LOW TEMPERATURE HEAT CAPACITY OF SCANDIUM
AND ALLOYS OF SCANDIUM

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Low temperature heat capacity of scandium and alloys of scandium¹

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The heat capacity of three electrotransport purified scandium samples has been measured from 1 to 20K. The resultant electronic specific heat constant and Debye temperature are 10.33 ± 0.015 mJ/gm-atom K² and 346.7 ± 0.8 K respectively, and these values are believed to be truly representative of intrinsic scandium.

Alloying studies have also been carried out to investigate the band structure of scandium based on the rigid band model, with zirconium to raise the electron concentration and magnesium to lower it. The results are then compared to the theoretical band structure calculations. Zirconium additions up to 0.5 at. % increases the electronic specific heat constant; then γ decreases monotonically with further zirconium additions up to 34 at. % Zr. The electronic specific heat constant decreases slowly with increasing magnesium concentration up to 8 at. % Mg. The resultant density of states curve after correcting for electron-phonon interaction is qualitatively consistent with the theoretical band structure calculation by S. G. Das, but apparently not consistent with other such calculations. Enhancements other than the

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electron-phonon interaction are important, particularly that due to spin fluctuation, in order to bring the experimental results into agreement with the theoretical density of states. Dilute zirconium and magnesium has an anomalous effect on the Debye temperature of scandium; however, the cause for this behavior is not understood.

Low temperature heat capacity measurements have also been made on some dilute Sc-Fe alloys. An anomaly is observed in the C/T vs T^2 plot, but the C vs T curve shows no evidence of magnetic ordering down to 1K, and electrical resistance measurement from 4 to 0.3K also indicates that no magnetic ordering took place. It is believed that for Fe concentration less than between 50 to 85 ppm (atomic), the Sc-Fe alloys in the as cast condition behave as a pure Kondo system. This is confirmed by the agreement between the theoretical and experimental excess entropy and also by the concentration-independent peak in the excess heat capacity. At 85 ppm (atomic) Fe and above, impurity-impurity interaction begins to come into play, giving extra contribution to the excess heat capacity. Annealing causes the randomly distributed Fe atoms to cluster, increasing the excess heat capacity and further complicates the picture.

I. INTRODUCTION

Scandium is the first member of the transition metals and the lightest of the rare earth metals. Scandium has three valence electrons beyond the argon rare gas core and in this respect is associated with the lanthanide metals which also have three valence electrons beyond their respective rare gas core. Because of this configuration of three valence electrons beyond the rare gas core, scandium possesses many similar properties in its general chemistry and metallurgy to those observed for the lanthanide metals. Furthermore, energy band calculations (1) have established that the conduction electron band structure and Fermi surface geometry of scandium are similar to those found for yttrium and the heavy rare earth metals (2).

However, the single most important property of scandium lies in its unique position in the transition metals series. Being the first transition metal it is a light element, yet it possesses a relatively high melting point and structural strength, particularly when compared to the corresponding properties of non-transition metals preceding it in the periodic table. Hence a thorough understanding of the properties of scandium, especially its electronic structure in the metallic state, is pertinent to the study of the transition and rare earth metals, and can provide valuable information on the role of the d-electrons in the transition metals. To facilitate this understanding a knowledge of reliable physical property data on the physical, electrical and magnetic behavior of scandium is important.

Unfortunately, the results reported in the literature to date for most of these properties show a wide range of values and rarely have identical results been reported on measurements of two different scandium samples (see reference 3). For example, the low temperature heat capacity results of six different samples give the electronic specific heat constant ranging from 10.3 to 11.3 mJ/gm-atom K² and the Debye temperature ranging from 344 to 470K. This large variation is due to the different impurity level, particularly iron (4), in the samples measured. An anomaly in the heat capacity at low temperatures has been found in three of the six samples. Room temperature magnetic susceptibility results have been reported for 15 samples with values ranging from 220×10^{-6} to 370×10^{-6} emu/gm-atom. The purest and best characterized sample measured by Spedding and Croat (5) showed a maximum in the magnetic susceptibility around 30K which disappeared when dilute amounts of magnetic as well as non-magnetic impurities were added, indicating the sensitivity of the physical properties of scandium to impurities. Electrical resistivity values ranging from 50 to 90 μ ohm-cm are found for thirteen samples. The agreement between results for the Hall coefficient and thermoelectric power are even worse than the above three properties. All these results suggest that scandium may have an unusual band structure that is particularly sensitive to dilute impurities, much more so than most of the transition and rare earth metals.

A survey of the literature yields five band structure calculations for scandium with three of these calculations done between 1973 to 1976.

However, each of the theoretical calculations predicts a different Fermi level and different features in the shape of the density of states curve (see section on the discussion of heat capacity results of scandium). There are a number of physical properties that are intimately related to the density of states at the Fermi level, among them are the electronic specific heat constant and the Pauli spin paramagnetic susceptibility. To understand the electronic nature of scandium, low temperature heat capacity measurements were made on a series of scandium based alloys containing zirconium to raise the electronic concentration and magnesium to lower it. Assuming the rigid band model to hold at least over small alloying concentrations, the band structure ($N(E_F)$ vs E) can be calculated from the variation of the electronic specific heat constant with the electron concentrations following the method outlined by Hoare, Matthews and Walling (6). The resultant density of states curve can then be compared with theoretical calculations to check which is more likely to be the correct one.

In order that meaningful results and conclusions can be drawn from these measurements, physical property parameters that are truly representative of intrinsic scandium must first be established. This is done by low temperature heat capacity measurements on scandium that have been purified by electro transport-refine where the iron impurity level is reduced to around 1 to 2 ppm atomic (4), and magnetic susceptibility and resistivity measurements on single crystals of electrotransported scandium. The results thus obtained will not only serve as the

basis reference points, but also allow some of the recent reported results on the so-called "high purity" scandium to be re-examined.

Interesting phenomena have been observed when small amount of magnetic impurities (particularly the iron group impurities) are added to the noble metals (7). Depending on the concentration of the magnetic impurity, either a "Kondo system" when the concentration is low or a "spin glass system"--when the concentration increases, is formed. Associated with these effects are anomalies in the resistivity, magnetic susceptibility, heat capacity and thermoelectric power (8). Since impurities, notably iron, are known to affect the physical properties of scandium drastically as is evidenced from the disagreement among the results reported of the physical properties of different scandium samples, low temperature heat capacity measurements were made on some dilute Sc-Fe alloys (with iron concentration less than 120 ppm atomic) to study the magnetic contribution to heat capacity by the dilute iron impurities, and to check whether the "Kondo" or "spin glass" effects are present.

II. BACKGROUND THEORY

Heat capacity measurement at low temperatures can give important information concerning the electronic structure of metals as well as electrical and magnetic phenomena. There are excellent text books where this information is discussed in detail (9, 10), hence only a brief review of the well-known theory of low temperature heat capacity is given below.

For most normal metallic materials, there are two contributions to the heat capacity at low temperatures, namely, the electronic and the lattice contributions. The electronic contribution can be given to a good approximation by the expression:

$$C_{el} = (2/3)\pi^2 k^2 N(E_F) T = \gamma T \quad (1) \text{ where}$$

k = Boltzmann constant

$N(E_F)$ = density of states at the Fermi level for one spin
direction

T = temperature

γ = electronic specific heat constant.

$$\text{therefore } N(E_F) = \frac{3\gamma}{2\pi^2 k^2} \quad (2)$$

It can be seen from the above equation that C_{el} is proportional to temperature and that the proportionality constant is related to the density of states at the Fermi surface. The density of states referred to here is the density of states averaged over all of the Fermi surface

so that no specific details of the band structure are explicitly obtainable from the specific heat of the electrons. However, useful information about the band structure can still be obtained by alloying the metal with a higher or lower valent metal and measuring the heat capacity of the alloys. Changes in γ between alloys can be used to explain changes in the band structure with alloying.

At low temperatures, the lattice contribution to heat capacity can be analyzed in terms of the Debye model which treats the solid as a dispersionless elastic continuum. This leads to an expression:

$$C_L = (12/5)R\pi^4 \left(\frac{T}{\theta_D}\right)^3 = \beta T^3 \quad (3) \text{ where}$$

R = gas constant

θ_D = Debye characteristic temperature

For most metals, the T^3 -dependence of the lattice contribution to heat capacity is found to be valid for only the temperature range of $T \leq \theta_D/50$.

Thus, the total heat capacity can be written as

$$C = C_{el} + C_L = \gamma T + \beta T^3 \quad (4)$$

rewriting the above equation as $C/T = \gamma + \beta T^2$ which is the equation of a straight line with C/T and T^2 as variables, γ and β can then be evaluated from a plot of C/T vs T^2 where the intercept gives the electronic specific heat constant and the slope of the line gives β from which the Debye characteristic temperature can be calculated.

In the rigid band approximation (11), changing the electron concentration Z by alloying changes the level of the Fermi energy but

not the form of the band structure, hence variation of γ with Z reflects the form of $N(E_F)$. Assuming the rigid band model to hold over a wide range of energies, low temperature heat capacity measurements from a number of metals and alloys can be used to determine the rigid band shape following the method of Hoare, Matthews and Walling (6). Assuming the number of electrons in the s-band to remain constant, it is supposed that scandium, when alloyed with a higher or lower valent metal, the effect would be to increase or decrease the number of conduction electrons in the d-band with the shape of the conduction band remaining the same as the host metal. Thus, if n_c and n_o denotes the number of electrons per atom in the d-band for an alloy of fractional concentration c and that for the pure metal respectively,

$$n_c = n_o \pm c, \text{ if the alloying element (solute) contains one more or less d-electron than the host metal (solvent)}$$

then

$$dn_c = \pm dc$$

From the definition of the density of states

$$2N(E) = \frac{dn_c}{dE}, \text{ where the factor of "2" comes in because } N(E) \text{ refers to the density of states for one spin direction only}$$

therefore

$$2N(E)dE = dn_c = \pm dc, \text{ and}$$

$$\pm \frac{1}{2} \int_0^c \frac{1}{N(E)} dc = \int_{E_o}^{E_c} dE = E_c - E_o \quad (5)$$

Using this relation, the shape of the $N(E)$ vs E curve may be determined graphically from the γ vs c curve since $\gamma = \frac{2}{3} \pi^2 k^2 N(E_F)$.

The elements chosen to alloy with scandium for the band structure studies are zirconium and magnesium. Zirconium is chosen as the higher valent solute over titanium because a complete hcp solid solution exists over the entire concentration range from pure scandium to pure zirconium, whereas only limited solid solubility exists for titanium in scandium. Magnesium is chosen as the lower valent solute.

If there are other contributions to the heat capacity, for example, a magnetic contribution, these can be studied by subtracting the electronic and lattice contributions from the total heat capacity which is obtained from direct measurement. The excess heat capacity can then be analyzed by both its temperature dependence and entropy. In order that such an analysis can be carried out, accurate knowledge of the electronic specific heat constant and the Debye characteristic temperature must be available.

III. EXPERIMENTAL PROCEDURE

A. Calorimetry

The low temperature calorimeter used in this project is designed for accurate measurement of small samples in the temperature range of 1 to 20K. The calorimeter is of the isolation heat-pulse type where the measurement is carried out in the following manner. A mechanical heat switch allows the addenda (heater, thermometer and sample holder) and specimen to cool down to the desired temperature by bringing it into contact with a low temperature heat sink such as a liquid helium pot system. Once cooled, the mechanical heat switch is opened, thermally isolating the addenda and specimen. A known amount of electrical current is then applied for a known length of time and from the temperature rise during this time interval the heat capacity can be calculated using the equation $C = Q/\Delta T$, where Q is the quantity of heat that causes the temperature rise ΔT .

The dewar assembly used for the calorimeter is shown in figure 1. The nitrogen dewar provides a 77K environment which together with the vacuum space maintained by a mechanical fore pump act as shields for the interior helium dewar which serves as the liquid helium reservoir.

The calorimeter, as shown in figure 2, is suspended from the top of the dewar assembly by two stainless steel tubes which also serve as the pumping lines for the helium pot and the sample chamber. The helium pot is pumped by a Microvac Stokes pump while vacuum in the

Figure 1. Dewar assembly for the calorimeter

Figure 2. The low temperature calorimeter

sample chamber is maintained by an oil diffusion pump backed with a mechanical fore pump. The helium pot and the sample chamber sit inside a stainless steel can which is directly immersed in liquid helium and thus functions as the 4K shield. This 4K shield is joined to the calorimeter by a woods metal seal.

The helium pot system contains the liquid helium utilized to achieve a temperature of 1K. A Whitney valve is used to allow liquid helium to flow from the reservoir through a 1/16 inch diameter thin-walled stainless steel tube into the pot. By reducing the vapor pressure over the liquid helium in the pot a temperature of approximately 1K can be achieved. The optimum procedure calls for pumping on the helium pot through an orifice located part way down the pot. Pump-down time is improved by having the orifice located part way down because the orifice is not needed until the liquid helium has gone through the λ -point at 2.2K and because approximately 20 percent of the liquid helium must be removed to reach 2.2K. The size of the orifice in this calorimeter is 30/1000 of an inch.

The pot is machined from a solid OFHC copper block and has a volume of approximately 100 cc. A 3/8 inch diameter stainless steel tube is silver soldered to the top to act as the pumping line for the pot. Silver soldered to the bottom of the pot are copper posts for thermal anchoring of electrical leads and the components of the heat switch.

The sample chamber consists of three main parts: 1) the wall of the sample chamber which functions as the 1K radiation shield; 2) the mechanical heat switch which controls the thermal contact between the addenda and sample with the helium pot system; and 3) the addenda which holds the sample. These are shown in detail in figure 3.

The wall of the sample chamber is machined from an OFHC copper block and is screwed onto the helium pot. This wall ensures that the sample is exposed to controlled environment at the temperature of the helium bath in the helium pot system.

The heat switch consists of a horizontal copper bar pivoted at one end on a stainless steel hinge pin which reduces friction in the switch. A stainless steel music wire is attached to the middle of the copper bar and passes upward through the center of the helium pot and is fastened onto a bellow-sealed vacuum valve which actuates the switch. A number of radiation shields in the form of stainless steel discs are mounted on the music wire to prevent the sample chamber from direct exposure to room temperature at the top. Thermal contact between the addenda and helium pot is made by clamping a wire extending from the addenda between the horizontal copper jaw and a copper post silver soldered onto the base of the helium pot. To restrain the switch and reduce vibration, a beryllium-copper spring is mounted between the base of the helium pot and the lower jaw of the switch. To thermally anchor the heat switch lengths of copper braids are used to attach the wire and lower jaw of the switch to the base of the pot.

Figure 3. Sample chamber of the calorimeter

Typically about 100 ergs of heat are generated when the switch is slowly opened at about 1K.

The addenda is consisted of the sample holder, heater and thermometer. The sample holder is made from 5 mil thick copper foil in the shape of a pan with a diameter of $5/8$ " and $1/8$ " high wall. Evenly spaced around the pan and silver soldered to it are three pairs of copper eyelets. From one of the eyelets a length of copper wire extends upward to the jaw of the heat switch.

The addenda and sample are heated resistively and the heater is a length of 1 mil-diameter 92% Pt - 8% W wire wound bifilarly around the wall of the pan and General Electric 7031 varnish is used to thermally and mechanically anchor the heater to the wall of the pan. 92% Pt - 8% W wire is chosen on the basis of strength, high resistance and low temperature coefficient of resistance, small low-temperature heat capacity and low thermal conductivity.

The support for the addenda is provided by the sample chamber. Two $1/8$ " diameter rings are soldered to one-half of a copper cylinder split along its axis as shown in figure 3. Three small copper hangers are spaced evenly around the perimeter and soldered to the ring. The addenda is then suspended from these hangers with lengths of nylon threads to the eyelets on the sample pan. Both the position and rigidity of the addenda mounting can be adjusted with these hangers.

Due to the asymmetry of the pot system and the sample chamber, and the pumping lines extending from them, there may be a tendency

for the calorimeter to pull to one side at low temperature. To ensure that this does not happen, three pointed nylon screws are located at the bottom of the pot and sample chamber to restrain this movement.

All electrical leads from the heater and thermometer are thermally anchored at a copper post which is silver soldered to the base of the helium pot. 92% Pt - 8% W wires run from the heater and thermometer and are thermally anchored by wrapping around the copper post and cemented by GE varnish. These are then joined by Number 36 gauge manganin wires which pass upward inside a thin-wall teflon tubing through the center of the helium pot and then inside a stainless steel tubing before exiting at the top brass plate at room temperature. The stainless steel tubing holding the wires is in contact with the helium bath and is sealed at the top plate with stycast epoxy.

The thermometer circuit is shown in figure 4 where a four-lead technique is used to measure the resistance of the germanium resistance thermometer (GRT) mounted on the addenda. A germanium resistance thermometer is chosen for this low temperature heat capacity work because of its independence of thermal history, small heat capacity and good temperature sensitivity. The thermometer calibration was provided by C. A. Swenson's research group by comparison with two standard germanium resistance thermometers GR 618 and GR 803. Resistance R and temperature T values obtained in this calibration were fitted by means of a least square technique of the form

$$\ln T = A_0 + A_1 \ln R + A_2 (\ln R)^2 + \dots$$

Figure 4. The GRT electrical circuit

The scatter of the data from this fit was approximately $\pm 1\text{mK}$. Because of the complexity of the resistance - temperature relationship, it was necessary to fit the data over narrow temperature ranges of 1.004K to 5.232K, 5.232K to 18.070K, and 18.070K to 78.0K. The breaking point for each range was determined by those points which had the same resistance and temperature to within 1mK and the same slope to within 0.5 percent.

The current supply for the GRT is shown in figure 4. Voltage is supplied by twenty 1.35 volt mercury batteries. Resistors placed in series with the GRT allowed current selection of 0.1, 1.0, 2.0, 4.0, 6.0 and 10.0 μA . A detailed description of the electronics used in heat capacity measurement can be found in David K. Thome's thesis (12).

Temperature measurement is obtained by measuring the voltage drop across the GRT using a Leeds and Northrup K-5 potentiometer and a high impedance Keithley 150B microvolt-ammeter as a null detector-amplifier. By bucking out most of the emf (E_1 and E_2) from the GRT with the potentiometer, and using the microvolt-ammeter to measure the difference between the potentiometer reading and null (E'_1 and E'_2), the drift in temperature of the sample is monitored. This difference is amplified by the Keithley 150B and displayed on a Texas Instrument strip chart recorder.

In this heat capacity measurement, heat is applied in the form of joule heating generated in a known resistance (heater) mounted in the addenda. The heater circuit is shown in figure 5 where the current

Figure 5. The heater electrical circuit

used is supplied by a constant current supply. A three lead connection to the heater is employed. Two current leads and one potential lead are connected to the two heater leads on the wall of the addenda, and the second heater potential lead is connected to the other current lead at the thermal anchor at the copper post. This technique will account for the heat generated in the leads as one-half of the heat generated in the lead enters the addenda and one-half goes to the thermal anchor (13, 14). To determine the resistance of the heater as a function of temperature, known current is passed to the heater and the voltage drop across the heater is measured.

B. Data Acquisition and Reduction

The heat capacity of a sample, usually between 1 to 3 grams, is measured in the following way. First a flat surface is obtained on the sample by cutting with a low-speed diamond saw. After the sample has been weighed to within 0.1 milligram, 6 milligram of Apieizon N grease is added to the flat end of the sample to improve thermal contact with the sample holder. The sample is then placed in the sample holder and the tension in the nylon threads suspending the sample holder adjusted to ensure rigidity so as to reduce vibration and the chance of a thermal short with the 1K shield. The copper 1K shield is screwed onto the helium pot and the 4K shield stainless steel can attached on by means of a woods metal seal. The calorimeter is leak-checked and placed inside the dewar assembly. The helium pot

and its pumping line are evacuated and backfilled with helium gas. The sample chamber is pumped by an oil diffusion pump backed with a mechanical fore pump and when the sample chamber has reached a minimum vacuum of approximately 10^{-5} torr, the system is ready for cool-down. The system is cooled overnight with liquid nitrogen in the dewar and only mechanical contact is used to cool the sample. When the pressure in the sample chamber reaches approximately 10^{-6} torr, liquid helium is transferred into the helium reservoir in the inner dewar. By drawing a slight vacuum in the helium pot, cold helium gas is drawn into the pot through the Whitney valve. Once liquid helium begins to condense in the pot, the vacuum in the pot can be removed. The sample is cooled to 4.2K by means of the mechanical heat switch. Inasmuch as it takes the cryogenic system a couple of hours to stabilize for low temperature operation, data are taken from 4K to 20K first, after which the heat switch is closed and the vapor pressure in the pot reduced until the addenda and sample reach 1K. The heat switch is then opened and data taken from 1K to 4.2K.

Before the heat switch is opened and data actually taken, the electronics are turned on to allow for warm-up and stabilization. The appropriate thermometer and heater currents are selected for the particular temperature range. When the temperature of the sample and addenda has reached equilibrium after the heat switch is opened, a heat pulse is applied. The drift in temperature is monitored on the Texas Instrument strip chart recorder and after a temperature rise of approximately $\Delta T = T/25$, where T is the temperature of the sample and

addenda, the heat pulse is turned off. The temperature drift is again recorded for about 100 seconds after the drift rate becomes linear which is usually in about 10 to 20 seconds. The GRT potentiometer settings before and after the heat pulse are recorded as well as the elapsed time of the heat pulse and the heater current setting. The timer is reset to zero and the calorimeter is ready to take another data point. All heat capacity data are taken in at least two separate runs with the sample warmed to liquid nitrogen temperature between runs to check for reproducibility of data. No systematic deviation from one run to the next is found.

To compensate for the heat-leak from the sample during the heat pulse, the drift rates before and after the heat pulse are extrapolated to the midpoint of the heat pulse to determine the off null readings E'_1 and E'_2 , as shown in figure 6. The E'_1 and E'_2 values are added to the potentiometer readings of E_1 and E_2 to give E_1^T and E_2^T , corresponding to the initial and final voltage readings for the temperature of the sample and addenda. The start and finish of the heat pulse are recorded as a jump in the red pen of the recorder, facilitating the determination of the mid-point of the heat pulse.

To eliminate the error introduced by thermal emfs, the thermometer current is reversed after every five data points are taken and the drift rate monitored on the strip chart recorder. The difference between the forward and reversed voltage readings is due to thermal emfs. Assuming the thermal voltage to change with time, a correction based on this difference between forward and reversed voltage is made to each

Figure 6. Schematic of a typical heat capacity point

data point. A computer is used to calculate the heat capacity using the following equation:

$$C(T) = \frac{(I^2 R t) / \Delta T - CAD(T)}{\text{gm atom}}$$

where

$C(T)$ = heat capacity of sample at temperature T

I = heater current

R = heater resistance

t = time of heat pulse

$CAD(T)$ = heat capacity of addenda as a function of temperature

ΔT = temperature rise due to heat pulse

gm atom = number of gram atom of sample measured.

The heat capacity of the addenda is measured in a previous run following the same procedure to give the quantity $CAD(T)$ needed in the above equation, with 6 milligram of Apieizon N grease added to the sample holder. The data are then least square fitted to an equation of the form:

$$CAD(T) = A_1 T + A_2 T^3 + \dots$$

To improve the fit between data and the above equation, the temperature range is divided into five regions with each region overlapping one another. The cross-over is determined by those points which have the best fit. The scatter in fitting the data with the equation is random and never exceeds 1 percent.

