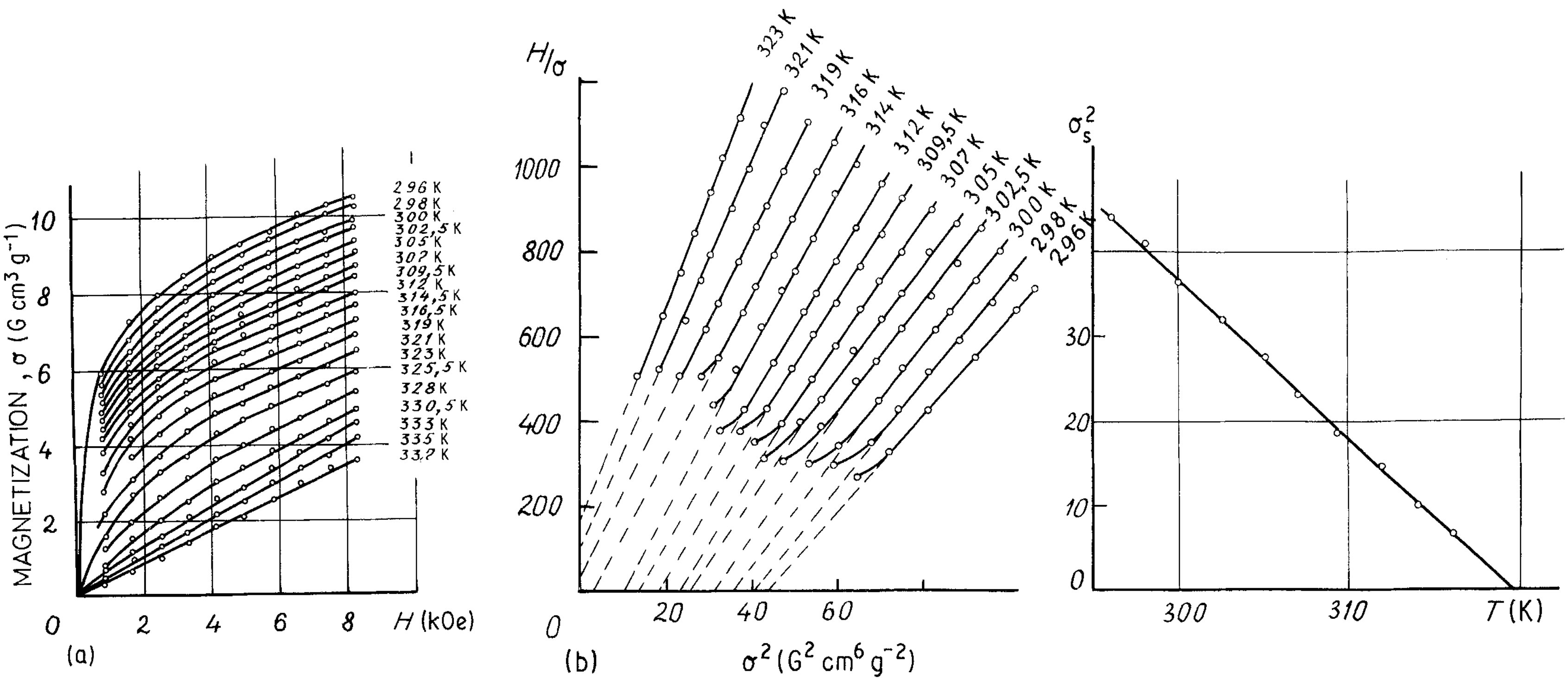


Figure 4 (a) Magnetization isotherms for Cr_5Te_6. (b) Dependence of H/σ on σ^2 at different temperatures and the temperature dependence of σ_s^2 for Cr_5Te_6.

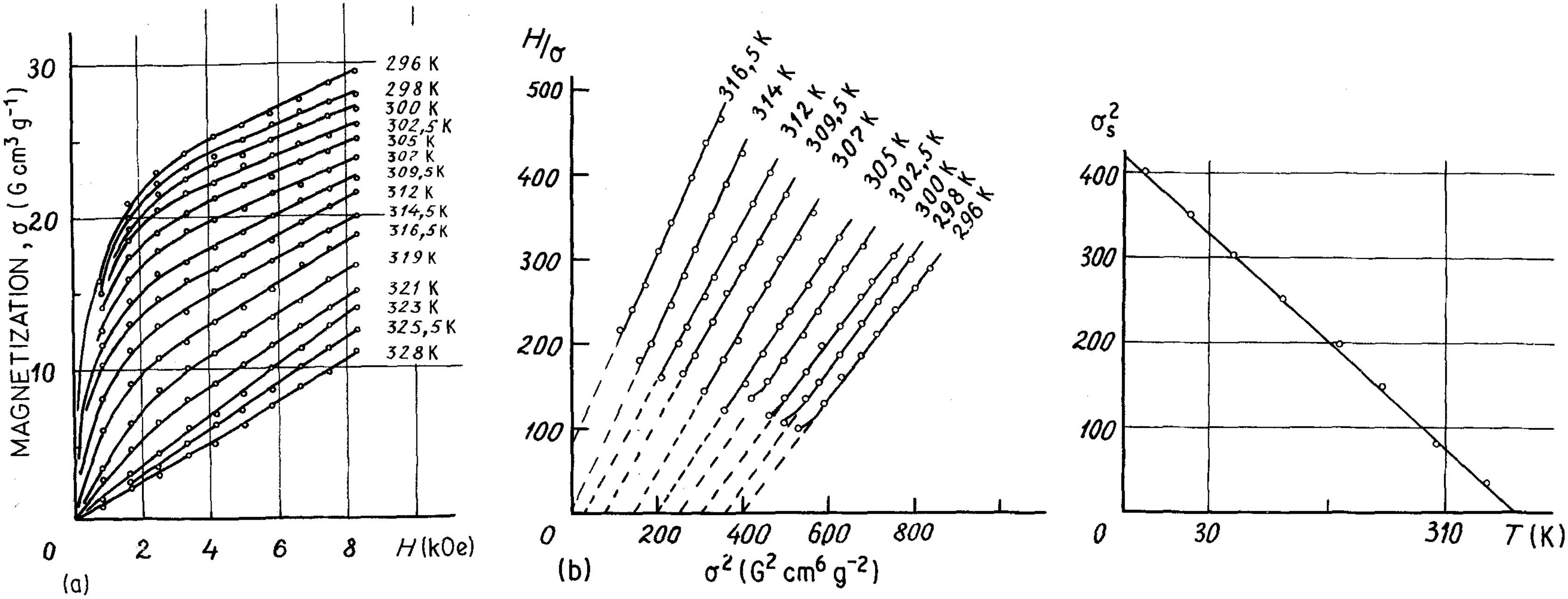


Figure 5 (a) Magnetization isotherms for Cr_3Te_4. (b) Dependence of H/σ on σ^2 at different temperatures and the temperature dependence of σ_s^2 for Cr_3Te_4.

to zero at temperature $T \sim 150\,\mathrm{K}$. At 300 K in a field of 2 kOe, magnetization nears zero.

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