C. Sample Preparation

Scandium as prepared at the Ames Laboratory is carried out by the calcium reduction of scandium fluoride, followed by vacuum melting to remove volatile impurities. The metal is further purified by sublimation into a tungsten-lined tantalum condenser at 1350°C in a vacuum of 10^{-9} torr, and the distillate is arc-melted under argon atmosphere into the final form in the shape of a finger (15). Scandium prepared in this manner usually contains between 30 ppm to 60 ppm (atomic) iron unless special precautions are taken. Mass spectrometric analysis of a typical scandium sample prepared by the above method is shown in table 1. However, since heat capacity measurement of a scandium sample containing 30 ppm (atomic) iron was found to exhibit an anomaly in the standard C/T vs T^2 plot, much purer scandium with respect to the iron impurity was needed in order to arrive at the electronic specific heat constant and the Debye temperature truly representative of intrinsic scandium as well as the starting materials for alloy studies. Since diffusion studies by Dariel et al. showed that gold (16, 17), silver (17), cobalt (17) and iron (18) are fast diffusers in the rare earth metals, the possibility of purifying scandium with respect to the iron group metals by solid state electrotransport was suggested. The rare earth metals are not likely to move under an electric field gradient because of their similarity to scandium. In electrotransport-refining the sample, in the shape of a rod, is heated by internal resistance using a high density DC electric current which causes many of the

Table 1. Chemical analysis of scandium as routinely prepared at the Ames Lab. All analysis are from mass spectrometry except hydrogen, oxygen, and nitrogen are from vacuum fusion analysis. All are atomic ppm.

Element	Concentration	Element	Concentration	Element	Concentration
H	357	Ga	< 0.02	Re	< 0.2
Li	Not detected	Ge	< 0.03	Os	< 0.3
Be	< 0.1	As	< 0.006	IR	< 0.1
B	< 0.001	Se	< 0.1	PT	< 0.2
C	37	Br	< 0.04	Au	< 0.03
N	26	Rb	< 0.003	Hg	< 0.04
O	267	Sr	< 0.008	TL	< 0.02
F	28	Y	5.7	Pb	< 0.08
Na	0.2	Zr	< 0.3	Bi	< 0.02
Mg	< 0.01	Nb	< 0.5	Th	< 0.3
Al	00.1	Mo	< 0.2	U	< 0.1
Si	< 0.1	Ru	< 0.2	La	3.3
P	< 0.006	Rh	< 0.03	Ce	0.6
S	< 0.2	Pd	0.01	Pr	0.3
Cl	5	Ag	< 0.01	Nd	0.5
K	< 0.1	Cd	< 0.03	Sm	0.2
Ca	0.20	In	< 0.01	Eu	< 0.07
Ti	< 0.08	Sn	< 0.04	Gd	< 2
V	< 0.007	Sb	< 0.02	Tb	< 0.09
Cr	< 0.8	Te	< 0.03	Dy	< 0.2
Mn	0.060	I	< 0.01	Ho	< 0.08
Fe	30	Cs	< 0.002	Er	< 0.2
Co	0.51	Ba	0.09	Tm	< 0.06
Ni	2	Hf	< 0.4	Yb	< 0.1
Cu	2.2	Ta	0.56	Lu	< 0.1
Zn	< 0.1	W	1.9		

impurities to migrate with the flow of electrons to the anode end of the rod.

The first scandium sample purified by electrotransport (ET-1) was 16.5 cm long and 0.25 cm in diameter. In recent studies on polymorphic transition metals (Th, Zr, Gd, Hf, Ti and Fe), the highest electric mobilities of interstitial and metallic solutes have been observed in the high temperature bcc phase (19, 20, 21, 22, 23). Hence the sample was heated above the polymorphic transition temperature in scandium to 1360°C for 80 hours under a 130 torr pressure of purified helium using a current density of 1300 A/cm². The resistance ratio ($R_{300}/R_{4.2}$) of the original scandium was increased from 32 to 330 in the purest section of the refined sample. Mass spectrometric analysis showed that the iron concentration was reduced to as low as 0.6 ppm (atomic) in this section of the rod, and a profile of iron impurity concentration along this rod is shown in Figure 7. Mass spectrometric analysis of the first electrotransport-refined scandium is shown in table 2. The concentration of the magnetic lanthanides in this sample totaled 29 ppm, with 16 ppm Gd being the highest.

Three other scandium samples (16 cm long and 0.6 cm diameter) were electrotransport purified in similar manners, but with the samples heated to only 1275°C under a purified helium atmosphere of 130 torr, which is below the transformation temperature of 1337°C. A current density of only 700 A/cm² was required to heat the sample to the lower temperature because of the poor heat dissipation of the thicker sample.

Figure 7. Profile of Fe concentration along ET-1

Table 2. Chemical analysis of electrotransported scandium ET-1. All analysis are from mas spectrometry and are atomic ppm

Element	Concentration	Element	Concentration	Element	Concentration
Li	< 2	Se	< 0.2(0.4)	Os	< 0.6
Be	< 0.1	Kr	< 0.09	Ir	< 0.2
B	0.003(0.08) ^a	Rb	< 0.007	Pt	< 0.3
Na	10	Sr	< 0.02	Au	< 0.7
Mg	< 0.2	Y	2	Hg	0.3
AR	1	Zr	< 4	Tl	< 0.05
Si	6.6(19)	Nb	< 3	Pb	< 0.2
P	< 0.02(0.04)	Mo	0.2	Bi	< 0.04
S	< 2(20)	Rm	< 0.6	Th	< 0.6
cl	6(100)	Rh	< 0.06	U	< 0.2
K	2	Pd	< 0.2	La	7.8
Ca	0.1	Ag	< 0.03	Ce	5
Ti	0.8	Cd	< 0.05	Pr	2.0
V	< 0.09	In	< 0.03	Nd	< 0.5
Cr	0.2(2.4)	Sn	< 0.09	Sm	0.51
Mn	< 0.01(4.2)	Sb	< 0.04	Eu	< 0.1
Fe	0.6(98)	Te	< 0.05	Gd	16
Co	0.2	I	< 0.03	Tb	1
Ni	3(30)	CS	< 0.003	Dy	1.9
Cu	3(36)	Ba	0.2	Ho	0.47
Zn	0.2	Hf	< 0.7	Er	1.4
Ga	< 0.04	Ta	23	Tm	0.1
Ge	< 0.06	W	380	Yb	< 0.2
As	< 0.01	Re	< 0.4	Lu	< 5.1

^aNumbers in parentheses are concentration in untreated rod.

For this reason and because the mobility of the solutes is quite low in the hcp form, the samples were heated for an extended period of 500 hours, 1225 hours, and 675 hours respectively for the second, third and fourth electrotransported samples. The purified sample had a bamboo-type structure with each segment being a single crystal.

For the second electrotransported sample ET-2, wet chemical analysis of the sample gave an iron concentration of 5.0 ppm (atomic) near the cathode end of the rod and 2.7 ppm (atomic) at the anode end. Mass spectrometric analysis showed that the center of the rod had an iron concentration of 0.5 ppm (atomic) and the total magnetic lanthanide concentration in this sample was 11 ppm with 5.5 ppm Gd being the highest. For the third electrotransported sample (ET-3), mass spectrometric analysis along the rod gave a profile of the nine highest impurities as shown in table 3. Only electrotransported scandium was used as the starting materials for alloy studies.

An attempt was also made to purify single crystals of scandium by electrotransport refining on the third run. First a single crystal of scandium was grown by the strain-anneal method at 1200°C under a 10^{-8} torr vacuum. At the end of five days the furnace was turned down slowly, cooling at the rate of approximately 150°C per hour. A single crystal, about 5 cm long was obtained in the shape of a finger with the a-axis running approximately along the length of the finger. After aligning the crystal using the back-reflection Laue X-ray technique, two single crystals in the shape of 1/4" x 1/4" x 5/16" bars were

Table 3. Mass spectrometric analysis of the third electrotransport -
refine Sc ET-3 in ppm (atomic)

Element/section	A ^a	B	C	D	E	F
Fe	1	2	0.7	3	1	1
Y	13	12	10	12	8	10
Ld	6	6	8	7.5	3.6	5.5
Ce	0.95	1.0	0.9	1.0	1.4	0.8
Gd	7.5	5.5	8	10.5	16	7.5
Tb	0.7	0.9	1.1	0.8	1.0	0.6
Cr	3	0.1	0.2	0.6	0.4	4
Cu	1.2	6	2.6	6.5	4.6	9
Ni	0.6	0.5	< 0.1	1.7	< 0.5	5

^aFor position of sections along rod, see figure 8.

spark-cut from the finger with the a-axis running along the axis of one bar and the c-axis running along the axis of the other bar. These single crystals were then hand-polished into the shape of rods 1/4" in diameter, with the a- and c-axis along the lengths of the rods respectively. Two polycrystalline scandium rods were spot-welded on either end of the a- and c-axis single crystals in the arrangement as shown in figure 8. Resistance ratio after electrotransport refining are as follows (24):

$$\text{c-axis: } R_{300}/R_{4.2} = 269$$

$$\text{a-axis: } R_{300}/R_{4.2} = 355$$

All alloys, with the exception of the Sc-Mg alloys, were prepared by arc-melting weighed amounts of each components under a partial argon atmosphere. To ensure homogeneity, the samples were each turned over four times and re-arc melted. After the alloys were made, they were weighed again to ensure no excessive loss in weight due to vaporization or gain in weight due to contamination. The samples were then sealed under a partial helium atmosphere in tantalum crucibles which had been previously outgassed at the annealing temperatures and annealed in vacuum to ensure the formation of homogeneous solid solutions. The heat treatments consisted of annealing at 900°C for one week for the Sc-Zr alloys and 765°C for one week for the Sc-Fe alloys. After heat treatments, the samples were examined metallographically to ensure that only homogeneous solid solutions were formed without second phase being present.

x - positions where mass spectrometric analysis were taken

Figure 8. Schematic for single crystal arrangement and mass spectrometric analysis of ET-3

The Sc-Mg alloys cannot be prepared by the conventional arc-melting method due to the great difference in melting points. Scandium melts at 1539°C while magnesium melts at 650°C and boils at 1090°C. Instead the Sc-Mg alloys were prepared by a deposition-diffusion method (25). Scandium strips (4 cm x 0.6 cm x 0.15 cm) were attached by means of tantalum wires onto the lid of a tantalum crucible as shown in figure 9. Weighed amounts of magnesium were placed in the bottom of the crucible and a circular tantalum plate with a diameter slightly larger than the diameter of the crucible and a 70/1000" hole in the middle was placed on top of the magnesium to act as a vapor barrier. The function of the vapor barrier was to slow the rate of magnesium vapor passing upward into the chamber where the scandium strips were hung. The crucible was then arc-welded shut under a partial helium atmosphere and heated under a 10^{-5} torr vacuum in a resistance furnace to 1300°C and kept at that temperature for one week. The magnesium vaporized, passed upward through the hole in the vapor barrier and was deposited on the surface of the scandium strips and diffused in to form the Sc-Mg alloys. All tantalum crucibles used had been previously outgassed at 1300°C and holding the samples at this temperature for one week allowed homogenization of the alloys. The top 0.3 cm of each strip was discarded to avoid tantalum contamination from the tantalum wire. Electron microprobe and X-ray analysis were used to check the composition of the alloys and to see if a composition gradient existed; no such composition gradient was found to exist for any of the Sc-Mg alloys. A plot of the unit cell

Figure 9. Ta crucible for making Sc-Mg alloy

volume versus magnesium concentration is given in figure 10 where it can be seen that within experimental error, Vegard's rule is followed.

For the Sc-Fe alloys, Sc-Fe-I and Sc-Fe-II, in the as cast condition and containing respectively 30 ppm and 50 ppm iron (atomic), were taken from the scandium stock as prepared conventionally at the Ames Laboratory. To make the two samples Sc-Fe-III containing 85 ppm iron (atomic) and Sc-Fe-IV containing 111 ppm iron (atomic), a master sample having an iron concentration of 5000 ppm (atomic) was first prepared. Then the two alloys were made by arc-melting together weighed amounts of the master sample with Sc-Fe-I. The samples were each turned over four times during arc meltings to allow for homogeneity and heat capacity measurements carried out on these as cast samples. The samples were then sealed in tantalum crucibles under partial helium atmosphere and annealed under vacuum at 765°C for one week and heat capacity measurements were then made on these annealed samples. The sample containing 19 ppm iron (atomic) in the annealed condition was Croat's sample 4-155 (26).

D. Error Analysis

The Cryocal #3979 germanium resistance thermometer used in this investigation was calibrated by Dr. C. A. Swenson's research group, Ames Laboratory, to an accuracy of ± 0.5 mK between 1 to 5K and ± 3 mK above 5K. This would introduce an error in temperature measurement of not more than 0.05%. The constant current supply for the potentiometer has

Figure 10. Variation of unit cell volume with Mg concentration

been temperature compensated to drift less than 0.2 parts per million per degree Centigrade (Kelvin), allowing the voltage to be read to within 0.02% of the true value. The heater current is also provided by a constant current supply and is read to within 0.001 mA when its value enters the equation for heat capacity calculation, and thus has a maximum error of 0.02%. The current to the heater, timer and marker-pen of the strip chart recorder are all triggered with a relay to close contacts within 2 milliseconds of each other. The time of the heat pulse is read to within 0.1 milliseconds, introducing an error of not more than 0.01%. The weight of the sample and the amount of N grease added are all measured to 0.0001 gram, and the error associated with this measurement is less than 0.01%. The sum total of all these uncertainties would give an error of not more than 0.3%. The largest error is probably produced by the extrapolation of the temperature to the mid-point of the heat pulse.

To check the overall operation and the validity of the thermometry, and also to determine the percent accuracy that can be obtained from this apparatus, the heat capacity of the 1965 Calorimetry Conference Copper Standard was measured between 1 to 20K. The results were then compared with the reference equation (27) given for this copper standard. There is no systematic deviation between the results of the heat capacity measurement and that generated from the reference equation, and the scatter from the standard values lies within $\pm 1.5\%$ below 4.2K and within 1% from 4.2 to 20K. Least square fit of copper results gives

$\gamma = 0.6939 \pm 0.0020 \text{ mJ/gm-atom K}^2$ and $\theta_D = 344.2 \pm 0.5\text{K}$ which agrees very well with the values reported by Cetas et al. (28) of $\gamma = 0.6932 \pm 0.0040 \text{ mJ/gm-atom K}^2$ and $\theta_D = 343.7 \pm 1\text{K}$, the values reported by Martin (29) of $\gamma = 0.6915 \pm 0.0034 \text{ mJ/gm-atom K}^2$ and $\theta_D = 345.8 \pm 1.2\text{K}$ and finally that by Osborne et al. (27) of $\gamma = 0.6943 \text{ mJ/gm-atom K}^2$ and $\theta_D = 344.5\text{K}$. The γ values deviates by 0.2% from that reported by Osborne et al. on the same copper standard while θ_D deviates by less than 0.1%; when compared to the results of Cetas et al. and Martin, γ deviates by 0.1% while θ_D deviates by less than 0.3%. This lends confidence to the γ and θ_D values obtained in this investigation on Sc and Sc base alloys by least square fitting the low temperature heat capacity results.

IV. RESULTS

A. Scandium

The electronic specific heat constant γ and the Debye temperature Θ_D as derived from the heat capacity results of three electrotransport-refined Sc are shown in table (4) together with the results which are reported by earlier investigators (30, 31, 32, 33, 34, 35). Also included in the table are the iron impurity concentrations which are important to the interpretation of the results. As can be seen from the values reported by earlier investigators, γ varies from 10.3 to 11.3 mJ/gm-atom K^2 (almost 10% variation) while Θ_D varies from 344 to 470K (an enormous 30% variation). Such large variations, especially for the Debye temperature are most unusual. Furthermore, two of the investigators noted a departure from linearity in the standard C/T vs T^2 plot below 2K (34, 35) and a third showed a similar anomaly below 5K (33). The inclusion of a Schottky T^{-2} term (36) in their analysis of heat capacity results to explain the rise at low temperature in the C/T vs T^2 plot did not give the correct γ and Θ_D values, indicating that a T^{-2} term cannot account for the excess heat capacity due to the iron impurity. The nature of this contribution will be discussed under the section on Sc - Fe alloys.

In this study, heat capacity was first carried out on a routinely prepared scandium sample containing 30 ppm (atomic) iron. In the C/T vs T^2 plot, an anomaly was found at 1.1K as shown in figure 11. A

Figure 11. Heat capacity results for two Sc samples

Table 4. Heat capacity results on various scandium samples

γ (mJ/gm-atom K ²)	Θ_D (K)	Fe conc. (ppm atomic)	Temp. Range (K)	Reference
11.3 $\pm$ 0.1	470 $\pm$ 80	56	1.7 - 4.2	30
10.3 $\pm$	--	--	--	31
10.9 $\pm$ 0.1	344 $\pm$ 25	60	0.15 - 3.0	32
10.66 $\pm$ 0.1	359.5 $\pm$ 4	80	1 - 23	33
10.72 $\pm$ 0.03	425.6 $\pm$ 14	95	1.14 - 4.2	34
10.72 $\pm$ 0.05	359 $\pm$ 9	40	0.5 - 4.2	35
10.426 $\pm$ 0.012	391.4 $\pm$ 1.5	30	1.03 - 19.7 ^a	
10.313 $\pm$ 0.008	344.7 $\pm$ 0.8	1.6	1.09 - 20.0	ET-1 ^b
10.354 $\pm$ 0.004	346.8 $\pm$ 0.4	0.5	1.06 - 20.5	ET-2 ^b
10.331 $\pm$ 0.005	347.9 $\pm$ 1.2	0.7	1.09 - 20.0	ET-3 ^b

^aThis study, routinely prepared Sc.

^bThis study, electrotransported Sc.

least square fit of data above 1.5K in the linear region gave $\gamma = 10.426 \text{ mJ/gm-atom K}^2$ and $\Theta_D = 391.4\text{K}$. This γ value is about the same as the lowest value previously reported but the Θ_D value falls near the middle of the range of values reported, see table 4. Similar results were obtained with scandium samples containing larger amount of iron, except that the magnitude of the anomaly increases with higher iron concentration (refer to section on Sc-Fe alloys).

The heat capacity results obtained from measurements on three separate electrotransport-refined scandium samples agree very well with each other. The first heat capacity measurement (ET-1) was carried out on seven pieces of electrotransported scandium, approximately 1 cm long and 0.25 cm in diameter, and weighing a total of 0.82 gm with an average iron concentration of 1.6 ppm (atomic). No anomaly was found down to 1.09K in the C/T vs T^2 plot. The second and third heat capacity measurements (ET-2 and ET-3) were made on larger samples - 0.6 cm in diameter, with the ET-2 measurement consisting of two pieces, weighing 1.7 gm and with an iron content of 0.5 ppm (atomic) and the ET-3 measurement consisting of 1 piece, weighing 0.85 gm and with an iron impurity level of 0.7 ppm (atomic). Again no anomaly was found in heat capacity down to the lowest temperatures.

The resultant γ and Θ_D values are virtually the same for all three electrotransported samples and the weighted average values gave $\gamma = 10.337 \pm 0.015 \text{ mJ/gm-atom K}^2$ and $\Theta_D = 346.7 \pm 0.8\text{K}$.

The temperature dependence of the Debye temperature of scandium (ET-2) is shown in figure 12, where it can be seen that the Debye

Figure 12. Temperature dependence of the Debye Temperature of the scandium sample (ET-2)

temperature remains constant over a large temperature range up to 10K before it begins to deviate negatively from linearity with increasing temperature. The temperature range over which Θ_D is constant is about twice as large as is found for many metallic substance.

The values for the electronic specific heat constant and the Debye temperature are believed to be truly representative of intrinsic scandium and these values will be used in making any calculations and comparison with theoretical data.

B. Sc-Zr Alloys

With the exception of the 0.5 atomic percent Zr in Sc alloy, all alloys were made using electrotransported Sc and Zr as the starting materials to ensure that the iron impurity level was reduced to a minimum. Wet chemical analysis on the electrotransported Zirconium provided by F. A. Schmidt (FRS-27-98) gave an iron content of 10 ppm (atomic). For the $\text{Sc}_{0.95}\text{Zr}_{0.05}$ alloy the starting materials were electrotransported Sc and a piece of Zr containing 47 ppm (atomic) iron. Starting with the 5.0 atomic percent Zr alloy, electrotransported Zr was added to make the following alloys in the sequence of 7.5 at. %, 15 at. %, 20 at. %, 25 at. %, 26.5 at. %, 28 at. %, 30 at. % and 34 at. %. Similarly, the 0.5 at. % Zr in Sc sample was used to make the 1.0 at. % and 3.5 at. % alloys, and 2.0 at. % Zr in Sc was used to make the 8 at. %, 9.0 at. %, 10 at. %, 12 at. % and 17.5 at. % alloys. Then an alloy of composition 0.25 at. % Zr in Sc was made from electrotransported Sc and Zr as the starting materials.

The heat capacity results of all the Sc-Zr alloys follow the same trend of linearity in the C/T vs T^2 plot as in pure scandium, with the linear relationship followed up to about 10K. Values for the electronic specific heat constant γ and the Debye temperature θ_D as derived from least square fitting the heat capacity results are given in table 5. These are plotted against the zirconium concentration in figures 13 and 14. Figure 15 shows the heat capacity results of this study in comparison with works done by Betterton and Scarbrough (34), and Jenson and Maita (37). It can be seen from the figures that γ increases with zirconium addition up to 0.5 atomic percent, then decreases monotonically with further zirconium addition up to the highest zirconium concentration carried out in this study - 34 at. %. Combining with results reported by Betterton and Scarbrough, and Jenson and Maita, γ is observed to continue to decrease to the value corresponding to 90 at. % Zr, then γ increases to the value corresponding to pure Zr. The Debye temperature also increases sharply with zirconium additions, reaching a maximum at 0.5 at. % Zr. It then decreases with further zirconium addition as shown in the figures. The sharp rise in Debye temperature from 346.7 to 368.7K with the addition of 0.5 at. % Zr parallels the sharp rise in the electronic specific heat constant which is most unusual, indicating the sensitivity of the Debye temperature to solute addition.

Table 5. Heat capacity results of the Sc-Zr alloys

Composition (atomic %Zr)	ϑ (mJ/gm-atom K ²)	Θ_D (K)
Pure Scandium	10.337 $\pm$ 0.015	346.7 $\pm$ 0.8
0.25	10.605 $\pm$ 0.010	353.9 $\pm$ 0.5
0.50	11.003 $\pm$ 0.015	368.7 $\pm$ 1.0
1.0	10.935 $\pm$ 0.003	367.2 $\pm$ 0.5
2.0	10.564 $\pm$ 0.007	364.9 $\pm$ 1.8
3.5	10.411 $\pm$ 0.003	365.1 $\pm$ 0.4
5.0	10.134 $\pm$ 0.003	364.0 $\pm$ 0.6
7.5	9.704 $\pm$ 0.006	363.6 $\pm$ 1.1
8.0	9.548 $\pm$ 0.004	359.6 $\pm$ 0.5
9.0	9.337 $\pm$ 0.005	354.6 $\pm$ 0.4
10.0	9.198 $\pm$ 0.003	349.5 $\pm$ 0.3
12.0	8.906 $\pm$ 0.005	349.9 $\pm$ 0.5
15.0	8.562 $\pm$ 0.005	351.2 $\pm$ 1.1
17.5	8.216 $\pm$ 0.003	348.6 $\pm$ 0.3
20.0	7.905 $\pm$ 0.004	353.0 $\pm$ 0.4
25.0	7.317 $\pm$ 0.004	343.6 $\pm$ 0.4
26.5	7.163 $\pm$ 0.003	344.8 $\pm$ 0.3
28.0	7.018 $\pm$ 0.013	346.5 $\pm$ 0.7
30.0	6.793 $\pm$ 0.003	344.9 $\pm$ 0.3
34.0	6.362 $\pm$ 0.004	343.2 $\pm$ 0.3

Figure 13. Variation of λ with electron concentration

Figure 14. Variation of θ_D with electron concentration

Figure 15. Variation of θ_D and γ with Zr concentration

C. Sc-Mg Alloys

Low temperature heat capacity measurements were carried out on four Sc-Mg alloys with the following compositions which were determined by electron microprobe analysis: 1.89 ± 0.05 , 3.31 ± 0.08 , 4.40 ± 0.13 and 6.99 ± 0.30 at. % Mg. In all cases neither a second phase nor a concentration gradient were found. The first alloy made was one with a concentration of 4.40 at. % Mg and this was then used to make the alloy with 6.99 ± 0.30 at. % Mg. Similarly, the 1.89 at. % Mg in Sc alloy was used to make the alloy with 3.31 at. % Mg. The reason for not carrying the investigation past a magnesium concentration higher than 8 at. % is because it is important that Mg be in complete solid solution in Sc. Joseph and Gschneidner (38) have studied the solid solubility of magnesium in some lanthanide metals, and based on the similarity between scandium and the lanthanides, the solid solubility limit of magnesium in scandium is expected to be between 10 to 15 at. %.

The heat capacity results are plotted in figures 13 and 14 and tabulated in table 6. Also tabulated is the unit cell volume of the Sc-Mg alloys. As can be seen from the plots, the electronic specific heat constant decreases slowly as magnesium is added while the Debye temperature is again very sensitive to the magnesium concentration as in the case of the Sc-Zr alloys. The Debye temperature drops rapidly as dilute amount of magnesium is added as contrasted to the rapid increase in Θ_D when a dilute amount of zirconium is added. It then

Table 6. Heat capacity results of the Sc-Mg alloys

Composition (atomic % Mg)	γ (mJ/gm-atom K ²)	Θ_D (K)	unit cell volume (Å ³)
1.89 ± 0.05	9.875 ± 0.010	336.9 ± 0.7	49.8297 ± 0.0076
3.31 ± 0.08	9.802 ± 0.032	331.7 ± 1.9	49.7922 ± 0.0108
4.40 ± 0.13	9.737 ± 0.003	553.8 ± 0.3	49.7208 ± 0.0010
6.99 ± 0.30	9.578 ± 0.011	344.4 ± 1.1	49.5755 ± 0.0220

oscillates in value with increasing magnesium concentration with the error limit in the determination of the Debye temperature smaller than the variation of θ_D with magnesium concentration.

D. Sc-Fe Alloys

Low temperature heat capacity measurements were carried out on the Sc-Fe alloys both in the as cast and annealed conditions. In all cases, deviations from linearity in the standard C/T vs T^2 plot are observed at low temperatures with C/T increasing with decreasing temperature below a certain critical temperature (see figure 11). The magnitude of this anomaly increases with the iron concentration and is sensitive to the heat treatments involved, being greater in magnitude for the annealed samples than for the as cast samples. Excess heat capacity, obtained by subtracting from the total heat capacity the lattice and electronic contributions, is plotted against temperature in figures 16 and 17 for the as cast and annealed conditions respectively. The solid line represents the best fit curve through the data points.

In figure 16, it can easily be seen that the excess heat capacity for both the samples containing 30 and 50 ppm iron (atomic) in the as cast condition reaches a maximum at approximately 1.09K, while for the sample containing 85 ppm no peak is found with the excess heat capacity decreasing with increasing temperature. However, the excess heat capacity is disproportionally much greater than that of the two samples

Figure 16. Excess heat capacity of the Sc-Fe alloys in as cast condition as a function of temperature

Figure 17. Excess heat capacity of the Sc-Fe alloys after annealing as a function of temperature

containing 30 and 50 ppm iron. A broad maximum is found for the sample containing 111 ppm iron which drops off to zero abruptly above 5K.

After annealing at 765°C for one week, the excess heat capacity increases for all samples (compare figures 16 and 17), particularly so for the two alloys with 30 and 50 ppm iron. The peaks in the excess heat capacity shift to much lower temperatures than that reached in this investigation for these two samples. A Sc-Fe alloy containing 19 ppm iron (atomic) was also measured and the excess heat capacity plotted as shown. This is Croat's (26) sample #4-155. As is shown in figure 17, the excess heat capacity increases with increasing iron concentration. While no maximum in excess heat capacity is observed for the three lowest iron concentration alloys, a plateau is found for the sample with 85 ppm iron around the lowest temperature reached, about 1.1K. The broad maximum found in the as cast condition for the sample containing 111 ppm iron narrows down and shifts to a lower temperature of about 2.3K. A second shoulder is also observed at approximately 5K.

Despite the anomaly found in the C/T vs T^2 plots, the C vs T curves show no evidence of magnetic ordering down to 1K. To confirm this, electrical resistance was measured by Spencer (39) on Sc-Fe-II containing 50 ppm iron (atomic) from 4 to 0.3K. The electrical resistance was found to be constant within the experimental background noise and independent of temperature indicating that probably no magnetic ordering took place in either the arc-melted or annealed sample.

V. DISCUSSION

A. Scandium

For non-interacting electron gas, it has been shown that the electronic contribution to specific heat is given by the equation

$$C_{el} = \frac{2}{3} \pi^2 k^2 N_o(E_F) T = \gamma_o T$$

where $N_o(E_F)$ is the bare or free density of states at the Fermi level per atom per spin direction. However, experimentally the electronic contribution to heat capacity is given by

$$C_{el} = \frac{2}{3} \pi^2 k^2 N(E_F) T = \gamma T$$

The difference between γ and the "free electron" value γ_o arises from the periodic potential of the lattice and various direct and indirect interactions. This difference is frequently represented by the effective mass ratio

$$\frac{m^*}{m} = \frac{\gamma}{\gamma_o}$$

$N(E_F)$ and γ are related to $N_o(E_F)$ and γ_o by the relationship

$$\frac{N(E_F)}{N_o(E_F)} = \frac{\gamma}{\gamma_o} = 1 + \lambda$$

where λ is the total enhancement factor and can be expressed as

$$\lambda = \lambda_{ep} + \lambda_{ee} + \lambda_{spin}$$

where λ_{ep} = electron-phonon enhancement

λ_{ee} = coulombic or electron-electron enhancement factor

λ_{spin} = contribution due to spin fluctuation or the electron-paramagnon enhancement factor.

Generally λ_{ee} is small compared to λ_{ep} and λ_{spin} for transition metals (40) and of the order of or smaller than the uncertainty in λ_{ep} . Thus the equation can be simplified to

$$\frac{N(E_F)}{N_0(E_F)} = \frac{\gamma}{\gamma_0} = 1 + \lambda_{op} + \lambda_{opin}$$

There are several methods for obtaining the electron-phonon enhancement factor: 1) λ_{ep} can be calculated from an integration of the electron-phonon matrix element over the Fermi surface, and Allen and Cohen (41) had calculated λ_{ep} for seventeen non-transition metals using an empirical pseudopotential and empirical phonon spectrum (when available, 2) λ_{ep} can be obtained from extrapolation of the electronic specific heat coefficient $\gamma(T)$ at high temperature to OK since at high temperatures, the electron-phonon enhancement factor is zero. Grimwall (42) had shown that at $2\theta_D$, the mass enhancement due to electron-phonon interaction is essentially zero and Knapp and Jones (43) had calculated an electron-phonon enhancement factor for scandium of $\lambda_{ep} = 0.3 \pm 0.05$ using the high temperature heat capacity results of Weller and Kelley (44) and Dennison et al. (45), 3) for strong-coupling superconductors, λ_{ep} can be extracted from electron tunneling results (46), 4) McMillan's equation for the superconducting transition temperature (47)

$$T_c = \frac{\Theta_D}{1.45} \exp \left[-\frac{1.04(1 + \lambda_{ep})}{\lambda_{ep} - \lambda_{ee}(1 + 0.62 \lambda_{ep})} \right] \text{ can be used to calculate } \lambda_{ep}$$

if T_c , Θ_D and λ_{ee} are known, and 5) from NMR results where Ross et al.

(48) had calculated $\lambda_{ep} = 0.3$ for scandium. Knowing λ_{total} from experimental results and band structure calculation λ_{spin} can be estimated if λ_{ep} is known.

There are five different band structure calculations for scandium (49, 1, 50, 51, 52). Table 7 shows the methods and the parameters used in each of the calculations. Also shown in the table are the density of states at the Fermi level as well as the effective mass ratio calculated using the respective band structure density of states and that obtained from heat capacity measurement. Choosing the band structure calculation by Das (51) who gave a total density of states at the Fermi level of $26.73 \text{ Ry}^{-1} \text{ atom}^{-1}$, or $1.965 \text{ eV}^{-1} \text{ atom}^{-1}$ ($0.983 \text{ eV}^{-1} \text{ atom}^{-1} \text{ spin}^{-1}$), the effective mass ratio is computed to be $m^*/m = \partial/\partial_0 = 2.233$ (for reasons of this choice, see section on Sc-Zr alloy system).

Thus $\lambda_{total} = 1.232$ and using $\lambda_{ep} = 0.3$ for scandium, a value of $\lambda_{spin} = 0.93$ is obtained. This indicates that the virtual scattering of electrons on the Fermi surface via spin fluctuations play a dominant role in enhancing the density of states in addition to that due to the electron-phonon interaction for scandium. Beck and Schrieffer (53) and Doniach and Engelsberg (54) had also suggested that the effect of spin fluctuation is analogous to the phonon mass enhancement but arises from emission and absorption of spin fluctuation as found in the

Table 7. Theoretical band structure calculation for scandium

Investigators	Methods	Crystal potential	Atomic configuration	<u>Lattice parameters</u>		$N_0(E_F)$ ($\text{eV}^{-1} \text{atom}^{-1} \text{spin}^{-1}$)	Effective mass ratio m^*/m
Fleming and Louck	APW ^a with full slater $\rho^{1/3}$ term	Warped muffin-tin potential with radius of 3.044Å	3d4s ²	6.253 au	9.965 au	1.139	1.925
Altman and Bradley	Cellular method	Sc ³⁺ potential filled		6.25 au	9.94 au	0.647	3.389
Das Freeman Koelling Muller	Relativistic APW with full slater $\rho^{1/3}$ term	Warped muffin-tin potential of 3.082 Å	3d4s ²	6.2421 au	9.9466 au	1.308	1.677
Das	APW with full slater $\rho^{1/3}$ term	Warped muffin-tin potential	3d ² 4s	6.2391 au	9.9316 au	0.983	2.233
Supta and Freeman	APW with full slater ρ term	Warped muffin-tin potential with radius of 2.9872Å	3d ² 4s	6.2391 au	9.9316 au	1.176	1.865

^aAPW = argumented plane wave method.

paramagnetic susceptibility in palladium. This value of λ_{spin} agrees reasonably well with that quoted by Das (51) of $\lambda_{\text{spin}} = 1.24$ calculated from the molecular field parameter in random phase approximation.

Using McMillan's equation for superconducting transition temperature and Bennemann and Garland (55) equation for $\lambda_{\text{ee}} = 0.26N_o(E_F)(1+N_o(E_F))^{-1}$, a value of $T_c = 0.016\text{K}$ is obtained which is consistent with the experimental results to date.

It can be seen from the above that the electron-phonon enhancement factor alone cannot explain the discrepancy between the experimentally determined density of states for scandium and that obtained from band structure calculations. Either the electron-phonon interaction is more complicated than can be described by a constant λ_{ep} or there are other contributions to the conduction electron mass enhancement, particularly that associated with the interaction between the conduction electron and the persistent spin fluctuation which is shown to be about three times stronger than the electron-phonon interaction. Such a large exchange enhancement can also be found in palladium which is responsible for Pd large magnetic susceptibility, and is also the reason for the large exchange-enhanced spin susceptibility of scandium. This large electron-paramagnon interaction together with the comparatively small electron-phonon interaction is probably responsible for the absence of superconductivity in scandium.

For most metals, the Debye approximation to the lattice contribution to heat capacity is valid only over a short temperature region of

$T \leq \theta_D/50$. But for scandium the Debye model is found to be valid up to almost 10K before it deviates negatively from a constant value with increasing temperature, implying the phonon spectrum is dispersionless below 10K and can adequately be described by the first term in the power series expansion of the phonon density of states. The most recent work on the elastic constant measurements on single crystals of scandium is done by Fisher and Dever (56). Their results on a sample containing 40 ppm Fe and 500 ppm Th (by weight) gives a Debye temperature of 355K calculated using the formula by Wolcott (57) for hexagonal metals. This value of the Debye temperature calculated from elastic constants falls within the range of Debye temperatures determined from heat capacity measurements for the scandium samples containing rather "high" iron impurity level (see table 4).

B. Sc-Zr Alloys

Low temperature heat capacity measurements on the Sc-Zr alloy system had been carried out previously by Jensen and Maita (37), and Betterton and Scarbrough (34). Their combined results show that the superconducting transition temperature of zirconium rapidly decreases as scandium is added. They also found that the electronic specific heat constant at first decreases with scandium addition, reaching a minimum at about 90% Zr - 10% Sc, then γ increases as the concentration of scandium increases. For the Debye temperature, their results show a gradual increase as scandium is added (see figure 15).

In the analysis of their results to explain the disappearance of superconductivity as scandium is added to zirconium, Jensen and Maita assumed that the electron-phonon interaction to be a constant (V_{ep} is arbitrarily chosen to be 0.7 eV) for the series of Sc-Zr alloys under investigation and they used the BCS formula (58) for superconducting transition temperature T_c modified to take into account the effect of electron-phonon interactions on the normal electronic properties (59, 60) to calculate what the Coulomb interaction must be to fit the experimental data:

$$T_c = \theta_D \exp(-1/g)$$

$$g = N_o(0)(V_{ep} - V_c)/(1 + N_o(0)V_{ep}), \quad \text{where}$$

N_{ep} = electron-phonon interaction

V_c = Coulomb or electron-electron interaction

$N_o(0)$ = unenhanced density of states

They found that, as compared to other transition metals with less than half-filled d shells, the net attractive electron-electron interaction which is responsible for superconductivity sharply decreases as the number of d-electrons is decreased when moving from zirconium to scandium (or a rapid rise in the Coulomb and other repulsive interactions as scandium is added to zirconium). Together with the apparently large exchange enhancement of spin susceptibility of pure scandium, a behavior observed to be similar to that found near the filled end of the transition metal series (i.e. near Pd), they suggested that the proximity of a d-band edge may be causing the absence of superconductivity and an

anomalously large spin susceptibility for both the front and tail regions of the transition metals.

Betterton and Scarbrough (34) analyzed their low temperature heat capacity results of the Sc-Zr alloys as dependent on the bare density of states $N_o(E_F)$, the electron-phonon interaction V_{ep} and Coulomb interaction V_c in two extreme cases. In the first case, the unenhanced density of states $N_o(E_F)$ was assumed to remain constant in the alloys and changes in the electronic specific heat constant were assigned to be due to the variation in the electron-phonon interaction. In the second case, the electron-phonon interaction was assumed to be constant and variations in γ were attributed to changes in $N_o(E_F)$. They had also calculated the $N_o(E_F)$ and V_{ep} values for pure zirconium to be used in the analysis of their data in both cases. To arrive at these values, they used the experimental values of γ and Θ_D for zirconium and the formula $N(E_F)V_{ep} = (1 + \sqrt{\zeta}) / \ln(1.14\Theta_D/T_c)$ due to Garland (61) and the value of ζ obtained by Bucher et al. (62) from their analysis of the isotope effect on the superconducting transition temperature of zirconium, $T_c \propto M^{-1/2}(1-\zeta)$. Thus, they obtained the values for Zr as follows:

$$N_o(E_F) = 0.46 \text{ eV}^{-1} \text{ atom}^{-1}$$

$$V_{ep} = 0.52 \text{ eV-atom, and}$$

$$V_c = 0.25 \text{ eV-atom}$$

In the first case, physically unrealistic values were obtained for the alloys and in particular, both the V_{ep} and V_c values for pure

zirconium were unreasonably large (~ 1.7 eV-atom). In the second case, smaller and more reasonable variations in V_c similar to that calculated by Jensen and Maita were found. With this assumption of constant electron-phonon interaction, the decline in γ from pure scandium to a minimum near zirconium could be understood in terms of the rigid band model with the gradual filling of a partially occupied band of scandium to a near filling of the four lower bands at zirconium. The results of the density of states after correcting for electron-phonon enhancement correlated fairly well with the theoretical density of states of pure zirconium calculated by Loucks (2) using the augmented plane-wave method, with the exception that a hump in $N_o(E_F)$ at 0.6 eV below the Fermi surface of zirconium in the theoretical density of states curve is not seen in the experimental results. They concluded that the effects of scandium in decreasing γ in the zirconium rich region of the Sc-Zr alloy system were in qualitative agreement with the rigid band model of dependence on the electron/atom ratio, assuming the electron-phonon interaction as nearly constant.

The two investigation on the Sc-Zr alloy system cited above were made near the Zr-rich end of the phase diagram with the lowest Zr concentration alloy being 10 at. % Zr. On the basis of the variation of physical property values reported and recent band structure calculations for scandium, it was decided that investigation be carried out near the Sc-rich end of the phase diagram. Nineteen Sc-Zr alloys were made from electrotransported Sc and Zr as the starting materials with the composition ranging from 0.25 at. % to 34 at. % Zr. The results

of the low temperature heat capacity measurements are tabulated in table 5 and in figure 13 and 14.

A survey of the literature shows there are five band structure calculations for scandium (49, 1, 50, 51, 52). Their methods of calculation and the parameters used are listed as shown in table 7 together with the value of the density of states at the Fermi level. Three of the band structure calculations (50, 51, 52) are plotted against electron concentration in figure 18. The density of states curve due to Gupta and Freeman, and that due to Das are plotted from the actual values generated in the output of their computer calculations of the density of states histograms, while the curve due to Das et al. is drawn from values obtained from their density of states plot. Figure 19 gives the density of states curves by Gupta and Freeman and Das where the shaded portion of the curve represents the filled band of Sc; the arrows represent the corresponding electron concentration. As can be seen from figure 18, both Das and Gupta and Freeman predict that the Fermi level lies below a peak in the density of states plot, with Das' peak in the density of states lying at an electron concentration of 3.02, and Gupta and Freeman's maximum situated at an electron concentration of 3.32. Das et al. predict that the Fermi level lies beyond a maximum in the density of states curve and increasing the electron concentration would decrease the density of states, reaching a minimum at an electron concentration of about 3.15. Altmann and Bradley also show that the Fermi level is situated at a peak in the density of

Figure 18. Density of states curves as a function of electron concentration

Figure 19. Theoretical band structure calculations

states, with the density of states decreasing on either side of the Fermi level. Also shown in figure 18 are the experimental density of states curve determined from low temperature heat capacity measurements and that after correcting for electron-phonon enhancement.

To correct for the electron-phonon enhancement in the Sc-Zr alloys, we start with $\lambda_{ep} = 0.30$ for pure scandium as determined by Knapp and Jones (43) and Ross et al. (48), and $\lambda_{ep} = 0.37$ for pure zirconium obtained by using McMillan's equation for superconducting transition temperature and T_c value determined by Jensen and Maita (37) and ρ and Θ_D values quoted by Gschneidner (63). To calculate λ_{ep} for the alloys, Auluck's empirical relationship (64) correlating T_c , λ_{ep} and $N_o(E_F)$ with the concentrations of the alloys for transition-metal binary alloy is used, $\lambda_{ep}(x) = x\lambda_A + (1 - x)\lambda_B + ax(1 - x)$ where λ_A, λ_B are the electron-phonon enhancement factors for Sc and Zr respectively, and $x, (1 - x)$ the atomic concentration for Sc and Zr respectively, and $a =$ constant.

Since the alloy $Sc_{0.05}Zr_{0.95}$ is found to be superconducting by Jensen and Maita with $T_c = 0.095K$, the constant "a" in the above equation can be solved for and Auluck's equation becomes

$$\lambda_{ep}(x) = 0.30x + 0.37(1 - x) - 1.19x(1-x)$$

for which λ_{ep} can be calculated for all the alloys. The results of the calculations are tabulated in table 8 where the values for the density of states after correcting for electron-phonon enhancement $N_o(E_F)$, the superconducting transition temperature T_c and the electron-phonon interaction are shown.

Table 8. Calculations from heat capacity results

Composition (at %Zr)	γ (mJ/gm atom K ²)	$N(E_F)^a$ (eV ⁻¹ atom ⁻¹ spin ⁻¹)	λ_{ep}^b	$N_O(E_F)^c$ (eV ⁻¹ atom ⁻¹ spin ⁻¹)	T_c (K)	V_{ep} (eV-atom)	λ_{other}^d
Sc	10.337	2.193	0.30	1.687	0.016	0.178	0.93
0.25	10.605	2.250	0.297	1.735	0.020	0.171	1.05
0.50	11.003	2.335	0.294	1.804	0.018	0.163	1.13
1.0	10.935	2.320	0.289	1.800	0.013	0.161	1.10
2.0	10.564	2.241	0.278	1.753	< 0.01	0.159	1.01
3.5	10.411	2.209	0.262	1.750	< 0.01	0.150	0.99
5.0	10.134	2.150	0.247	1.724	< 0.01	0.143	0.96
7.5	9.704	2.059	0.223	1.683	< 0.01	0.133	0.89
8.0	9.548	2.026	0.218	1.663	< 0.01	0.131	0.86
9.0	9.337	1.981	0.209	1.638	< 0.01	0.128	0.83
10.0	9.198	1.952	0.200	1.627	< 0.01	0.123	0.81
12.0	8.906	1.890	0.183	1.598	< 0.01	0.115	0.77
15.0	8.562	1.817	0.159	1.568	< 0.01	0.101	0.72
17.5	8.216	1.743	0.140	1.528	< 0.01	0.092	0.67
20.0	7.905	1.677	0.124	1.493	< 0.01	0.083	0.62
25.0	7.317	1.553	0.094	1.419	< 0.01	0.063	0.53
26.5	7.163	1.520	0.085	1.401	< 0.01	0.061	0.50
28.0	7.018	1.489	0.080	1.379	< 0.01	0.058	0.46
30.0	6.793	1.441	0.071	1.345	< 0.01	0.053	0.44
34.0	6.362	1.350	0.057	1.277	< 0.01	0.045	0.30

^aDensity of states determined from heat capacity results.

^bElectron-phonon enhancement factor determined from Suluch's equation.

^cExperimental density of states corrected for electron-phonon interaction.

^d $\lambda_{other} = \lambda_{total} - \lambda_{ep}$.

The conclusions that can be drawn from figure 18 are as follows:

1) The rigid band model is valid for dilute Zr in Sc as the experimental density of states decreases monotonically with increasing zirconium concentration at a concentration greater than 10 at. % Zr and does not show the features predicted by the theoretical band structure calculations at higher zirconium concentrations.

2) For dilute solutions of zirconium in scandium, the experimental $N_O(E_F)$ curve is consistent with Das' calculated density of states curve. The maximum at 0.5 at. % Zr correlates fairly well to the peak at 2 at. % Zr as predicted by Das (51) as compared to the maximum at 32 at. % Zr predicted by Gupta and Freeman (52). Both theoretical calculations by Das et al. (50) and Altmann and Bradley (49) do not show a peak in the density of states curve at an electron concentration close to 3.0. No comparison is made with the band structure calculation by Fleming and Loucks (1) since they did not include a density of states plot in their paper.

3) Even though the rigid band model is qualitatively correct for dilute alloys, other enhancements besides the electron-phonon interactions must be at work to bring the theoretical density of states curve to agreement with the experimental results obtained from low temperature heat capacity measurements. Spin fluctuation may be important in the alloys as it has been shown to be important in the case of pure scandium.

4) Using the theoretical band structure calculation by Das (51), enhancements other than that due to electron-phonon interactions, λ_{other}

are calculated and listed in the last column of table 8. The main contribution to λ_{other} probably comes from spin fluctuation λ_{spin} . Whereas the electron-phonon interaction decreases with zirconium additions to scandium, the electron-paramagnon interaction is quite sensitive to the zirconium concentration and the density of states. λ_{spin} reaches a maximum at 0.5 at. % Zr and then decreases smoothly with higher zirconium concentration.

Croat (26) had measured the magnetic susceptibility of some dilute alloys of Ti and Zr in Sc while Martynova et al. (65) had measured the magnetic susceptibility of Sc-Zr alloys up to 30 at. % Zr. For most metals, the total contribution to the magnetic susceptibility can be analyzed into the following components

$$x_{\text{total}} = x_p + x_L + x_i + x_v$$

where x_p = Pauli spin paramagnetism and is related to the density of states by the relation $x_p = 2\mu^2 N(E_F)$, μ being the Bohr magneton

x_L = Landau diamagnetism associated with the conduction electrons

x_i = diamagnetism due to the ion core, and

x_v = van Vleck orbital paramagnetism.

However, to breakdown the total magnetic susceptibility into its respective contributions is extremely difficult due to the lack of reliable quantitative predictions, hence the magnetic susceptibility results of Croat and Martynova et al. can only be analyzed qualitatively. For all the contributions to the total magnetic susceptibility, that due to the

diamagnetism of the core and conduction electrons are probably small compared to that contributed by Pauli spin paramagnetism and van Vleck orbital paramagnetism. If the van Vleck orbital paramagnetism remains constant or only slowly varies in all the alloys, then the variation in the magnetic susceptibility with either the titanium or zirconium concentration can solely be attributed to the variance of the Pauli spin paramagnetism with electron concentration, and thus can be correlated to the density of states. The results of their magnetic susceptibility measurements are tabulated in table 9.

One important point that needs to be considered in Croat's results is that his sample contained an iron impurity level of 19 ppm (atomic) and as can be seen from the discussion on the Sc-Fe alloys, there is an extra contribution to magnetic susceptibility due to the presence of Fe-Fe interaction and how this contribution varies with the zirconium and titanium concentration is not known. Martynova et al. did not give a chemical analysis of their samples.

With this in mind, Croat's results agree qualitatively with the findings of this investigation as the magnetic susceptibility of the Sc-Ti alloys reaches a maximum at 3.0 at. % Ti and then decreases with further increases in Ti concentration. For the Sc-Zr alloys, a maximum is found at 0.5 at. % Zr. The lowest zirconium concentration alloy studied by Martynova et al. was 10 at. % Zr and hence no information can be obtained about the fine features found near the Sc-rich end of the alloy system; however, the plot of the magnetic susceptibility vs concentration agrees very well with the plot of the electronic specific

Table 9. Magnetic susceptibility results for scandium

Croat's results ^a		Martynova et al. results ^b	
Specimen	$\chi(\text{emu/gm}) \times 10^{-6}$	Specimen	$\chi(\text{emu/gm}) \times 10^{-6}$
Sc	8.639	Sc	5.616
Sc-0.5 at %Ti	8.765	Sc-10 at %Zr	4.560
Sc-1.0 at %Ti	8.949	Sc-20 at %Zr	3.837
Sc-2.0 at %Ti	9.109	Sc-30 at %Zr	3.359
Sc-3.0 at %Ti	9.243	Sc-70 at %Zr	2.587
Sc-4.0 at %Ti	9.197	Sc-80 at %Zr	2.502
Sc-5.0 at %Ti	9.068	Sc-90 at %Zr	2.502
Sc-5.0 at %Ti	9.068	Sc-90 at %Zr	2.476
Sc-7.0 at %Ti	8.702	Zr	2.698
Sc-0.5 at %Zr	8.742		
Sc-1.5 at %Zr	8.598		

^aValue at 10K.^bValues obtained by extra polation to 0K.

heat constant vs zirconium concentration as shown in figure 15. The magnetic susceptibility decreases as zirconium is added to scandium, reaching a minimum at approximately 90 at. % Zr, and then increases to the value corresponding to pure zirconium.

The most surprising results of this study on the Sc-Zr alloy system is the variation of the Debye temperature with zirconium concentration. There is a rapid 6% increase in the Debye temperature as 0.5 at. % Zr is added. It then decreases smoothly to the value corresponding to zirconium. To check whether this initial increase in Θ_D is real or not, heat capacity measurements were made on an electrotransported Sc sample and on the same sample after it had been heat-treated under the same conditions as the Sc-Zr alloys, i.e. arc-melted and annealed at 900°C for one week. Heat capacity results give $\bar{\alpha} = 10.320 \pm 0.009$ mJ/gm-atom K² and $\Theta_D = 343.8 \pm 1.2$ K before heat treating and $\bar{\alpha} = 10.337 \pm 0.006$ mJ/gm-atom K² and $\Theta_D = 339.0 \pm 2.7$ K after heat treating. Both of these $\bar{\alpha}$ values agree very well with that given in table 4 for electrotransported scandium. There is a 4K difference in Θ_D after annealing; however, this difference is just slightly greater than the range of error in the measurement. Thus the increase in Θ_D with dilute zirconium additions is real.

An increase in the Debye temperature usually signifies a stiffening of the lattice, but the cause for the initial increase in the rigidity of the scandium lattice by minute zirconium addition followed by the gradual loosening as the zirconium concentration increases is not understood. The atomic size factor (66) for Sc-Zr is 1.03 while measurement

(67) of the axial ratio shows that the deviation from scandium is about 2%. Hence the two metals are very compatible as there is complete solid solubility between scandium and zirconium.

C. Sc-Mg Alloys

The low temperature heat capacity results of the Sc-Mg alloys are analyzed in the same fashion as the Sc-Zr alloys to study the band structure of Sc based on the rigid band model. To correct for the electron-phonon enhancement in the experimental density of states, Auluck's equation is again used to calculate the enhancement factor λ_{ep} .

Allen and Cohen (41) and Janak (68) both used an empirical pseudopotential and phonon spectra in a one-orthogonalized plane-wave approximation method to calculate λ_{ep} for magnesium and a series of transition metals, assuming a spherical model of the phonon and the Fermi surface. Allen and Cohen gave $\lambda_{ep} = 0.35$ while Janak's results had $\lambda_{ep} = 0.39$ for magnesium. Taking the average, $\lambda_{ep} = 0.37$ for magnesium in the calculations. Since only dilute solutions of Mg in Sc are involved, the quadratic term in Auluck's equation may be neglected without introducing a significant error, and the equation reduces to

$$\lambda_{ep}(x) = 0.3x + 0.37(1 - x)$$

where x , $(1-x)$ are the concentrations of Sc and Mg respectively.

The computed λ_{ep} values are tabulated in table 10 together with the corrected density of states, electron-phonon interaction and other

Table 10. Calculations from heat capacity results

Composition (at.%Mg)	γ (mJ/gm-atom K ²)	$N(E_F)$ (eV ⁻¹ atom ⁻¹ spin ⁻¹)	λ_{ep}	$N_0(E_F)$ (eV ⁻¹ atom ⁻¹ spin ⁻¹)	V_{ep} (eV-atom)	λ_{other}
1.89 $\pm$ 0.05	9.875 $\pm$ 0.010	2.095	0.301	1.610	0.187	0.925
3.31 $\pm$ 0.08	9.802 $\pm$ 0.32	2.080	0.302	1.597	0.189	0.920
4.40 $\pm$ 0.13	9.737 $\pm$ 0.003	2.066	0.303	1.585	0.191	0.950
6.99 $\pm$ 0.30	9.578 $\pm$ 0.011	2.032	0.306	1.549	0.197	0.954

mass enhancement factors, λ_{other} . The experimental density of states and that corrected for electron-phonon interaction is plotted against the electron concentration in figure 18 along with the results for the Sc-Zr alloys. It can be seen from the plot that both Das (51) and Gupta and Freeman (52) predicted a gradual decrease in the density of states with magnesium addition, hence the results of this investigation confirm qualitatively their calculations. However, like in the case of the Sc-Zr alloys, enhancements other than the electron-phonon interaction are important. This is obvious by comparing the values for λ_{other} and $\lambda_{\text{ep}} - \lambda_{\text{other}}$ is about three times the values for λ_{ep} .

The most amazing result in this study is the drastic effect of dilute impurities, namely Mg and Zr, on the Debye temperature of Sc. The Debye temperature is a measure of the stiffness of the lattice and since all these three metals are hexagonal in structure and have very similar atomic sizes, this variation in the Debye temperature is not expected. The cause for the initial stiffening of the lattice by dilute zirconium additions and softening of the lattice by dilute magnesium is not understood. The puzzling fact is that since Θ_D is inversely proportional to the square-root of the atomic mass, then as zirconium is added the Debye temperature should decrease (which is found to be the case at higher zirconium concentrations) while Θ_D should increase as magnesium is added; however, the reverse is observed here. Such behavior has been observed in other low temperature heat capacity studies. In their investigation on the electronic specific heat of χ -phase alloys of copper and silver, Migutani, Noguchi and

Massalski (69) found that nickel additions changed the Debye temperature from 342.2K for pure copper to 341.1K at 1.0 at. % Ni, then Θ_D increased to 344.9K at 2.4 at. % Ni and 346.3K at 4.4 at. % Ni. Ga additions up to 1 at. % did not affect Θ_D , at concentrations greater than 3 at. % Ga, the Debye temperature decreased monotonically to 300.2K at 19.9 at. % Ga. In their studies on the silver-base alloys, both Ga and In increased the Debye temperature at dilute concentrations - 2.1 at. % Ga addition increased Θ_D from 223.4K for pure Ag to 225.1K while 3.7 at. % In increased it to 224.7K. This is very similar to that observed in this study except the magnitude of the variations is much smaller in their investigation, plus the fact that their "most dilute" alloys is quite concentrated when compared to this investigation of less than 1 at. %. In and Ga additions to Ag definitely show the same trend as that observed in the Sc-Zr case, but data are lacking in the concentration region between pure Ag and their most dilute alloys. The change in Θ_D by 1 at. % Ni addition is within the experimental error, but further Ni additions do increase the Debye temperature.

D. Sc-Fe Alloys

The fact that dilute Fe impurities contribute an excess heat capacity to Sc causing an anomaly in the C/T vs T^2 curve together with the finding that no magnetic ordering is observed in the electrical resistivity down to 0.3K are similar to the behavior observed when dilute magnetic transition metal solutes are dissolved in noble metals.

The phenomena found in the case of dilute transition metals in simple metal hosts can be described in terms of the "Kondo" or "spin glass" effect depending on the concentration of the solutes. Good reviews on these two subjects are given by J. Kondo (70) and A. J. Heeger (8) on the Kondo effect, and P. W. Anderson (71) and J. A. Mydosh (72) on the spin glass system, hence only a brief summary of these two effects is given below.

The character of magnetic transition occurring in an alloy depends critically on the concentration c of the magnetic impurities present in the alloy. As temperature is lowered there are two competing interactions occurring between the magnetic impurity and conduction electrons: 1) single-impurity (Kondo) interaction with characteristic energy kT_K where T_K is the Kondo temperature, 2) impurity-impurity (RKKY) interaction (73) with characteristic energy cV_O , V_O being the strength of the RKKY interaction. A low c where $cV_O \ll kT_K$, the impurities are non-interacting and single-impurity effects by impurity-conduction electron interactions are dominant. The specific heat anomaly which occurs over a wide range of temperature has a concentration independent peak about $T_K/3$ (74). With increasing concentration, the excess heat capacity ΔC deviates from the concentration-proportional single-impurity limit and approaches an approximately concentration independent, temperature proportional value. At a critical concentration where $cV_O > kT_K$, interaction effects dominate and local impurities begin to interact via the RKKY mechanism - indirect exchange via the conduction electrons. The broad specific heat anomaly has a peak at a temperature proportional to

c and of the order of cV_0/k . As the temperature is lowered to $T \ll cV_0/k$, a spin glass state is reached where the impurity spins "freeze out" and become locked in random directions, i.e. the average vector of all local moments give no net macroscopic moment and there is no long range magnetic ordering (71). But the freezing occurs at a well-defined temperature T_0 characteristic of the alloy system. Some examples for the single-impurity and impurity-impurity interactions are: Triplett and Phillips (75) reported that at concentrations less than 51 ppm (atomic) Cr in Cu, a pure Kondo system exists with $T_K = 2.1K$ and spin $S = 3/2$ for Cr, and above 730 ppm (atomic) Cr impurity-impurity interactions are dominant. For Fe in Cu (7) single-impurity effects are important below 81 ppm (atomic) Fe with $T_K = 28K$ and $S = 3/2$ for Fe whereas at about 380 ppm (atomic) Fe, impurity-impurity interactions are important (76); also some pairing of Fe atoms are found at 640 ppm (7). Pure Kondo effect exists between 0-20 ppm Mn in Zn (77) with $T_K = 0.24K$ and $S = 1.5 - 2.0$ for Mn (78), while impurity-impurity effects dominate at concentrations between 213-1200 ppm Mn.

Associated with these two effects are anomalies in specific heat, resistivity, susceptibility and thermoelectric power. The anomalies in resistivity and susceptibility for either a pure Kondo or pure spin glass system are best summarized in figure 20 (79). In a pure Kondo system, interactions between local moment spin S on the impurity and conduction electron spin s is usually described in terms of a s-d exchange Hamiltonian $H = -2JS \cdot s$ where J is the effective exchange

Figure 20. Susceptibility and resistivity anomalies of pure Kondo and spin glass systems

parameter. Negative values of J lead to a spin-scattering contribution to the resistivity ρ_{Kondo} which increases with decreasing temperature. This together with the phonon-scattering resistivity ρ_{Phonon} of the host which decreases with decreasing temperature leads to the well-known resistivity minimum at T_{min} . The inflection point of ρ_{Kondo} determines the characteristic Kondo temperature T_K defined by $kT_K = D \exp(1/N|J|)$ where D is the band width and N is the density of states at the Fermi level. As the concentration increases into the spin glass region, indirect RKKY interactions between impurities become important and below a characteristic temperature T_0 , impurity spins become locked in a random direction. This so-called spin glass freezing temperature T_0 is marked by a sharp peak in the susceptibility (80) and also by an abrupt hyperfine splitting of the Mossbauer lines (81). However, there is no genuine evidence of either antiferro- or ferromagnetism associated with the susceptibility maximum (71). The "locking in" of impurity spins below T_0 destroys the growth of the delicately balanced Kondo state and reduces the spinflip scattering between the impurity and conduction electron spins. In a spin glass alloy, ρ_{spin} is forced to fall off at temperatures near or below T_0 , resulting in a resistivity maximum at T_{max} (82). In general, there is no exact relationship between T_0 and T_{max} (79). Another important point to note in connection with figure 19 is that ideal spin glass systems are difficult to realize and presence of correlated pairs, triplets (clustering) will complicate the picture. Due to the fact that clustering affects susceptibility with little apparent influence to resistivity since contribution to resistivity from

impurity pairs is negligible compared to that from isolated impurities, susceptibility peaks are sometimes observed in alloys where no resistivity maximum can be found, e.g. in Cu-0.1 at. % Fe clustering is important (83, 84). Also the susceptibility focuses on the type of impurities which order even if it is a small minority. That the majority of impurities need not take part in the so-called spin glass freezing is best illustrated in the heat capacity measurements of $\text{Au}_{0.92}\text{Fe}_{0.08}$ and $\text{Au}_{0.99}\text{Fe}_{0.01}$ through T_0 (85) where no maximum is observed in the specific heat though the susceptibility measurement on the same samples shows sharp peaks characteristic of spin glass freezing.

In an excellent review article Phillips (7) has summarized the theoretical and experimental results on the heat capacity of dilute alloys with separate sections on the impurity-conduction electron interaction and impurity-impurity interaction. Since each type of interaction has a characteristic temperature associated with it, the heat capacity of a particular system may be dominated by impurity-conduction electron interaction in one concentration and temperature region, and by impurity-impurity interaction in another. Typically for impurity-impurity interaction, its excess heat capacity at low temperature is independent of concentration of the solute or some other non-linear function of concentration, and that it has an ordering temperature proportional to concentration. Also the $1/r^3$ fall-off of the RKKY interaction allows some form of scaling law with c and T for the heat capacity (86). Phillips (7) emphasized that the theoretical predictions

are for "pure" systems only and not valid for the concentration regions where both effects occur; also there is no clear theoretical basis for a choice between the various predictions.

Returning to the heat capacity results of the Sc-Fe alloys in this investigation, the maximum found in ΔC in a ΔC vs T plot for the 30 ppm and 50 ppm Fe samples in the as cast condition is essentially at the same temperature and is thus independent of concentration (see figure 16). No maximum is found for the 85 ppm Fe sample while a broad maximum exists for the 111 ppm Fe sample. It is believed that for Fe concentrations less than between 50-85 ppm (atomic), the Sc-Fe alloys in the as cast condition behave as a pure Kondo system with $T_K = 3.3K$ (three times the peak temperature found for the 30 and 50 ppm Fe samples). Excess entropy calculations shown in Table 11 also agree very well with the theoretical value of $ck \ln (2S+1)$ for these two samples, where c is the impurity concentration, k the Boltzmann constant and S is the spin of the impurity. At 85 ppm (atomic) Fe and above, there are Fe-Fe interactions giving rise to the excess entropy. Thus both types of interactions are probably present in the sample with 85 ppm Fe. The highest Fe concentration Sc-Fe alloy (111 ppm) may or may not be in a pure spin glass state. When annealed, the randomly distributed Fe atoms begin to cluster (but do not precipitate out of solid solution). The clusters formed interact with each other via the long range RKKY interactions, producing extra contributions to the excess heat capacity and entropy over the single-impurity limit; the impurity spins are then "locked in"

Table 11. Excess entropy results for the Sc-Fe alloys

As cast				Annealed	
Fe conc. ppm(atomic)	Experimental (mJ/gm atom K)	Theoretical (mJ/gm atom K)		Fe conc. ppm(atomic)	Experimental (mJ/gm atom K)
		Fe only	All magnetic impurities		
30	0.379	0.346	0.386 ^a	30	>3.700
50	0.686	0.577	0.666 ^a	50	>6.355
85	>5.645	0.981		85	>7.017
111	>5.553	1.281		111	>7.317

^aFor detail of calculations, see Appendix I.

at a lower freezing temperature as shown in figure 17 where the peaks of ΔC have shifted to lower temperatures. Also in the annealed condition, "pure" impurity-impurity type interaction probably does not occur due to the complication introduced by clustering.

Taking $T_K = 3.3K$ and the supposition that impurity-impurity interaction comes into play between 50 to 85 ppm Fe, the strength of the RKKY interaction can be calculated and is given by: 8.82×10^{-40} mJ/mole $< V_0 < 1.5 \times 10^{-39}$ mJ/mole. The distance of interaction between Fe-Fe atoms can also be calculated and found to be amazingly large, approximately 38 to 44 Sc atoms lie between two iron atoms (for details of calculation, see Appendix 2). Also the peak for the heat capacity anomaly for the alloy with 111 ppm Fe in the as cast condition is calculated to be of the order of 4 to 7K which agrees reasonably well with the broad maximum found between 2 to 5K for this particular sample. No peak is observed for the 85 ppm Fe sample since single-impurity effects are probably still important and contribute to the excess heat capacity; also it is very difficult to separate the two types of interactions.

Attempts to fit the data for the excess heat capacity of the two alloys in pure Kondo state to the theoretical predictions given in the review article by Phillips (7) failed, the reason is not understood. In the annealed conditions the excess heat capacity increases with iron concentrations and the plots of ΔC vs T for each alloy seems to be roughly parallel to each other (see figure 17). Yet no correlations with concentration and temperature can be found for the excess heat

capacity. The degree of complication introduced by clustering during annealing is not known.

Now with the understanding of the role played by even minute iron impurities in mind, the resistivity (87) and susceptibility (5) results of the "purest" scandium samples measured so far are re-examined. Spedding and Croat (5) observed a previously unreported susceptibility maximum at 30K which disappeared as both non-magnetic and magnetic impurities were added. Heat capacity measurement had been carried out on this same sample with 19 ppm (atomic) Fe under the same heat-treat condition and an anomaly is again found in the C/T vs T^2 curve. The excess heat capacity is plotted against temperature as shown in figure 17. The observed maximum in susceptibility is probably due to Fe impurity-impurity interaction which is confirmed by the heat capacity results discussed above, and also by the fact that the maximum disappeared as increasing impurities are added. The effect of the non-magnetic impurities is probably to dilute the interaction by effectively screening the Fe atoms. With Gd and Er additions, the contribution due to these two magnetic impurities probably just overwhelms that due to Fe as can be seen from the enormous increase in susceptibility with increasing Gd and Er additions. The addition of 0.1 at. % Fe greatly increases the susceptibility and the maximum disappears also. However, iron-rich second phase precipitates are found in the sample whose magnetic moments are probably large enough to completely overshadow that contribution from the Fe-Fe interaction found in their "pure" sample. The samples used

by Spedding et al. (87) in their resistivity measurements contained 70 ppm (atomic) Fe and were heat-treated at 700°C for two days. These authors presented the data which might probably be interpreted to show a shallow minimum at 8K, but the depth of the minimum is about the same as the precision of the measurements. This iron impurity level of 70 ppm (atomic) falls in the concentration range of 50 - 85 ppm where impurity-impurity interactions begin to take over the Kondo effect. If the minimum in resistivity is real, then Sc-Fe alloys with 70 ppm (atomic) Fe is still in the Kondo state and the concentration regime where impurity-impurity interaction starts is narrowed down to 70 to 85 ppm (atomic). If the minimum observed is due to scatter in the data, the results can be explained similar to that for the Cu-0.1 at. % Fe (83, 84) where clustering effects give a maximum in susceptibility while no anomaly is observed in the resistivity measurement.

VI. CONCLUSION

Reliable low temperature heat capacity results have been obtained for scandium by measurements on scandium samples that have been electrotransport purified to reduce the iron impurity level to about 1 or 2 ppm (atomic), yielding values for the electronic specific heat constant and the Debye temperature that is believed to be truly representative of intrinsic scandium. Alloying with zirconium and magnesium allow the band structure of scandium to be studied at an electron/atom ratio close to that for the pure metal. The results indicate that the rigid band model for dilute alloys is qualitatively consistent with the theoretical band structure calculations by Das, but apparently not consistent with other such calculations. The influence of dilute Zr and Mg on the Debye temperature is anomalous and not understood. Alloying studies with dilute iron impurities show that for Fe concentrations less than between 50-85 ppm (atomic), the Sc-Fe alloys in the as cast condition behave as a pure Kondo system; impurity-impurity interactions come into play as the concentration of Fe increases above 50 ppm (atomic). Annealing allows the Fe atom to cluster and further complicates the picture.

It is hoped that the results of this investigation will be helpful to theorists by providing them with reliable physical property parameters and to stimulate further investigation into other properties of scandium.

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IX. APPENDIX 1

Sc-Fe-I with 30 ppm (atomic) Fe, as cast

Impurity	Concentration (ppm atomic)	Spin S	$\Delta S = ck \ln(2S+1)$ (mJ/gm atom K)	$\Sigma \Delta S$ (mJ/gm atom K)
Fe	30	3/2	0.346	0.346
Ni	2	0.243 ¹	0.007	0.353
Co	0.5	0.508 ¹	0.003	0.356
Gd	< 2	J=7/2	< 0.030	< 0.386

Sc-Fe-II with 50 ppm (atomic) Fe, as cast

Impurity	Concentration (ppm atomic)	Spin S	$\Delta S = ck \ln(2S+1)$ (mJ/gm atom K)	$\Sigma \Delta S$ (mJ/gm atom K)
Fe	50	3/2	0.576	0.576
Cr	1	3/2 ²	0.011	0.587
Ni	20	0.243 ¹	0.070	0.657
Co	1.5	0.508 ¹	0.009	0.666
Gd	< 7	J=7/2	< 0.100	< 0.766

¹Value taken from Gray (88, p. 5-170).²Triplett and Phillips (75).

APPENDIX 2

Impurity-impurity effects occur between 50 to 85 ppm (atomic) Fe
 sphere of polarization about an impurity atom is given by

$$V_p = \frac{4}{3} \pi r^3$$

$$\text{volume/unit cell} = \frac{\sqrt{3}}{2} a^2 c = 49.95 \text{ \AA}^3 \text{ for Sc}$$

of atoms/unit cell for Sc = 2

Let n = # of Sc atoms in volume V_p

$$n = 2 \times \frac{\frac{4}{3} \pi r^3}{49.95}$$

concentration of impurity $c = 1/n = 50$ to 85 ppm (atomic) Fe or $n = 1/c$

$$\text{equating } n = 1/c = 2 \times \frac{\frac{4}{3} \pi r^3}{49.95}$$

get $r = 60.40 \text{ \AA}$ to $71.28 \text{ \AA}$ for $c = 85$ to 50 ppm (atomic)

For Sc 1 atomic distance = $3.24 \text{ \AA}$

therefore $r = 19$ to 22 Sc atoms, or

there are 38 to 44 Sc atoms between two Fe atoms.

APPENDIX 3. HEAT CAPACITY RESULTS

Heat Capacity Results
Electrotransport Purified Scandium ET-1

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0974	11.3220	4.4280	49.9691
1.1323	11.5524	4.4838	50.2148
1.1666	12.0716	4.4838	50.5727
1.2041	12.3477	4.6149	52.4097
1.2469	12.8895	4.6773	52.8327
1.2927	13.3230	4.7945	54.6836
1.3492	14.0303	4.8549	55.2786
1.3507	13.8814	4.9488	56.6180
1.4227	14.8001	5.0150	57.3612
1.5041	15.6206	5.0744	58.8174
1.6075	16.7645	5.1547	59.5790
1.6114	16.7808	5.2731	60.8323
1.6847	17.6416	5.3592	62.0986
1.7406	18.1164	5.4667	63.9114
1.8084	18.9621	5.5630	64.7505
1.8347	19.2360	5.6648	66.8071
1.9119	20.0804	5.7774	67.4381
1.9888	20.7899	5.8408	69.9221
2.0263	21.1532	5.9502	70.8664
2.1253	22.3344	5.9542	71.4265
2.1711	22.8659	6.0617	72.8956
2.3175	24.3401	6.1907	74.8426
2.3407	24.6676	6.3200	77.4776
2.4270	25.8271	6.4609	79.6375
2.4339	25.8039	6.6135	82.3871
2.6165	27.8371	6.7705	85.1914
2.6535	28.2822	6.9297	87.4887
2.8014	29.9239	7.0750	90.4138
2.8972	31.1049	7.2468	92.4486
3.0017	32.3038	7.3671	94.3161
3.1404	33.9422	7.5490	98.2014
3.2187	34.9377	7.5751	98.5701
3.3516	36.5033	7.7701	102.6612
3.3932	36.9892	7.8975	103.8208
3.5549	39.0583	8.0675	107.8660
3.5914	39.4302	8.1966	110.1385
3.7796	41.6747	8.3217	112.1940
3.8635	42.6811	8.4598	115.1453
4.0064	44.3212	8.5307	117.0579
4.0967	45.4681	8.5904	117.3700
4.2333	46.8176	8.7920	122.2986
4.2790	47.9953	8.8074	122.7528
4.2929	48.1245	9.0644	128.2599
4.3034	48.0492	9.0649	128.6817

Heat Capacity Results
Electrotransport Purified Scandium ET-1
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
9.2922	134.3953	12.8021	231.4455
9.2928	136.2340	13.0397	240.9648
9.5290	139.7205	13.1365	245.8560
9.5378	140.1426	13.3544	251.2519
9.6676	142.1535	13.7014	256.1174
9.7775	145.1724	13.8927	275.7002
9.9054	149.0756	14.3138	285.2158
9.9731	150.0326	14.4124	296.9585
10.2296	156.2610	14.8791	316.4795
10.3234	158.5362	14.9719	321.8298
10.5537	164.8699	15.3725	339.6831
10.6592	166.8686	15.6544	353.7307
10.8548	173.7199	15.7040	361.2664
10.9721	177.8114	16.2899	391.4880
11.1769	180.0487	16.3983	394.0046
11.1932	182.9514	17.2031	443.6621
11.4081	188.6735	17.2852	450.4148
11.5336	192.5074	18.1121	504.6138
11.7749	198.6535	18.3040	517.5093
11.9170	202.7918	19.1206	576.0525
12.1846	213.3201	19.2340	584.1641
12.3425	217.5290	20.0334	645.1775
12.6330	225.0582		

Heat Capacity Results
Electrotransport Purified Scandium ET-2

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0653	11.1441	1.2223	12.7227
1.0820	11.2357	1.2236	12.7778
1.0999	11.5064	1.2697	13.2347
1.1210	11.7030	1.2728	13.2980
1.1416	11.9125	1.3217	13.7959
1.1454	11.8118	1.3224	13.7123
1.1470	11.9661	1.3849	14.4029
1.1632	12.0240	1.3862	14.4767
1.1795	12.2408	1.4622	15.2337
1.1814	12.3362	1.5540	16.2057
1.2042	12.5708	1.5579	16.2272
1.2120	12.6096	1.6404	17.0751

Heat Capacity Results
Electrotransport Purified Scandium ET-2
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.6946	17.7532	5.3681	62.6689
1.6981	17.7975	5.4796	64.2405
1.7138	17.8958	5.5648	65.4259
1.7993	18.8698	5.6904	67.4568
1.8029	18.8589	5.7419	68.0761
1.8942	19.9162	5.9081	71.1815
1.8989	19.9974	5.9238	70.8378
1.9999	21.0245	5.9933	72.0216
2.0140	21.3062	6.1133	73.7609
2.1320	22.5264	6.1632	74.7132
2.1526	22.7809	6.2164	75.7491
2.1915	23.1406	6.3645	78.1971
2.2426	23.7581	6.4410	79.5838
2.4145	25.6687	6.5803	81.8916
2.4670	26.1752	6.6631	83.1616
2.5811	27.5548	6.8174	85.7176
2.6861	28.5944	6.9039	87.0954
2.7344	29.3000	6.9941	88.7028
2.8558	30.5586	7.1694	91.5148
2.8978	31.0863	7.2589	92.9439
2.9043	31.1896	7.3737	95.1739
2.9990	32.3343	7.5077	97.2055
3.0906	33.4496	7.6724	100.3753
3.1545	34.0475	7.7308	101.2807
3.2723	35.4938	7.9527	105.5568
3.3477	36.4505	7.9626	105.5721
3.5391	38.6503	8.0928	108.2029
3.5390	38.8637	8.1977	110.5894
3.6525	40.1594	8.2913	112.2687
3.6901	40.7167	8.4705	115.9532
3.8550	42.6440	8.4795	115.7847
3.9744	44.5430	8.5835	117.7116
4.0551	45.0209	8.6686	119.9877
4.2625	47.7015	8.7643	122.1746
4.2750	47.9049	8.8634	124.1856
4.2934	48.2349	8.9756	126.7536
4.4257	50.1026	8.9877	127.2799
4.4828	50.8040	9.1953	131.0084
4.6121	52.4620	9.1986	131.8985
4.6663	53.0345	9.4119	136.6250
4.8256	55.4038	9.4247	136.6097
4.8502	55.4147	9.5534	139.8491
5.0249	57.8686	9.6646	142.3501
5.0740	58.5725	9.7896	144.9009

Heat Capacity Results
Electrotransport Purified Scandium ET-2
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
9.9123	148.3596	13.2405	247.3959
10.0242	150.0933	13.4339	254.5263
10.0662	152.3214	13.5687	259.6653
10.2868	156.8782	13.7773	267.7100
10.2932	158.5567	14.0058	277.7969
10.4425	161.2527	14.0958	180.7700
10.4802	163.4177	14.3967	290.5256
10.5674	165.0680	14.4287	295.1672
10.7572	169.8842	14.8906	315.2058
10.8592	172.4049	15.0939	324.8462
11.0762	179.9597	15.3982	340.3855
11.1895	182.3074	15.7976	359.4163
11.4185	188.2928	15.8736	365.2756
11.4314	189.0035	16.5059	398.5129
11.7924	199.4560	16.6605	408.0591
11.7958	198.8973	17.2216	440.8064
11.9898	205.2318	17.4112	453.0715
12.1384	209.4877	17.8367	481.4363
12.2724	214.3497	18.1646	505.6868
12.4403	219.1709	18.5074	526.4138
12.5698	223.1042	18.9019	557.5908
12.7373	228.9962	19.1188	570.2998
12.8874	234.9968	19.8129	625.6331
12.9253	235.5143	20.4444	681.6150
13.2324	247.8908		

Heat Capacity Results
Electrotransport Purified Scandium ET-3

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1004	11.4297	1.4182	14.7850
1.1216	11.6546	1.5004	15.6646
1.1446	11.8918	1.6092	16.8186
1.1814	12.2823	1.7526	18.3546
1.2014	12.4938	1.8339	19.2354
1.2209	12.6996	1.9955	20.9903
1.2437	12.9375	2.1554	22.6371
1.2895	13.4195	2.3620	25.0304
1.3186	13.7249	2.4744	26.2700
1.3544	14.1015	2.5314	27.0753

Heat Capacity Results
Electrotransport Purified Scandium ET-3
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
2.5666	27.2934	7.5506	97.9141
2.6698	28.4655	7.7154	100.9550
2.7773	29.6784	8.1328	108.9160
2.8895	30.9652	8.5304	116.7823
2.9217	31.3423	8.8858	125.1856
3.0742	33.1068	9.0331	129.3449
3.2521	35.1980	9.2936	133.0600
3.4618	37.6755	9.5419	141.5410
3.6728	40.2345	9.7902	147.2981
3.7512	41.1453	10.0641	152.0558
3.9448	43.4246	10.2014	154.1779
4.1119	45.7057	10.4695	160.7193
4.1908	46.7304	10.7504	169.4267
4.2749	47.7895	11.0675	179.9703
4.3022	48.1220	11.4173	186.9457
4.4805	50.4289	11.6739	195.4633
4.6765	53.0307	12.0581	207.3245
4.8566	55.4857	12.4855	221.8452
5.0161	57.4416	12.9633	237.1157
5.2771	61.3177	13.4934	255.1848
5.3869	62.8907	13.9222	271.4982
5.5535	65.3253	14.5312	293.6033
5.7300	68.0163	15.2532	323.3397
5.8526	69.5357	15.9325	369.9574
5.9020	70.5109	16.5405	398.1208
6.2224	75.4044	16.9582	425.3333
6.3139	76.8225	17.6366	479.4689
6.5672	80.9331	18.4075	518.0559
6.8049	84.9181	19.2560	598.7066
6.9803	87.8150	20.1677	635.1460
7.2542	92.5942		

Heat Capacity Results for Sc-Zr Alloys
0.25 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0685	11.3849	4.6609	53.7739
1.1070	11.8003	4.7116	54.6703
1.1462	12.2218	4.8284	55.9932
1.1954	12.7528	4.8690	56.6290
1.2253	13.0762	4.9871	58.1860
1.2689	13.5526	5.0117	58.6673
1.3244	14.1457	5.1759	60.9414
1.3856	14.8123	5.1934	61.1207
1.4422	15.4246	5.3710	63.5649
1.4913	15.9633	5.3792	63.5846
1.5364	16.4479	5.5680	66.6158
1.5968	17.1135	5.5805	66.6149
1.6599	17.8055	5.7229	68.9778
1.7309	18.5836	5.7996	69.8316
1.8152	19.5013	5.9544	72.6331
1.8770	20.1222	5.9559	72.3352
1.9424	20.9203	6.1480	75.5308
2.0030	21.6022	6.1921	76.4610
2.0703	22.3446	6.3520	78.6555
2.1459	23.1906	6.5664	81.6617
2.1710	23.4744	6.5852	82.3337
2.2797	24.6950	6.8022	85.9537
2.3933	25.9822	6.8095	85.9541
2.5163	27.3840	6.9924	89.0195
2.6419	28.8232	6.9967	89.3490
2.7150	29.6729	7.2506	93.6953
2.8293	30.9950	7.2536	93.3088
2.9514	32.4270	7.5403	98.3595
3.0837	34.4391	7.5530	98.8162
3.2127	36.0158	7.8643	104.9189
3.2716	36.6506	7.8783	104.9287
3.3852	37.8712	8.1755	111.0694
3.5139	39.4898	8.1815	110.4884
3.6540	41.3036	8.4178	115.1000
3.8212	43.4722	8.4389	115.6891
3.9020	44.1151	8.7450	122.4022
4.0381	46.1004	8.8148	122.6584
4.1744	47.7144	9.0504	129.4532
4.2534	48.6091	9.2113	131.7945
4.2792	48.8803	9.3824	136.2572
4.3758	50.2553	9.5964	140.5780
4.4077	50.5241	9.7601	144.4950
4.5095	52.0393	9.9905	149.8140
4.5544	52.4440	10.1060	153.0555

Heat Capacity Results for Sc-Zr Alloys
0.25 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
10.3237	158.5390	14.3989	294.9368
10.5643	165.3590	14.7859	310.7078
10.7791	169.4468	15.1685	328.5706
11.0144	177.4920	15.6411	350.8777
11.3212	184.8876	15.9278	367.3306
11.5031	191.2623	16.6419	403.4709
11.9496	204.0924	16.7933	423.1172
12.0292	208.4274	17.5376	456.6372
12.5007	222.6257	17.7116	471.8418
12.6711	226.5412	18.3748	509.3643
13.0819	242.2813	18.6996	541.1492
13.3218	250.2117	19.2197	575.0244
13.7060	267.2070	19.6231	610.9309
14.0290	277.7776	20.1258	641.6443

Heat Capacity Results for Sc-Zr Alloys
0.50 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.2179	13.4706	2.5374	28.9337
1.2712	14.0958	2.5626	29.3230
1.3219	14.6525	2.6000	29.5724
1.3816	15.3305	2.7917	31.6676
1.4422	16.0582	2.8507	32.6646
1.4912	16.7614	2.8699	32.6774
1.5183	17.0524	2.9014	33.1494
1.5449	17.4285	2.9130	33.2585
1.5995	18.0104	2.9203	33.2392
1.6205	18.1984	2.9996	34.2842
1.7285	19.4069	3.0136	34.5899
1.7701	20.0678	3.1016	35.5234
1.7795	20.1147	3.1109	35.8234
2.0241	22.9675	3.2112	36.8872
2.0597	23.2862	3.2163	36.9804
2.0863	23.3096	3.2405	37.2747
2.1725	24.6654	3.3215	38.2558
2.3528	26.5910	3.3493	38.6605
2.3640	26.8774	3.3625	38.5814
2.4621	27.9856	3.4589	39.8020

Heat Capacity Results for Sc-Zr Alloys
 0.50 atomic percent Zr
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.4781	40.2088	7.3448	96.2864
3.5689	41.2215	7.5479	99.7472
3.6150	41.9013	7.6538	101.8782
3.6903	42.8363	7.7898	104.2166
3.7677	43.9112	7.8996	106.2763
3.8331	44.4778	8.1229	110.3958
3.8953	45.3913	8.1917	111.9893
3.9121	45.6897	8.4443	116.0955
3.9429	46.0383	8.4583	117.1881
4.0475	47.2555	8.7368	121.2821
4.0550	47.1567	8.7465	121.7598
4.1680	48.5117	8.9745	126.2228
4.2072	49.1814	9.0532	127.9750
4.2732	49.7455	9.1273	129.5172
4.3876	51.7308	9.2594	132.3867
4.5114	53.5794	9.4726	136.9027
4.6414	54.9730	9.6026	139.8655
4.7806	56.8761	9.8582	147.6032
4.8826	57.8423	9.9967	151.7445
5.0159	59.9612	10.2921	159.5255
5.0916	61.1069	10.4359	160.0202
5.1805	62.2241	10.7756	169.6568
5.2672	63.3953	10.9466	173.7209
5.3614	65.1877	11.1773	179.9134
5.4181	65.6907	11.3649	184.1988
5.5147	67.4824	11.6255	191.6744
5.5791	67.8134	11.9574	201.7211
5.5998	68.4177	12.0674	205.0968
5.6815	69.6934	12.5498	220.2963
5.7791	71.1989	12.5536	219.3047
5.8366	71.8536	13.0839	238.8849
5.9551	73.6570	13.1139	239.9055
6.0172	74.5390	13.5174	254.0107
6.1454	76.4697	13.7206	260.0271
6.2089	77.9415	14.1150	277.1699
6.3478	79.8376	14.2997	281.9644
6.4190	81.0312	14.7832	304.4343
6.5031	82.3897	15.0413	314.6584
6.5767	83.7213	15.5351	339.4790
6.7222	85.6158	15.8223	356.0425
6.8065	87.5088	16.2508	375.1082
6.9733	89.5721	16.7329	400.2383
7.0633	91.4677	16.8413	406.8691
7.2488	94.1712	17.5822	452.4768

Heat Capacity Results for Sc-Zr Alloys
0.50 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
17.7690	460.5366	19.1922	559.3665
18.3489	502.8433	20.1079	634.9548

Heat Capacity Results for Sc-Zr Alloys
1.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0461	11.4788	1.8592	20.5961
1.0494	11.5000	1.9125	21.1981
1.0890	11.9947	1.9380	21.4278
1.0908	12.0184	2.0250	22.4430
1.1297	12.4581	2.0285	22.4616
1.1310	12.4873	2.1350	23.7041
1.1644	12.8062	2.1370	23.8431
1.1655	12.7831	2.1757	24.0854
1.2029	13.2305	2.2211	24.7399
1.2031	13.2651	2.2247	24.8592
1.2316	13.5751	2.2712	25.3091
1.2390	13.6698	2.3388	26.1220
1.2699	13.9634	2.3721	26.4484
1.2923	14.2450	2.4506	27.3304
1.3208	14.5240	2.4765	27.7124
1.3511	14.8689	2.5649	28.6883
1.3657	15.0269	2.5842	28.8846
1.4027	15.3884	2.6135	29.2507
1.4178	15.5963	2.6835	30.0726
1.4585	16.0026	2.7306	30.7180
1.4628	16.0779	2.7345	30.6707
1.5055	16.5602	2.8592	32.3088
1.5285	16.8187	2.9954	34.0785
1.5671	17.1922	3.0019	33.9348
1.5949	17.5632	3.1356	35.5563
1.6245	17.8787	3.1633	35.9720
1.6569	18.2609	3.2452	36.9107
1.6911	18.5490	3.2831	37.1766
1.7264	19.0455	3.3573	38.1514
1.7670	20.3432	3.3795	38.6906
1.7747	19.5983	3.5113	40.3125
1.8169	20.1179	3.5122	40.3336

Heat Capacity Results for Sc-Zr Alloys
 1.0 atomic percent Zr
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.6606	42.1251	7.3496	95.7430
3.6766	42.1730	7.4429	98.1042
3.8140	43.9212	7.6579	100.8493
3.8404	44.4115	7.7636	104.0655
3.8660	44.6769	7.9999	107.5827
3.9938	46.1201	8.1381	111.9201
4.0016	46.3009	8.3848	114.9442
4.1606	48.3794	8.5311	118.8538
4.1980	48.9674	8.7024	121.3420
4.2868	49.6488	8.8478	124.7504
4.2915	50.0176	9.0598	127.8878
4.4409	52.0164	9.2306	132.2792
4.4446	51.9639	9.4011	134.4633
4.5995	54.0442	9.5974	140.2690
4.6051	53.9530	9.7843	143.6367
4.7725	56.5045	9.9813	150.8578
4.7790	56.4647	10.2020	152.5953
4.9349	58.6760	10.4200	159.5167
4.9463	58.6150	10.5890	164.8547
5.0854	60.9235	10.7956	171.2911
5.0954	60.7852	11.1320	178.0299
5.2807	63.3910	11.3152	184.9150
5.2839	63.6541	11.6302	191.5430
5.4666	66.1473	11.9444	201.6918
5.4731	66.2802	12.1949	208.3297
5.6734	69.1631	12.6714	226.9108
5.6924	69.5617	12.8130	227.9005
5.9075	72.7173	13.3469	247.5666
5.9171	72.7782	13.3847	249.6464
6.0743	75.5061	14.0048	274.2234
6.0768	75.6361	14.0461	271.3813
6.2157	77.1024	14.7830	304.4033
6.2797	78.7292	14.7941	308.3545
6.4317	80.4746	15.6373	340.7263
6.4968	81.8382	15.6724	348.0659
6.6479	84.3921	16.6340	391.4446
6.7261	85.5634	16.6534	401.0691
6.8921	87.9774	17.4976	447.8718
6.9742	90.2677	17.7856	467.5222
7.0830	91.3326	18.3525	506.1736
7.1751	93.6894	19.2404	567.9314

Heat Capacity Results for Sc-Zr Alloys
2.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1262	12.3369	4.4961	50.9511
1.0574	11.1710	4.6215	52.5574
1.0855	11.5274	4.7366	54.4078
1.1152	11.8106	4.8424	55.6482
1.1470	12.2017	4.9649	57.3974
1.1794	12.4990	5.0936	58.9223
1.2173	12.8970	5.2182	60.8878
1.2652	13.4202	5.3631	62.5743
1.3298	14.1198	5.4552	64.1551
1.3911	14.7693	5.6052	66.5949
1.4560	15.4622	5.7862	69.9169
1.5025	16.0153	5.9599	71.9650
1.5632	16.6964	6.1446	74.3177
1.6404	17.5093	6.2824	76.2285
1.7126	18.3116	6.4908	80.2727
1.7974	19.2516	6.7278	83.7239
1.8691	20.0991	6.9792	87.9354
1.9678	21.1517	7.2501	92.2084
2.0854	22.4175	7.4616	96.3429
2.2015	23.7384	7.7595	103.8353
2.3028	24.8389	8.0609	108.2305
2.3069	24.7858	8.3236	112.8185
2.4011	25.8333	8.6062	117.5479
2.4953	26.9422	8.8165	122.5074
2.6141	28.3770	9.1305	127.4218
2.7326	29.8318	9.4749	136.3986
2.7969	30.5228	9.8614	145.7161
2.9224	32.0221	10.2856	155.6609
3.0527	33.4410	10.6359	163.6429
3.1806	34.9152	11.0410	174.2761
3.3145	36.3674	11.4224	186.1379
3.3594	37.0810	11.8255	196.7498
3.4672	38.1279	12.2668	209.7922
3.5521	39.1168	12.6490	222.9247
3.6317	40.3963	13.1429	241.2536
3.7483	41.6953	13.6845	260.2646
3.8046	42.3513	14.2833	282.4336
3.8952	43.7313	14.9889	312.9675
3.9832	44.8976	15.7878	353.5923
4.0732	45.7231	16.7115	402.2092
4.1677	46.9485	17.7498	471.3069
4.2646	48.2235	18.8656	541.1565
4.2730	48.2365	19.9786	626.2556

Heat Capacity Results for Sc-Zr Alloys
3.50 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1145	11.9768	3.7814	41.5221
1.1628	12.1688	3.8254	42.0659
1.2191	12.7644	3.8796	43.0635
1.2481	13.0726	3.9197	43.3835
1.2654	13.2550	3.9609	43.0789
1.2751	13.3579	4.1082	45.5148
1.2983	13.6040	4.1868	46.5155
1.3109	13.7359	4.2606	47.4385
1.3514	14.1680	4.3214	48.2197
1.4052	14.7408	4.3875	49.0579
1.4298	15.0024	4.4233	49.5037
1.5123	15.8837	4.4907	50.3605
1.5697	16.4966	4.5594	51.3114
1.6085	16.9133	4.6062	51.8446
1.6874	17.7594	4.6748	52.8067
1.7206	18.1158	4.7113	53.2293
1.7598	18.5388	4.7866	54.2178
1.8660	19.6864	4.8257	54.7208
1.9407	20.4955	4.8651	55.2619
1.9982	21.1229	4.9554	56.4476
2.0494	21.6807	5.1029	58.4224
2.1058	22.2964	5.1643	59.2607
2.2639	24.0339	5.1990	59.7479
2.3115	24.5580	5.2367	60.2487
2.3902	25.4287	5.3008	61.1347
2.4457	26.0428	5.3589	61.9385
2.5110	26.7865	5.4142	62.7032
2.5603	27.3429	5.5060	63.9787
2.6790	28.6408	5.5884	65.1467
2.7419	29.3652	5.6415	65.9213
2.8510	30.6044	5.7208	67.0375
2.9106	31.3045	5.7763	67.8338
2.9841	32.1163	5.8821	69.3674
3.0477	32.8724	6.0332	71.5826
3.1182	33.6795	6.1437	73.2205
3.2098	34.7071	6.2079	74.2001
3.2556	34.9630	6.3337	76.0887
3.3471	36.3439	6.4340	77.8219
3.3887	36.8557	6.5384	79.2352
3.4229	37.2238	6.6065	80.2967
3.4905	38.0581	6.7978	83.3164
3.5951	39.2964	6.8368	83.9522
3.6527	39.9893	7.0344	87.1323
3.7180	40.7616	7.2226	90.2331

Heat Capacity Results for Sc-Zr Alloys
3.50 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
7.3417	92.2390	11.1527	171.9457
7.5529	95.8718	11.3365	176.7383
7.6432	97.4066	11.9872	194.2489
7.8008	100.1625	12.4763	208.2713
7.9143	102.1936	12.9644	223.0040
8.0991	105.5371	13.2185	244.1934
8.2114	107.6059	13.8706	252.3256
8.3946	111.0882	14.2798	266.6544
8.5065	113.2133	14.9057	290.9649
8.7349	117.6298	15.2663	305.1697
8.8392	119.7187	15.9761	334.7350
9.1047	125.0616	16.3804	353.3745
9.2765	128.6124	16.8995	378.1660
9.4278	131.7891	17.5052	408.6139
9.6603	136.7691	17.9236	430.7441
9.8114	140.0863	18.3445	456.1698
10.1632	147.9991	19.0269	494.2805
10.3750	152.9083	19.8713	545.8511
10.6564	159.6151	20.4025	581.8466
10.9096	165.8037		

Heat Capacity Results for Sc-Zr Alloys
5.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0934	11.0537	1.5018	15.3499
1.0962	11.1815	1.5013	15.2886
1.1292	11.5453	1.5766	16.0752
1.1642	11.8362	1.6091	16.4799
1.2017	12.2572	1.6313	16.7192
1.2030	12.2372	1.7096	17.5535
1.2444	12.7044	1.7128	17.5705
1.2463	12.6709	1.7523	18.0182
1.2922	13.1821	1.7870	18.3381
1.2926	13.1926	1.8716	19.1255
1.3463	13.7279	1.9741	20.2664
1.3533	13.7905	2.0326	20.9149
1.4181	14.4598	2.0934	21.6191
1.4242	14.4782	2.1770	22.4933

Heat Capacity Results for Sc-Zr Alloys
5.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
2.2520	23.3030	5.2788	59.3229
2.3635	24.4991	5.3883	61.0345
2.3657	24.5353	5.4491	61.8557
2.5485	26.4452	5.5811	63.5529
2.5913	26.9564	5.6272	64.3074
2.7028	28.1921	5.6738	64.8445
2.7623	28.8270	5.7886	66.5540
2.8285	29.5897	5.7897	66.6170
3.0266	31.7777	5.7984	66.8705
3.0600	32.1305	5.9299	68.8117
3.1707	33.5274	5.9517	69.0029
3.2459	34.4391	5.9638	69.1346
3.3209	35.0551	6.0568	70.5708
3.4381	36.5430	6.0596	70.7894
3.5068	37.3148	6.1114	71.7357
3.6867	39.4294	6.1842	72.3321
3.7683	40.4474	6.1917	72.9571
3.8035	40.7666	6.2455	74.0145
3.9178	42.2616	6.3169	74.5414
3.9634	42.6304	6.3231	74.6887
3.9891	43.0288	6.3842	75.7758
4.0874	44.0277	6.4001	76.2109
4.1268	44.4888	6.4597	76.7582
4.1882	45.4832	6.4623	77.0745
4.2573	46.0765	6.5335	78.0134
4.2935	47.1517	6.5431	78.7151
4.3755	47.8090	6.6107	79.2563
4.3913	47.9576	6.6804	80.6535
4.4517	48.6813	6.6833	80.4597
4.5194	49.4127	6.6882	80.4501
4.5634	50.1395	6.8423	83.0100
4.5871	50.3694	6.8503	83.5247
4.6523	51.1440	6.8907	83.9332
4.7242	51.7588	7.0107	85.8898
4.7500	52.4063	7.0321	86.0284
4.7918	53.0534	7.0993	87.5890
4.8718	53.9189	7.2129	88.6398
4.9260	54.6015	7.2864	90.1711
4.9386	54.7966	7.4101	92.3559
5.0140	55.7710	7.4827	93.5245
5.1009	57.0300	7.6284	96.0623
5.1196	57.0484	7.8439	100.0244
5.2029	58.3023	7.8490	99.6932
5.2542	59.2934	7.9973	103.0914

Heat Capacity Results for Sc-Zr Alloys
5.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
8.0861	104.3807	12.6487	222.3255
8.2409	107.3602	12.8433	226.4629
8.3412	109.5051	13.1411	239.6039
8.5050	113.0608	13.3392	243.5008
8.6193	115.4539	13.5445	252.7822
8.7620	117.7297	13.9202	265.7417
8.8041	119.6311	14.0063	271.0042
9.0680	124.0599	14.5278	294.1997
9.1258	126.5659	14.5567	293.8838
9.2685	128.7783	15.1180	321.5955
9.4055	131.4286	15.2752	326.7651
9.6179	136.7739	15.6679	352.0500
9.7782	140.3105	15.9186	359.9851
10.0157	146.9471	16.1246	373.2854
10.1914	150.0583	16.6054	398.6316
10.4677	158.5659	16.7651	409.9646
10.5717	159.7690	17.2580	438.1643
10.9221	170.7640	17.5410	458.2563
11.0283	171.0717	18.0049	488.8840
11.2580	179.1173	18.3890	517.3547
11.4799	184.5905	18.8169	545.9583
11.7270	192.7881	19.2142	581.1997
11.9914	200.2183	19.5545	602.5120
12.1994	209.0763	20.3085	662.5376
12.4955	218.1293		

Heat Capacity Results for Sc-Zr Alloys
7.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1269	10.6761	1.3550	12.7819
1.1461	10.9807	1.3973	13.2386
1.1653	11.0196	1.4191	13.4289
1.1833	11.2055	1.4610	13.8762
1.2045	11.4751	1.5026	14.5133
1.2245	11.7743	1.5259	14.4973
1.2477	11.8084	1.5856	15.1387
1.2727	12.1176	1.6036	15.5509
1.3261	12.5930	1.6418	15.7419

Heat Capacity Results for Sc-Zr Alloys
 7.0 atomic percent Zr
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.6830	16.4918	4.6414	49.0234
1.7038	16.5340	4.7025	49.8150
1.7608	17.3067	4.7773	50.4597
1.7860	17.5535	4.8547	51.7565
1.8497	18.1906	4.9217	52.2778
1.9067	18.7505	4.9984	53.3843
1.9608	19.3156	5.0640	53.2588
2.0255	19.9301	5.1734	55.6707
2.0935	20.6399	5.2512	56.7654
2.1583	21.3038	5.3556	58.2896
2.1825	21.5972	5.4475	59.8652
2.3041	22.9168	5.5167	61.3001
2.3083	22.9152	5.6207	62.2596
2.3776	23.6108	5.6660	62.2886
2.4218	24.0153	5.7358	63.6693
2.5261	25.2728	5.7425	63.8088
2.5332	25.2222	5.8276	64.7577
2.6754	26.7447	5.8938	65.6663
2.6751	26.7873	6.0152	67.8942
2.7451	27.5495	6.0786	68.7988
2.8338	28.4406	6.2105	71.7579
2.9145	29.0215	6.2748	71.6133
2.9654	29.8984	6.4176	74.3249
2.9953	30.2360	6.4851	74.4602
3.0880	31.2956	6.6048	77.0064
3.1568	31.9460	6.6174	76.4560
3.2410	32.7396	6.7164	78.1448
3.3194	33.7758	6.8257	79.5326
3.3893	34.3781	6.9400	81.5020
3.5006	35.8414	7.0576	83.4020
3.5058	35.7994	7.1786	85.2364
3.6790	37.9287	7.2765	86.5670
3.6881	37.8372	7.4068	88.8081
3.7646	38.7930	7.4366	89.7171
3.8464	39.6198	7.6083	92.0204
3.9367	40.6743	7.6824	93.9762
4.0311	41.7708	7.8287	96.2278
4.1208	42.7259	7.8781	97.2432
4.1830	43.3702	8.0717	104.1362
4.3282	44.6261	8.1532	102.7371
4.3433	45.2993	8.3269	105.8845
4.4434	46.5428	8.4200	106.7169
4.5094	47.3754	8.6477	111.7732
4.5658	47.7855	8.7008	112.3188

Heat Capacity Results for Sc-Zr Alloys
7.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
8.8703	115.6333	13.6939	255.1834
9.0145	119.1622	13.8865	261.8938
9.1808	122.7403	14.1401	271.6353
9.2499	123.6899	14.5340	291.8535
9.5343	130.1339	14.7742	300.1672
9.6096	131.5891	15.2598	325.4155
9.9262	140.0245	15.3910	331.1748
10.0122	141.8960	15.9195	355.4875
10.3124	149.4060	15.9540	359.1406
10.4622	153.4035	16.3520	379.7280
10.6508	158.3716	16.5312	390.4448
10.9573	166.7237	17.1650	432.1841
11.1194	170.5807	17.2570	435.7346
11.3681	179.1512	17.9713	478.6541
11.5904	184.5321	17.9777	481.6521
11.8500	191.6011	18.7849	535.8079
12.1189	200.3291	18.7872	538.5623
12.4090	209.6243	19.6768	610.3723
12.7112	219.2701	19.6851	603.3469
13.0535	228.8891	20.4907	1031.5380
13.2482	239.0048		

Heat Capacity Results for Sc-Zr Alloys
8.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0637	10.2224	1.6807	16.2370
1.0959	10.5532	1.7388	16.8124
1.1299	10.8688	1.7774	17.1968
1.1663	11.2224	1.8500	17.9121
1.2054	11.5977	1.9235	18.6553
1.2438	11.9752	2.0238	19.6727
1.2952	12.4828	2.1317	20.7829
1.3491	13.0203	2.1660	21.0643
1.3997	13.4769	2.2576	22.0056
1.4551	14.0198	2.3558	23.0127
1.5035	14.4877	2.4698	24.2184
1.5646	15.1014	2.5961	25.5247
1.6240	15.6870	2.6832	26.3702

Heat Capacity Results for Sc-Zr Alloys
8.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
2.8315	28.0527	6.7272	77.0475
2.9929	29.8300	6.9817	81.1584
3.1399	31.3622	7.2553	85.5198
3.2728	32.8677	7.5604	90.7979
3.3390	33.4683	7.7979	95.1043
3.4531	34.6957	8.1316	100.9970
3.5550	35.7452	8.4625	107.4582
3.6507	36.9223	8.7652	112.6462
3.7415	37.7212	9.0815	118.6623
3.7668	38.0188	9.3400	124.2243
3.8808	39.5952	9.7185	132.9108
4.0001	40.6649	10.1313	141.9306
4.1188	42.3544	10.6060	153.6539
4.2314	43.4698	11.0342	164.8725
4.2648	43.8916	11.4285	175.1085
4.3730	45.0201	11.6960	182.7001
4.5036	46.8015	12.0584	193.9033
4.6383	48.3155	12.4912	207.5195
4.7814	49.9916	12.9744	224.0259
4.9140	51.8191	13.3694	239.2775
5.0711	53.7370	13.9186	259.0422
5.2179	55.6704	14.5518	284.9580
5.3782	57.8831	15.2656	317.8765
5.5517	60.4492	16.0536	358.0269
5.6597	61.7173	17.2499	423.5181
5.7968	63.5185	17.8988	467.0833
5.9625	66.0320	18.7100	526.6296
6.1448	68.4470	19.5553	587.9656
6.3452	71.4017	20.3125	658.6221
6.5011	73.5114		

Heat Capacity Results for Sc-Zr Alloys
9.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0545	9.8620	1.2022	11.2909
1.0931	10.2938	1.2442	11.6322
1.1319	10.6872	1.2956	12.1739
1.1675	10.9503	1.3523	12.7505

Heat Capacity Results for Sc-Zr Alloys
9.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.4193	13.3393	5.1009	53.6323
1.4816	13.9229	5.2717	56.4096
1.5073	14.1482	5.2800	55.7273
1.5608	14.7339	5.4537	58.6109
1.6396	15.4841	5.4725	58.3438
1.7470	16.5559	5.6104	59.7122
1.8573	17.6590	5.6822	61.4471
1.9149	18.2380	5.7183	61.8921
2.0266	19.3162	5.7940	62.8739
2.1300	20.3053	5.8916	64.2502
2.2163	21.1609	5.9589	65.3249
2.3129	22.0660	6.0772	67.0097
2.3438	22.5628	6.1484	68.1695
2.4356	23.5262	6.2731	70.1429
2.5504	24.6639	6.3863	71.7562
2.6664	25.8429	6.4881	73.2948
2.7835	27.1029	6.6488	75.5375
2.8141	27.4608	6.6556	75.4192
2.9166	28.4509	6.8170	78.0013
3.0421	29.7154	6.8872	79.0192
3.1644	31.2035	7.0642	82.0630
3.2977	32.5491	7.1521	83.1875
3.3106	32.5679	7.3476	86.6531
3.4269	33.9018	7.4440	87.9647
3.5567	35.2894	7.6574	91.8918
3.6724	36.4090	7.7648	94.0874
3.7964	37.8295	7.9438	96.7977
3.8287	38.2372	8.0267	98.6380
3.9468	39.4843	8.0709	99.2291
4.0536	41.0040	8.3150	103.3327
4.1504	41.9265	8.3205	103.9368
4.2489	43.1532	8.5861	109.3793
4.2640	43.5744	8.5970	108.8555
4.2688	43.4803	8.8835	115.5624
4.3870	44.6012	8.8962	115.1050
4.3889	44.5547	9.2127	120.4807
4.5090	46.2352	9.2254	120.9949
4.5122	46.1806	9.4730	125.9222
4.6379	47.7882	9.4876	125.7001
4.6446	47.8924	9.8614	136.3079
4.7775	49.2990	9.8667	136.5717
4.7866	49.7914	10.2937	153.1853
4.9253	51.4911	10.8011	158.6713
5.0960	53.5556	11.1424	166.1934

Heat Capacity Results for Sc-Zr Alloys
9.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
11.3466	173.2500	14.7059	293.4543
11.4510	175.1301	15.2613	320.4927
11.7777	185.1935	15.5449	331.8142
11.8251	186.0615	16.0845	357.5730
12.2955	201.8620	16.4155	378.2483
12.2959	202.1362	17.0322	411.5222
12.8063	218.8248	17.3945	435.7480
12.8190	219.1313	17.9316	471.8684
13.3726	241.7331	18.5522	517.8389
13.4010	239.8763	18.6833	524.0291
13.8930	257.7432	19.5910	598.2678
14.0422	264.4202	20.3225	660.9248
14.5388	285.4417		

Heat Capacity Results for Sc-Zr Alloys
10.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0913	9.2696	1.9140	16.3759
1.1316	9.5958	2.0003	17.1130
1.1726	9.9927	2.0279	17.3657
1.1991	10.1507	2.0280	17.3689
1.2206	10.3713	2.1237	18.2398
1.2676	10.7275	2.1714	18.6597
1.2976	11.0541	2.1757	18.6560
1.3177	11.1741	2.2166	19.0570
1.3815	11.7261	2.3093	19.8585
1.4167	11.9769	2.3369	20.0762
1.4546	12.3150	2.4148	20.7924
1.4867	12.6762	2.4529	21.1329
1.5475	13.1301	2.5288	21.7514
1.6249	13.7978	2.5670	22.1707
1.6464	13.9719	2.6934	23.2990
1.6775	14.1981	2.7167	23.9381
1.6901	14.3959	2.8357	24.5962
1.7073	14.5447	2.9025	25.2499
1.8085	15.4261	2.9615	25.8307
1.8466	15.7897	2.9713	25.9056
1.9082	16.3011	3.0771	26.9774

Heat Capacity Results for Sc-Zr Alloys
10.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.1235	27.3674	6.3543	63.2735
3.1882	28.0225	6.4291	64.4211
3.2535	28.7071	6.5398	65.8488
3.3245	29.2265	6.6462	67.3016
3.3866	29.9484	6.6963	67.8243
3.4806	30.8797	6.7522	68.4488
3.5428	31.4411	6.7780	69.1172
3.5883	31.8488	6.8971	70.6804
3.6338	32.4420	6.9697	71.7272
3.7518	33.5990	7.1200	73.7176
3.7738	33.6642	7.1988	74.9250
3.8806	34.7799	7.3499	77.1487
3.9934	35.8514	7.5571	80.2366
4.0340	36.3563	7.6997	81.9600
4.1840	37.8725	7.7303	82.6915
4.1934	37.9112	7.9287	85.9553
4.2646	38.8909	7.9701	86.7272
4.3014	39.1460	8.1823	90.7030
4.3882	40.1020	8.3095	92.6652
4.4468	40.5186	8.4430	94.9954
4.5094	41.4537	8.6231	98.8513
4.5272	41.3078	8.7180	99.6201
4.5835	41.9580	8.9111	102.9306
4.6389	42.4152	8.9243	104.0080
4.6637	42.8305	9.2435	110.1598
4.7195	43.2150	9.2756	109.3925
4.7769	44.0185	9.4335	113.3204
4.8057	44.4285	9.6220	116.9727
4.8690	44.9090	9.7834	121.0243
4.9420	45.9047	10.0239	125.5949
5.0143	46.5535	10.2014	129.9589
5.1128	47.8595	10.4826	135.5564
5.1962	48.6064	10.6759	140.6524
5.2919	49.8618	10.8932	145.9105
5.3849	50.8448	11.2032	153.7748
5.4841	52.3000	11.3732	157.6847
5.5844	53.1500	11.6097	164.5958
5.6895	54.7267	11.8688	170.9430
5.7995	55.9744	12.1419	179.4004
5.8262	56.2182	12.3602	184.7110
5.9517	57.9464	12.7732	197.9924
6.0234	58.8229	12.8238	198.9883
6.1448	60.4102	13.1973	210.6683
6.2213	61.5763	13.4437	220.9054

Heat Capacity Results for Sc-Zr Alloys
10.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
13.7340	228.5850	17.0538	385.3010
14.0884	243.8845	17.2949	401.0183
14.1587	246.9821	17.8041	428.8540
14.6317	266.3264	17.9954	441.1233
14.8013	273.6001	18.5739	482.3323
15.3472	297.8020	18.8119	493.6851
15.4295	299.9277	19.4378	539.6714
15.9204	324.1113	19.6999	559.5461
16.1318	333.4504	20.2320	607.2964
16.6137	360.5095		

Heat Capacity Results for Sc-Zr Alloys
12.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0756	9.5809	2.7899	25.9748
1.1072	9.8627	2.9390	27.5109
1.1207	10.0186	3.0588	28.7367
1.1655	10.3616	3.1619	29.7047
1.2049	10.7853	3.2066	30.2030
1.2798	11.4573	3.3240	31.4992
1.4083	12.6448	3.4538	33.0024
1.4473	12.9616	3.6000	34.2958
1.4696	13.2093	3.7483	35.8971
1.5292	13.7479	3.8366	36.8638
1.5933	14.3730	3.9719	38.2368
1.6580	14.9668	4.0704	39.2933
1.7280	15.6041	4.1711	40.3166
1.7715	16.0085	4.2738	41.7283
1.8565	16.8345	4.2883	41.7000
1.9336	17.5412	4.4125	43.1439
2.0105	18.2664	4.4423	43.4196
2.1151	19.2428	4.5686	44.9707
2.1678	19.7889	4.6015	45.2668
2.2743	20.8896	4.7382	46.8721
2.3892	22.0013	4.7700	47.3488
2.5063	23.1178	4.9234	49.2879
2.6192	24.2171	4.9400	49.3229
2.6556	24.6549	5.0916	51.9206

Heat Capacity Results for Sc-Zr Alloys
12.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
5.0951	51.0846	9.2191	117.3977
5.2863	53.8716	9.2411	117.7371
5.2876	53.5830	9.5786	125.0571
5.4788	56.1503	9.6031	125.5768
5.4795	56.2339	9.9787	135.8550
5.6892	58.9990	10.0015	134.1232
5.6899	59.0511	10.4270	144.6154
5.9167	62.3223	10.4320	143.4295
5.9172	62.2019	10.7978	154.6830
6.0708	64.3655	10.7996	153.5242
6.0815	64.3774	11.3295	168.7779
6.2831	67.3374	11.3321	168.0783
6.2847	67.3563	11.9534	186.2240
6.4977	70.8794	11.9662	188.1146
6.5006	70.5804	12.6699	209.7385
6.7275	73.8237	12.6900	211.5660
6.7288	74.0270	13.3727	232.9168
6.9747	77.3454	13.5404	241.8480
6.9782	77.3864	13.8828	253.2683
7.1750	79.7553	14.3896	273.5000
7.1783	80.8884	14.5371	280.6245
7.4517	84.9421	15.2220	311.1648
7.4575	84.8055	15.2604	314.7642
7.7684	90.8674	16.0914	356.7615
7.7799	90.7175	16.1054	358.4927
8.1273	96.9670	17.0239	410.9331
8.1322	96.6656	17.2014	421.5227
8.5204	104.1000	17.8963	466.8340
8.5276	104.1062	18.4221	505.4321
8.8519	109.9218	18.9163	543.2878
8.8677	110.3775	19.9957	632.6062

Heat Capacity Results for Sc-Zr Alloys
15.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0834	9.3308	1.1825	10.2089
1.1166	9.6211	1.2212	10.5453
1.1480	9.9014	1.2596	10.8525

Heat Capacity Results for Sc-Zr Alloys
15.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.3036	11.2621	5.0180	48.9424
1.3535	11.6587	5.1692	50.9327
1.4028	12.1339	5.3086	52.2390
1.4459	12.4517	5.4196	53.2182
1.4664	12.6647	5.4704	54.0043
1.5131	13.0772	5.6142	55.8576
1.5654	13.5761	5.7790	57.7924
1.6235	14.0982	5.9552	60.0612
1.6909	14.7237	6.1442	62.9492
1.7307	15.0729	6.2862	64.7347
1.8107	15.7949	6.4949	67.7444
1.9103	16.7211	6.7241	70.4487
2.0295	17.7389	6.9728	74.5252
2.1715	19.1105	7.2022	77.7300
2.2382	19.6248	7.3609	80.4428
2.3202	20.3487	7.6554	84.8059
2.4214	21.3050	7.9382	90.7431
2.5423	22.5014	8.1956	94.0800
2.6788	23.8793	8.4500	99.0667
2.7315	24.4993	8.6131	100.9085
2.8636	25.8270	8.9068	106.7029
3.0072	27.2833	9.2344	112.9409
3.1696	28.7669	9.5887	120.2556
3.3025	30.0105	9.9239	125.5757
3.3567	30.4362	10.1615	134.9121
3.4199	31.1078	10.5219	141.9413
3.4900	31.9748	10.8634	152.2114
3.6040	32.9643	11.2320	160.5554
3.6951	33.9582	11.6347	168.5351
3.8155	35.1895	11.9266	180.6731
3.9030	36.2084	12.3517	194.1932
3.9890	36.9599	12.8074	207.9170
4.0887	38.2035	13.3399	229.0069
4.1883	39.3298	13.9923	254.4801
4.2686	39.7701	14.6898	285.8623
4.3851	41.4248	15.5282	329.3462
4.5039	42.2378	16.4072	375.6184
4.6352	44.0578	17.4256	431.2173
4.7745	45.5947	18.5631	516.3796
4.8802	46.8292		

Heat Capacity Results for Sc-Zr Alloys
17.50 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0703	8.9343	4.9983	46.7162

1.1177	9.3501	5.1029	47.8971
1.1715	9.7930	5.1848	48.9461
1.2206	10.1934	5.3005	50.4149
1.2713	10.6164	5.3943	51.5760
1.3150	10.9490	5.5352	53.4718
1.3660	11.3588	5.6006	54.1626
1.4248	11.8560	5.7805	56.6001
1.4892	12.3848	5.8282	57.0366
1.5445	12.8635	6.0323	59.7216
1.5817	13.2098	6.1127	60.8036
1.6563	13.8103	6.2223	61.8947
1.7301	14.4357	6.3242	63.6904
1.8121	15.1187	6.4752	66.1612
1.8834	15.7606	6.5678	67.0884
1.9227	16.1096	6.7374	69.5042
1.9955	16.8336	6.8281	70.9967
2.0716	17.5164	6.9824	73.1660
2.1615	18.2924	7.1026	74.9830
2.2364	18.9939	7.2552	77.3778
2.2496	19.0186	7.4122	79.7202
2.3479	19.8651	7.4785	80.4211
2.4545	20.9049	7.6882	84.3572
2.5634	21.8493	7.7540	85.3070
2.6742	22.8999	8.0391	90.2487
2.7253	23.2573	8.0594	91.1108
2.8524	24.4359	8.3686	95.7166
2.9719	25.6126	8.4310	96.9340
3.1119	26.9953	8.6743	102.2508
3.2886	28.7413	8.7921	104.1908
3.4055	29.8335	8.9151	106.0192
3.5879	31.5224	9.1155	109.5538
3.7553	33.2855	9.2551	113.3501
3.9671	35.3939	9.3977	114.7971
4.1518	37.3910	9.6135	120.1013
4.2715	38.7686	9.7911	124.1693
4.2878	38.9948	9.9527	128.0763
4.4180	40.2980	10.2357	134.7376
4.4716	40.8598	10.2749	133.8334
4.5858	42.1712	10.5517	142.6459
1.6456	42.8859	10.6509	145.1148
4.7842	44.2939	10.9699	153.9309
4.8122	44.5326	11.2319	159.7774
4.9687	46.3683	11.4325	164.8760

Heat Capacity Results for Sc-Zr Alloys
17.50 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
11.7371	173.5695	15.2431	311.4529
11.8831	180.4174	16.0975	353.7505
12.3195	193.6565	16.1166	360.2361
12.3416	192.7817	16.9334	400.1262
12.9594	214.2235	16.9723	408.1741
12.9712	211.4050	17.8397	462.4827
12.9725	212.9516	17.8758	462.9944
13.6578	238.0560	18.7311	522.8533
13.7352	241.9507	18.7936	519.2632
14.4369	272.7952	19.5895	602.5461
14.5429	275.2957	19.6135	598.2910
15.2302	310.0444	20.3687	661.2236

Heat Capacity Results for Sc-Zr Alloys
20.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0560	8.3562	1.5278	12.1795
1.0627	8.4234	1.5817	12.6470
1.0838	8.6294	1.5940	12.7264
1.0981	8.7045	1.6566	13.2830
1.1135	8.9352	1.6569	13.3084
1.1293	8.9687	1.7273	13.8851
1.1454	9.1825	1.7278	13.8865
1.1627	9.2368	1.7667	14.1921
1.1797	9.4362	1.8077	14.5733
1.2004	9.4757	1.8554	14.9361
1.2175	9.7278	1.8586	15.0749
1.2400	9.8663	1.9328	15.6241
1.2663	10.1033	1.9628	15.8551
1.2890	10.2535	1.9947	16.1318
1.3179	10.4984	2.0542	16.6404
1.3343	10.5886	2.0955	16.9780
1.3797	10.9917	2.1336	17.2993
1.3835	11.0230	2.1680	17.6629
1.4376	11.4589	2.2159	17.8975
1.4552	11.6108	2.2436	18.2331
1.4609	11.6128	2.2798	18.5233
1.5034	12.0067	2.3543	19.2475

Heat Capacity Results for Sc-Zr Alloys
 20.0 atomic percent Zr
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
2.3932	19.5343	4.8753	43.5149
2.4564	20.2270	4.8874	43.6511
2.5066	20.5161	5.0152	44.9916
2.5640	21.0229	5.0163	45.2702
2.6136	21.5306	5.1708	46.7682
2.6390	21.8622	5.1827	47.2462
2.6596	21.9981	5.3129	48.7451
2.8645	22.2218	5.3642	49.2845
2.7426	22.7736	5.4612	50.3479
2.8230	23.5711	5.5198	51.2291
2.8570	23.6952	5.5636	51.4028
2.9670	24.6991	5.6138	52.1761
2.9805	25.0094	5.7225	53.4558
3.0647	25.5716	5.7806	54.2106
3.0998	26.1531	5.8940	55.5229
3.1231	26.1618	5.9584	56.2454
3.2433	27.3322	6.0777	57.9940
3.2648	27.4626	6.1474	58.8870
3.2815	27.6362	6.2789	60.6423
3.3813	28.5508	6.3505	61.5744
3.3970	28.6832	6.4929	63.0603
3.5204	29.7660	6.4998	63.0762
3.5279	30.0225	6.6560	65.6316
3.6351	30.5847	6.7245	66.8414
3.6535	30.6946	6.8918	68.9588
3.6611	31.1748	6.9788	69.8935
3.7353	31.5828	7.1090	72.2109
3.8137	32.5201	7.2499	74.1108
3.8381	32.7666	7.2985	75.1324
3.9018	33.5411	7.4108	76.0787
3.9806	34.0673	7.5485	78.8624
4.0170	34.7685	7.6063	79.6362
4.0861	35.3505	7.7265	81.1867
4.0976	35.0645	7.8240	83.6668
4.1823	36.6119	7.9394	84.6159
4.2792	37.4668	8.0613	87.3048
4.3750	37.8237	8.1853	89.0746
4.3888	37.8733	8.3199	91.7704
4.5033	39.5061	8.4556	93.7372
4.5119	39.5284	8.5100	94.6690
4.6426	40.9161	8.7413	99.2763
4.6442	40.9227	8.8028	99.8979
4.7774	42.4968	8.9325	101.9532
4.7800	42.4545	9.1204	105.4563

Heat Capacity Results for Sc-Zr Alloys
20.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
9.2342	107.2383	13.3426	221.1866
9.4683	112.1873	13.5011	251.1445
9.5997	115.3804	13.7615	237.0611
9.7852	119.8157	14.1083	251.9271
9.9473	123.2094	14.3189	260.5696
9.9981	126.2502	14.7700	281.5222
10.2145	129.1093	15.0174	291.8931
10.4442	135.5188	15.3895	311.6516
10.5244	136.4594	15.7914	329.5637
10.8132	143.5640	15.8977	338.6331
10.8563	143.8612	16.5377	373.2529
11.2200	153.5463	16.5439	376.5508
11.2252	153.2123	17.1623	412.2419
11.4999	160.5262	17.2002	411.9929
11.6277	164.3596	17.9173	465.2468
11.9166	174.9550	17.9481	468.0818
12.0617	177.7193	18.7219	528.2947
12.3408	188.1973	18.7895	532.9485
12.5635	194.6063	19.6566	604.4983
12.8082	203.7000	20.6293	702.8359
12.9639	207.6466		

Heat Capacity Results for Sc-Zr Alloys
25.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0515	7.7131	1.3485	9.9726
1.0919	8.0483	1.3521	9.9777
1.0970	8.0114	1.4005	10.3154
1.1289	8.3242	1.4013	10.3336
1.1322	8.3379	1.4403	10.6080
1.1633	8.5814	1.4422	10.6420
1.1662	8.5748	1.4592	10.7991
1.2011	8.8232	1.4821	10.9129
1.2039	8.8800	1.5046	11.1510
1.2415	9.1574	1.5278	11.3355
1.2465	9.2049	1.5648	11.5582
1.2929	9.5246	1.5943	11.8357
1.2936	9.5630	1.6222	12.0276

Heat Capacity Results for Sc-Zr Alloys
 25.0 atomic percent Zr
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.6543	12.3017	3.6620	29.1770
1.6904	12.5577	3.7478	29.9512
1.7270	12.8918	3.7854	30.4103
1.7631	13.2023	3.8941	31.3063
1.7691	13.2196	3.9187	31.7025
1.8111	13.5548	3.9424	31.7807
1.8544	13.9257	3.9444	31.6977
1.9068	14.3531	4.0556	33.0885
1.9629	14.7989	4.0759	33.4491
2.0275	15.2510	4.1732	34.0924
2.0595	15.5371	4.2021	34.1229
2.1302	16.0800	4.2706	35.0886
2.1343	16.1134	4.2813	35.4296
2.1474	16.3247	4.3859	35.8224
2.2195	16.6637	4.3939	35.7179
2.2446	16.9637	4.5069	37.5326
2.2561	17.5551	4.5207	37.5454
2.3123	17.5612	4.6372	38.8210
2.3811	18.1275	4.6499	38.8512
2.4110	18.4306	4.7798	40.0181
2.4964	19.1026	4.7867	40.7713
2.5063	19.2381	4.8583	41.2301
2.5215	19.3094	4.9270	42.0161
2.6111	20.0844	5.0134	42.4599
2.6280	20.2804	5.1043	43.5894
2.6865	20.8665	5.1819	44.5879
2.7285	21.1333	5.2802	45.8423
2.7704	21.5513	5.3649	47.0963
2.7866	21.6238	5.4986	48.6952
2.8785	22.4916	5.5599	48.9626
2.8923	22.6261	5.6694	50.7055
2.9152	22.7917	5.7069	51.5007
3.0206	23.7018	5.7944	51.3805
3.0607	24.1100	5.8342	52.1830
3.1504	24.7857	5.9572	53.5383
3.2060	25.2985	6.0156	54.9286
3.2703	25.7631	6.1448	56.2478
3.3357	26.3613	6.2086	57.2334
3.3567	26.4269	6.3535	59.0872
3.4109	26.9751	6.4167	59.5446
3.4100	26.7404	6.5691	61.7245
3.4738	27.5518	6.5715	61.6319
3.5308	28.0458	6.7344	63.8625
3.6197	28.7114	6.8005	64.6823

Heat Capacity Results for Sc-Zr Alloys
25.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
6.9797	66.9909	11.3490	153.6337
7.0607	68.7496	11.4221	155.1445
7.2532	71.1611	11.7964	166.5291
7.3427	72.8287	11.8158	167.7323
7.5602	75.6585	12.2773	182.8922
7.6547	77.3053	12.3077	182.2025
7.8872	81.3820	12.7822	200.1712
7.8949	81.2171	12.8266	198.3681
8.1516	85.5932	13.3596	220.9114
8.2496	86.9968	13.3938	219.3223
8.5281	92.0692	13.8829	238.3540
8.5966	93.0952	14.0558	242.3609
8.8976	97.2838	14.5266	266.4963
8.9747	100.1686	14.7154	275.9438
9.2135	105.0354	15.2614	302.3494
9.3901	108.1962	15.5393	317.1628
9.4656	108.6294	15.9726	340.5217
9.7615	116.9511	16.4089	365.3625
9.8509	118.9350	16.5539	370.5339
10.0337	121.6911	17.1382	409.9541
10.2069	127.5249	17.3958	429.0718
10.3695	129.5886	17.9390	463.3733
10.5178	131.5297	18.5302	521.5696
10.6940	137.6180	18.7298	529.6624
10.9331	142.5267	19.5853	600.9502
11.0431	145.7175	20.5505	698.7085

Heat Capacity Results for Sc-Zr Alloys
26.50 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0772	7.7554	1.2448	9.0076
1.0856	7.8366	1.2462	8.9837
1.1238	8.0706	1.2774	9.2561
1.1299	8.1989	1.2881	9.3333
1.1655	8.4077	1.3216	9.5956
1.1656	8.4187	1.3348	9.6860
1.2033	8.7200	1.3688	9.8984
1.2047	8.7097	1.3855	9.8416

Heat Capacity Results for Sc-Zr Alloys
 26.50 atomic percent Zr
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.4048	10.1883	3.1049	23.8219
1.4384	10.4151	3.1586	24.1888
1.4424	10.4592	3.2038	24.7177
1.4599	10.6072	3.3023	25.4440
1.4823	10.7706	3.3458	25.9575
1.5049	10.9081	3.4280	26.3858
1.5288	11.0946	3.5002	27.1296
1.5652	11.4079	3.5589	27.5601
1.5951	11.5893	3.6480	28.3218
1.6238	11.8441	3.6598	28.4205
1.6558	12.0905	3.6609	28.3513
1.6907	12.3498	3.6899	28.6551
1.7273	12.5710	3.8001	29.7763
1.7652	12.9388	3.8645	30.3175
1.7685	12.8812	3.9518	31.3115
1.8115	13.2751	4.0488	31.6028
1.8556	13.5531	4.0937	32.6076
1.9087	14.0101	4.1616	33.3172
1.9669	14.4246	4.1747	33.2859
1.9924	14.6970	4.2689	34.5278
2.0585	15.1195	4.3037	34.8052
2.0596	15.1272	4.3833	35.4209
2.1325	15.7477	4.4493	36.0952
2.1359	15.6900	4.5022	36.7998
2.1435	15.7723	4.6076	37.7802
2.1626	16.0324	4.6321	37.7865
2.2523	16.6330	4.7686	39.5545
2.2777	16.9033	4.7787	39.2829
2.3261	17.1891	4.9075	40.9582
2.3714	17.5698	4.9350	41.0567
2.4795	18.5285	5.0820	42.5910
2.5059	18.7799	5.0877	42.5503
2.5694	19.3141	5.2645	44.8215
2.5912	19.4711	5.2754	44.7191
2.6042	19.5566	5.4498	47.1245
2.6362	19.7812	5.4659	46.9832
2.6913	20.3993	5.6218	48.8409
2.7480	20.6383	5.6562	49.1080
2.8228	21.4897	5.7792	50.3013
2.8638	21.7516	5.7984	50.6851
2.9389	22.4119	5.9495	52.4067
2.9770	22.6628	5.9550	52.3900
3.0486	22.9309	6.1420	54.9922
3.0791	23.5238	6.1467	55.2371

Heat Capacity Results for Sc-Zr Alloys
26.50 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
6.3430	57.7091	10.4353	129.0967
6.3474	57.5661	10.7720	138.0805
6.5640	60.2879	10.9382	141.5668
6.5672	59.5997	11.3125	151.1043
6.7275	62.2882	11.5115	155.1687
6.8054	63.3742	11.9367	172.2547
6.9692	66.0777	12.0041	173.1009
6.9877	65.5746	12.5300	190.9838
7.2447	69.7131	12.5469	189.1525
7.2490	70.2083	13.0388	206.8110
7.5426	74.6773	13.0887	207.4979
7.5552	74.6175	13.6870	229.4460
7.8743	79.6612	13.6931	229.1107
7.8835	79.8594	14.3702	259.5159
8.1354	84.0730	14.3810	258.6340
8.2502	85.1893	15.0094	288.8767
8.4400	89.0361	15.1508	297.6199
8.5557	90.7556	15.8211	329.8159
8.7292	93.7914	16.0264	343.5530
8.8900	96.9314	16.7046	382.7153
9.0531	99.0536	16.7517	382.3120
9.2141	102.1857	17.5601	434.5474
9.3909	105.7992	17.7464	451.8047
9.5691	109.2376	18.3425	489.8496
9.6176	110.6537	18.9596	544.4202
9.9682	119.2310	19.1791	560.2600
9.9886	120.1595	20.0607	643.0403
10.2949	126.6374		

Heat Capacity Results for Sc-Zr Alloys
28.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
4.2686	33.7491	4.7163	37.7564
4.2978	33.6789	4.8567	39.5376
4.4398	35.0389	4.8585	39.3883
4.5705	36.6184	4.9881	41.0582
4.5778	36.5522	5.0000	40.7914
4.7118	37.8391	5.1823	42.9214

Heat Capacity Results for Sc-Zr Alloys
28.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
5.1851	42.6585	9.2188	100.3813
5.3684	44.9725	9.2216	100.9002
5.3731	44.9338	9.5762	107.9513
5.5704	47.2385	9.5887	108.2430
5.5727	47.1397	9.8727	115.3828
5.7823	49.8648	9.9688	118.0230
5.7895	49.8878	10.2900	125.4409
5.8973	51.1145	10.2916	123.6849
5.9387	51.4119	10.7564	138.9183
6.0817	52.8918	10.7700	135.2568
6.1483	53.6529	11.3071	150.5603
6.2783	55.5093	11.3129	151.2115
6.3505	56.7857	11.9432	169.0670
6.4966	58.6379	11.9515	168.5771
6.5687	59.3757	12.5002	186.2728
6.7265	61.5838	12.5462	185.4334
6.8066	62.8462	13.0020	203.0504
6.8931	63.6888	13.0925	203.2291
6.9894	65.1758	13.6606	228.0094
7.1538	66.9111	13.7056	225.9817
7.2504	69.0318	14.3760	258.3220
7.4487	71.6385	14.3941	259.0200
7.5525	73.3768	15.1708	289.3494
7.7649	76.4045	15.1695	294.3708
7.8983	78.9442	16.0083	341.8254
8.1221	81.7378	16.0227	337.0776
8.2732	85.1598	16.7547	382.4285
8.2903	84.9712	17.0369	403.3081
8.5467	88.7791	17.4977	438.1040
8.5984	90.4827	18.0954	478.8301
8.8823	94.9142	18.2582	490.5256
8.8910	94.7810	19.1164	555.9011

Heat Capacity Results for Sc-Zr Alloys
30.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1095	7.6301	1.1533	7.9158
1.1296	7.7702	1.1806	8.1439

Heat Capacity Results for Sc-Zr Alloys
30.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1950	8.2249	2.6288	18.6205
1.2257	8.4627	2.6545	18.9183
1.2430	8.5857	2.6905	19.2094
1.2716	8.7671	2.6920	19.1482
1.2950	8.8508	2.8454	20.4309
1.3226	9.1468	2.8536	20.4354
1.3270	9.1337	2.9959	21.6096
1.3586	9.3544	3.0230	21.8358
1.3696	9.4480	3.1421	22.1763
1.4027	9.6821	3.1794	23.0022
1.4040	9.6454	3.1948	23.3013
1.4403	9.8854	3.2272	23.4803
1.4405	9.9401	3.2694	23.5721
1.4830	10.2511	3.3161	24.3661
1.4841	10.1921	3.4115	25.1355
1.5057	10.3837	3.5645	26.5968
1.5319	10.5451	3.6263	26.9593
1.5593	10.7163	3.8377	29.0383
1.5672	10.7891	3.8457	28.8896
1.6236	11.1849	4.0094	30.1458
1.6257	11.2102	4.0169	30.3485
1.6907	11.7086	4.1844	31.6443
1.6920	11.7146	4.2579	32.7521
1.7693	12.2674	4.2588	32.8589
1.7702	12.2997	4.3997	33.7504
1.8127	12.5919	4.4063	34.1768
1.8337	12.7510	4.5549	35.3496
1.8597	12.9243	4.5564	35.5530
1.9083	13.2979	4.7068	36.9553
1.9342	13.4844	4.7101	37.1675
1.9935	13.9245	4.8537	38.3388
1.9946	13.9417	4.8587	38.3837
2.0622	14.3687	4.9650	39.3300
2.0626	14.3834	4.9993	39.9217
2.1361	14.9498	5.1517	41.5964
2.1385	14.9243	5.1811	41.7546
2.1488	15.0670	5.3546	43.7984
2.1594	15.1345	5.3671	43.9418
2.2527	15.9073	5.5634	46.0804
2.2818	15.9977	5.5709	46.0996
2.3641	16.7325	5.7758	48.3445
2.4071	17.1348	5.7758	48.4140
2.4902	17.6672	5.8954	49.6508
2.5446	18.0772	5.9371	50.0293

Heat Capacity Results for Sc-Zr Alloys
30.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
6.0761	51.9519	10.4261	125.8928
6.1434	52.7421	10.7620	134.3364
6.2761	54.4540	10.9157	138.3679
6.3463	55.3228	11.4046	151.1434
6.4898	56.8750	11.4978	154.0523
6.5698	58.1149	12.1369	173.2878
6.7207	59.9890	12.1521	174.4059
6.8081	61.1994	12.7228	192.6180
6.8986	61.9813	12.7904	194.3584
6.9860	63.5130	13.3631	215.8140
7.1501	65.8897	13.3702	214.0195
7.2465	67.1862	13.9382	239.0212
7.4403	69.8082	14.0071	241.2105
7.5474	71.5736	14.7103	273.7190
7.7634	75.1670	14.7399	275.9868
7.8808	77.0499	15.5677	314.9282
8.2534	82.7789	15.5808	318.6780
8.3948	85.6333	16.2062	351.9407
8.5613	87.6956	16.5552	371.9326
8.7270	91.5506	17.0098	444.3799
8.9042	93.8438	17.3323	421.8403
9.0419	96.5494	17.8983	462.0383
9.2361	100.5223	18.2418	491.6106
9.3809	102.6038	18.8749	538.0095
9.5864	106.7601	19.1063	563.0718
9.7507	110.7989	19.9586	639.0139
9.9673	117.1489	20.0191	645.9673
10.0181	116.8775	20.0669	648.0339
10.2923	123.3427		

Heat Capacity Results for Sc-Zr Alloys
34.0 atomic percent Zr

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0809	6.9537	1.3406	8.6344
1.1331	7.2990	1.4006	9.0270
1.1803	7.6266	1.4590	9.4113
1.2313	7.9103	1.5265	9.8457
1.2905	8.2775	1.5867	10.2362

Heat Capacity Results for Sc-Zr Alloys
34.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.6178	10.4682	6.0656	49.5371
1.6932	10.9590	6.2099	50.9062
1.7341	11.2856	6.2817	51.9424
1.8108	11.8194	6.4242	53.8303
1.8844	12.3039	6.4953	54.5088
1.9014	12.4349	6.6502	56.6108
2.0324	13.3463	6.7260	57.5890
2.1792	14.3074	6.8868	59.3392
2.3154	15.3271	6.9796	60.1330
2.4237	16.0556	7.1597	63.1662
2.4460	16.2639	7.1629	63.1674
2.5730	17.1839	7.3640	66.1688
2.7112	18.2888	7.4487	67.2930
2.8317	19.1033	7.6632	70.6565
2.9489	19.8543	7.7723	71.7815
2.9550	19.9887	8.0120	75.7972
3.0871	21.1351	8.1307	77.3347
3.2404	22.4308	8.3993	82.3378
3.4121	23.7484	8.5344	84.1456
3.5856	25.2310	8.8256	89.1998
3.6292	25.5674	8.8695	90.6376
3.8190	26.9725	9.1970	95.2791
4.0079	28.7354	9.2387	96.4915
4.1921	30.1944	9.5914	103.3566
4.2624	30.9272	9.6043	103.6036
4.2856	31.2511	9.9895	112.4388
4.4239	32.3235	9.9924	113.5783
4.4438	32.5231	10.4104	120.1176
4.6060	34.0977	10.4330	122.5911
4.6086	33.9666	10.7819	131.1419
4.7772	35.6341	10.9661	135.0369
4.7935	35.7564	11.3332	145.7538
4.9433	37.2301	11.5113	150.3577
4.9801	37.5389	11.9603	163.3298
5.0907	38.5409	12.2047	171.9082
5.1648	39.5127	12.6948	188.9851
5.2784	40.5269	12.9884	198.2559
5.3837	41.9525	13.2697	208.9600
5.4714	42.7445	13.6761	224.2534
5.5909	44.2979	13.8939	231.9825
5.6828	44.9048	14.3505	249.6413
5.8092	46.5894	14.9617	281.0994
5.9064	47.3182	15.0101	287.5620
6.0467	49.0384	15.6171	317.1453

Heat Capacity Results for Sc-Zr Alloys
34.0 atomic percent Zr
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
15.9146	333.2727	18.3122	501.2097
16.3174	358.4702	18.7641	538.5813
16.7327	382.8950	19.1659	575.9424
17.0194	399.2378	19.6662	623.2400
17.5650	441.1050	20.3851	698.5957

Heat Capacity Results for Sc-Mg Alloys
1.89 atomic percent Mg

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0526	10.4537	4.9413	54.9030
1.0892	10.8218	4.9624	55.3334
1.1286	11.2196	5.0895	56.9195
1.1660	11.5902	5.1026	57.1373
1.2039	11.9892	5.2710	59.3616
1.2412	12.3640	5.2835	59.8429
1.2921	12.8641	5.4659	62.2651
1.3481	13.4380	5.4841	62.3779
1.4170	14.1379	5.6659	64.7699
1.4803	14.7784	5.6882	65.6416
1.5038	15.0259	5.7847	66.9742
1.5811	15.8143	5.9135	68.8070
1.6570	16.5971	5.9556	69.7867
1.7279	17.3321	6.0652	70.5686
1.8102	18.1863	6.1441	72.6282
1.8599	18.6936	6.2813	74.3518
1.9581	18.7294	6.3501	76.1863
2.0603	20.7900	6.4957	77.9188
2.1689	21.9360	6.5668	79.0742
2.3073	23.4100	6.7098	81.9139
2.3678	24.0168	6.7267	82.1631
2.5124	25.6097	6.9768	86.4145
2.6390	26.9984	6.9772	86.4345
2.7660	28.3901	7.2208	89.2504
2.8980	29.8632	7.2480	91.1059
2.9397	30.3202	7.5491	95.6145
3.0797	31.9091	7.6078	97.4080
3.2406	33.7317	7.8931	102.6816
3.4195	35.8100	8.0010	103.9734
3.6042	37.8178	8.1549	107.3346
3.6640	38.8116	8.3839	111.0257
3.8345	40.7912	8.4513	114.1091
3.9633	42.3031	8.7429	119.7842
4.0874	43.7988	8.8209	120.5565
4.2227	45.5927	9.0557	126.5508
4.2727	46.4507	9.1862	128.9440
4.2856	46.5388	9.4002	133.5622
4.4101	48.0481	9.6006	137.7689
4.4402	48.6024	9.6885	141.4339
4.5504	49.7429	9.9954	147.5018
4.6062	50.4409	10.1966	154.2994
4.6980	51.9199	10.4405	159.9980
4.7800	52.7555	10.6702	167.2369
4.8563	53.8497	10.9412	172.9100

Heat Capacity Results for Sc-Mg Alloys
1.89 atomic percent Mg
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
11.2145	182.1184	14.8043	314.0366
11.5108	189.6218	15.0119	318.7681
11.7444	195.2179	15.5519	352.3091
12.0200	203.7789	15.8194	364.3030
12.4374	216.6871	16.6144	405.1558
12.5543	223.2731	16.7478	417.8352
13.1052	239.6416	17.7567	470.6968
13.2673	247.2011	17.8005	476.4834
13.7191	262.1953	18.9650	548.8318
14.0584	277.1360	19.0191	563.2932
14.4071	291.1841	20.1434	651.7380

Heat Capacity Results for Sc-Mg Alloys
3.31 atomic percent Mg

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1221	11.0739	2.4472	24.9637
1.1623	11.4763	2.5599	26.1908
1.2001	11.8554	2.7038	27.8008
1.2434	12.2896	2.8562	29.4174
1.2717	12.5755	3.0283	31.0482
1.3215	13.0770	3.0516	31.4679
1.3840	13.7077	3.2019	33.5304
1.4389	14.2824	3.3705	35.5369
1.4836	14.7160	3.5300	37.5866
1.5331	15.1855	3.6744	39.1463
1.5834	15.7307	3.7620	39.9392
1.6428	16.3388	3.9496	42.0110
1.7121	17.0500	4.0889	43.6981
1.7263	17.1947	4.1892	44.7169
1.7967	17.9206	4.2656	45.8192
1.8854	18.8091	4.2703	46.1570
1.9918	19.8834	4.4006	47.5661
2.0280	20.3025	4.4137	48.1463
2.0589	20.5219	4.5245	49.5275
2.1259	21.3889	4.5703	49.7312
2.2261	22.5144	4.6676	51.3362
2.3322	23.7342	4.7208	52.1686
2.3292	21.9489	4.8041	53.2559

Heat Capacity Results for Sc-Mg Alloys
3.31 atomic percent Mg
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
4.8688	54.0280	7.5602	97.0866
4.9320	54.9024	7.6707	100.2163
5.0077	55.8963	7.8842	104.7034
5.1091	56.9930	8.0122	106.9745
5.1959	58.9056	8.2511	112.3595
5.2852	60.0391	8.2824	112.5693
5.3852	60.8609	8.6046	120.6331
5.4790	62.7736	8.9690	127.0796
5.5772	64.0417	9.3744	135.2182
5.6872	65.4666	9.7771	145.0857
5.7911	67.6132	10.1568	152.9748
5.8319	68.4091	10.6413	167.8950
5.9230	69.0721	11.1451	183.6028
6.0327	71.3058	11.6294	198.8357
6.1465	71.6950	12.0850	214.0655
6.2276	73.4158	12.5468	228.7123
6.3529	74.7522	13.2526	255.0450
6.4420	76.7690	14.0361	287.5513
6.5130	79.0806	14.8351	325.7734
6.6688	81.3997	15.6982	376.2961
6.7233	82.2434	16.4905	416.9475
6.8138	83.8549	17.4331	483.9109
6.9501	86.4696	18.4106	569.4814
7.0720	88.2404	19.3256	629.4961
7.2553	92.0496	20.2084	704.4084
7.3554	92.6048		

Heat Capacity Results for Sc-Mg Alloys
4.40 atomic percent Mg

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0916	10.6878	1.2717	12.4529
1.1225	10.9918	1.2949	12.7040
1.1368	11.1381	1.3163	12.9147
1.1632	11.3900	1.3282	13.0318
1.1809	11.5592	1.3671	13.4250
1.2035	11.7950	1.3826	13.5784
1.2251	11.9897	1.4054	13.8099
1.2461	12.2034	1.4379	14.1283

Heat Capacity Results for Sc-Mg Alloys
4.40 atomic percent Mg
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.4451	14.2030	3.5143	36.3604
1.4839	14.5928	3.5409	36.5992
1.4876	14.6305	3.6693	38.0310
1.5098	14.8520	3.7191	38.4616
1.5324	15.0784	3.8277	39.8766
1.5556	15.3121	3.8864	40.5548
1.5822	15.5802	4.0249	42.0856
1.6397	16.1584	4.0790	42.6651
1.6579	16.3440	4.2126	44.0885
1.7281	17.0530	4.2627	44.4791
1.8087	17.8719	4.2698	44.6265
1.8638	18.4327	4.2958	45.1683
1.8832	18.6355	4.4234	46.4198
1.9132	18.9371	4.4772	47.4806
1.9339	19.1478	4.5765	48.4509
1.9931	19.7543	4.6434	49.4714
1.9937	19.7608	4.7164	50.1380
2.0585	20.4264	4.8189	51.5473
2.0622	20.4655	4.8635	51.7386
2.1341	21.2063	5.0025	53.9918
2.1378	21.2449	5.0122	54.0193
2.1655	21.5301	5.1798	56.2635
2.2180	22.0765	5.1875	56.2610
2.2226	22.1422	5.3685	58.6861
2.2831	22.7200	5.3791	59.0851
2.3400	23.4404	5.5635	61.7992
2.3936	23.9373	5.5829	62.0342
2.4609	24.6250	5.7319	64.0749
2.5171	25.1593	5.8011	64.6838
2.5762	25.7615	5.8346	65.2750
2.6555	26.6634	6.0141	67.9338
2.7016	27.0262	6.0460	68.3740
2.7055	27.2410	6.2108	70.8987
2.7449	27.4972	6.2433	71.0548
2.8376	28.6100	6.4188	73.8347
2.8660	28.9558	6.5258	75.4084
2.9782	30.1109	6.6436	77.5236
2.9946	30.2260	6.8159	80.1579
3.1209	31.5824	6.8467	80.5079
3.1252	31.8103	7.0672	84.2383
3.2862	33.5735	7.1552	85.6130
3.2985	33.7842	7.3468	89.0482
3.3673	34.6002	7.4466	90.6538
3.3691	34.5446	7.6506	94.5381

Heat Capacity Results for Sc-Mg Alloys
4.40 atomic percent Mg
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
7.6766	94.2206	12.0364	193.6576
8.0020	100.6969	12.5131	210.2140
8.0069	100.6932	12.6945	214.6893
8.2769	104.4185	13.2215	229.2178
8.3892	107.1428	13.3950	240.4404
8.5932	111.1858	14.0029	259.0154
8.8260	115.4762	14.0578	260.7888
8.9033	115.6091	14.7858	292.4673
9.2303	122.8994	14.7988	290.8596
9.2318	123.7717	15.5128	324.3906
9.5512	128.8257	15.5915	328.7925
9.5895	130.0344	16.3810	367.5229
9.8662	138.2899	16.3967	367.4368
10.0012	139.9359	17.3934	423.6536
10.2878	147.4592	17.3972	423.2371
10.4440	150.7280	18.3340	485.2854
10.7750	158.9385	18.3359	481.7915
10.9623	163.6682	19.1912	552.7104
11.3197	171.8167	19.1981	551.7930
11.5437	179.6324	20.1232	632.1897
11.9408	190.7367		

Heat Capacity Results for Sc-Mg Alloys
6.99 atomic percent Mg

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1292	10.8841	1.7129	16.6467
1.1658	11.2338	1.7928	17.3186
1.2022	11.5973	1.8071	17.5771
1.2435	12.0021	1.8879	18.3461
1.2928	12.4832	2.0018	19.5204
1.3248	12.7959	2.1400	20.9328
1.3655	13.1995	2.2910	22.4605
1.4184	13.6992	2.3366	22.8791
1.4826	14.3559	2.4284	24.0044
1.5296	14.8210	2.5437	25.1357
1.5423	14.9478	2.6545	26.3665
1.5855	15.3768	2.7409	27.1976
1.6435	15.9387	2.7457	27.3135

Heat Capacity Results for Sc-Mg Alloys
 6.99 atomic percent Mg
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
2.8771	28.6644	6.6598	77.7650
3.0361	30.3629	6.8005	81.8983
3.1622	31.8109	7.0675	85.2059
3.3161	33.6781	7.3536	89.9584
3.3461	33.6939	7.6576	95.2886
3.6076	36.9245	7.9945	102.1891
3.7587	38.5990	8.3173	110.2972
3.8928	40.5262	8.5580	114.7990
3.9072	40.2103	8.9582	123.3361
4.0513	42.7167	9.3818	133.3159
4.2402	44.3707	9.7791	142.5036
4.2826	45.1697	10.1217	150.0018
4.4035	46.9277	10.6000	161.8556
4.5285	48.3561	11.1271	172.7104
4.6561	49.4789	11.7172	188.2831
4.7893	51.1618	12.4066	203.8381
4.9296	53.2660	13.0471	222.9158
5.1066	55.7757	13.7064	245.1745
5.2835	58.2674	14.3944	268.2612
5.4697	61.1458	15.1893	299.2234
5.6781	63.8281	16.0772	331.9924
5.8238	66.3771	16.8037	375.7229
6.0293	69.1927	17.6028	403.8882
6.2216	72.5244	18.3715	433.1135
6.4312	74.9381	19.2270	469.5884

Heat Capacity Results for Sc-Fe alloys-As Cast
30 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0304	11.2200	2.4386	26.0228
1.0592	11.5703	2.4381	25.9042
1.0722	11.7519	2.5173	26.7714
1.0856	11.8479	2.6245	28.0261
1.0994	12.1120	2.6361	28.0104
1.1137	12.2301	2.8908	31.1099
1.1296	12.2952	3.0290	32.4738
1.1454	12.4073	3.1141	33.3856
1.1639	12.5890	3.2397	34.7060
1.1821	12.7491	3.3265	36.0063
1.1954	12.8937	3.5603	38.7465
1.2019	13.0111	3.7927	41.4090
1.2220	13.1804	4.0225	43.6553
1.2427	13.4075	4.2481	46.7389
1.2466	13.4224	4.3293	47.9313
1.2678	13.7000	4.4160	48.8110
1.2927	13.8453	4.5898	50.3993
1.3202	14.2205	4.8284	53.9774
1.3523	14.4891	4.8751	54.4220
1.3708	14.7348	5.0105	56.1487
1.3841	14.8178	5.1067	57.4599
1.3959	15.0244	5.3300	60.4706
1.4230	15.2060	5.4617	61.2115
1.4379	15.2964	5.4759	63.1242
1.4408	15.3666	5.4959	62.2198
1.4860	15.8069	5.6435	64.5342
1.5091	16.0848	5.6721	64.7426
1.5354	16.3892	5.7160	65.6296
1.5893	17.0446	5.8192	67.2518
1.6005	17.0801	5.8830	67.4869
1.6808	17.9066	5.9480	68.1796
1.7014	18.0817	5.9828	69.3513
1.7065	18.1989	6.0999	70.5918
1.7371	18.5367	6.1589	71.0356
1.7794	18.9566	6.2805	73.4937
1.7995	19.1509	6.3472	73.2301
1.9010	20.2171	6.3744	74.6357
1.9265	20.5358	6.5828	78.0523
1.9995	21.2550	6.6337	78.9826
2.0454	21.7472	6.7798	80.0797
2.1398	22.7410	6.9922	84.1464
2.2332	23.7863	7.1729	87.3095
2.3302	24.7888	7.2217	87.8508
2.3485	24.8767	7.3338	88.2820

Heat Capacity Results for Sc-Fe alloys-As Cast
30 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
7.5924	93.6398	11.4540	176.8868
7.7186	95.0687	11.5274	194.8828
7.8544	97.8091	11.8009	180.6688
8.0886	101.0559	11.8136	183.2887
8.1603	101.1589	12.0491	191.9554
8.3032	105.5767	12.1481	194.4353
8.3076	105.6044	12.2940	197.3987
8.4591	108.2311	12.5692	208.3083
8.5191	109.6267	12.5740	208.9144
8.6827	112.8899	12.8745	218.6195
8.7411	114.5527	13.1799	229.2281
8.8818	115.7744	13.6525	238.5564
8.9612	118.9614	13.8159	248.7926
9.0859	118.2163	14.1708	259.9460
9.1944	120.0015	14.7035	282.3867
9.2621	124.0199	14.7669	287.2854
9.3305	124.9279	15.1784	303.7078
9.3852	126.5744	15.3045	312.6248
9.5610	130.4003	15.8180	332.8159
9.6666	131.6989	15.9026	333.9507
9.8086	133.1044	16.4406	367.8457
9.9418	138.3685	16.4594	368.2336
10.0393	140.7872	17.0301	401.5530
10.2309	144.0472	17.1968	407.1973
10.2651	146.0081	17.5732	423.6309
10.3816	149.1549	17.9563	475.5337
10.5485	151.8254	18.0403	477.9851
10.6359	152.1373	18.4531	487.8411
10.7849	154.7225	18.6365	506.5056
10.8842	160.4673	18.8104	514.1367
11.1019	165.9918	19.2087	528.9719
11.1489	166.9556	19.2351	538.9954
11.4031	175.0978	19.6751	586.2739

Heat Capacity Results for Sc-Fe alloys-As Cast
50 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0664	11.6230	1.0756	11.8752

Heat Capacity Results for Sc-Fe alloys-As Cast
50 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0904	12.1538	2.3622	25.5342
1.0906	12.0563	2.3992	25.8826
1.0914	12.0379	2.4555	26.4565
1.1299	12.4452	2.4976	26.8655
1.1405	12.5142	2.5595	27.6636
1.1746	12.8186	2.5908	27.9534
1.1905	13.1542	2.6523	28.6906
1.2185	13.2620	2.6623	28.8127
1.2405	13.5488	2.7227	29.4153
1.2646	13.7544	2.7694	29.9824
1.2936	14.1203	2.8291	30.6370
1.3348	14.4325	2.8920	31.3608
1.3416	14.5156	2.9427	31.9384
1.3836	14.9787	3.0183	32.8737
1.3912	15.0442	3.0621	33.2404
1.4299	15.4249	3.1562	34.4516
1.4483	15.6520	3.1928	34.9429
1.4831	16.0043	3.2301	35.3441
1.4984	16.1474	3.2654	35.7825
1.5344	16.5470	3.3620	36.8150
1.5473	16.6945	3.3925	37.2862
1.5709	16.9003	3.5014	38.5230
1.5983	17.2139	3.5385	39.0194
1.6282	17.5310	3.6477	40.3067
1.6640	17.9107	3.6997	40.9154
1.6922	18.2267	3.8106	42.2675
1.7322	18.6219	3.8439	42.6205
1.7680	19.0406	3.8875	43.1192
1.7928	19.2829	3.8940	43.3048
1.8557	19.9886	3.9798	44.4449
1.8588	19.9729	3.9990	44.5192
1.9052	20.4996	4.0725	45.4533
1.9125	20.6752	4.1153	45.8806
1.9669	21.1342	4.1582	46.5979
1.9874	21.3292	4.2621	48.1799
2.0330	21.8173	4.2714	48.0490
2.0684	22.9370	4.4107	49.6438
2.1148	22.7508	4.4190	49.6589
2.1455	23.0896	4.5670	51.6339
2.1933	23.6357	4.5725	52.0608
2.2308	23.9838	4.7219	53.7202
2.2346	24.0339	4.7427	53.9438
2.2784	24.4964	4.8672	55.7029
2.3096	24.9339	4.9312	56.5687

Heat Capacity Results for Sc-Fe alloys-As Cast
 50 ppm atomic Fe
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
5.0138	57.7214	9.3584	132.7116
5.1951	60.0347	9.4038	134.2352
5.3153	62.0458	9.6257	138.9516
5.3793	63.0697	9.7316	141.6367
5.5582	65.6646	10.0045	147.9119
5.5704	65.7839	10.1484	152.1760
5.7328	67.9227	10.4517	159.3149
5.8012	69.0921	10.6152	164.1769
5.8345	69.9497	10.9496	171.7109
6.0216	72.5573	11.0134	174.1190
6.0424	72.4405	11.4242	184.0006
6.2131	75.6701	11.4335	185.0803
6.2137	75.6290	11.8131	195.3042
6.4219	79.0088	11.8457	197.0072
6.4261	79.1272	12.3137	212.3192
6.6473	82.6140	12.3154	212.1209
6.6506	82.5947	12.8310	229.1245
6.8250	85.2903	12.8342	229.7103
6.9069	86.4122	13.3145	247.4526
7.0695	89.8509	13.4067	248.6121
7.2266	91.8069	14.0270	272.5874
7.3508	94.1483	14.0747	272.9177
7.4813	96.3002	14.7559	303.7732
7.6623	100.4566	14.9213	311.3274
7.7831	101.8977	15.5767	340.9985
7.9458	105.5103	15.8291	354.7061
8.1322	108.6979	16.4303	383.6475
8.1583	108.9098	16.7266	401.4016
8.4553	114.5800	17.4057	440.7625
8.4593	114.5552	17.7387	462.6018
8.7507	120.8527	18.5632	518.2251
8.7546	120.1078	18.7794	533.9595
9.0018	125.6229	19.5503	590.7939
9.0643	126.8117	19.6614	600.8809

Heat Capacity Results for Sc-Fe alloys-As Cast
85 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0638	14.2289	4.5425	53.1174
1.0972	14.5342	4.6075	53.8191
1.1324	14.8857	4.6945	55.2522
1.1670	15.1362	4.7703	56.0497
1.2042	15.4738	4.8659	57.5206
1.2444	15.8398	4.9381	58.3792
1.2965	16.3335	5.0186	59.7620
1.3559	16.8948	5.0956	60.3388
1.4229	17.6006	5.1996	62.1172
1.4607	18.0052	5.2909	63.2312
1.5289	18.7171	5.3872	64.7868
1.5949	19.4743	5.4861	66.1443
1.6580	20.0963	5.5853	67.7431
1.7297	20.8336	5.6950	69.2778
1.8127	21.6924	5.7898	70.4853
1.8719	22.2713	5.9230	73.0300
1.9436	23.0915	5.9464	73.1008
2.0187	23.8178	6.0860	75.3944
2.1197	24.9434	6.1531	76.0771
2.2267	26.1537	6.2855	78.3332
2.2607	26.4656	6.3594	79.2974
2.3612	27.5868	6.5059	81.9130
2.4881	28.9193	6.5811	83.2931
2.5919	29.9638	6.7327	85.8973
2.6979	31.2001	6.8152	87.0305
2.7621	31.9081	6.9795	89.9169
2.8746	33.1176	6.9979	89.7492
2.9931	34.2994	7.1828	93.1064
3.1103	35.7071	7.2613	94.6364
3.2172	36.9388	7.4578	98.2048
3.2566	37.4106	7.5613	99.3136
3.3834	38.9991	7.7753	103.5555
3.4987	40.2720	7.8861	105.6513
3.5932	41.2977	8.1410	110.6396
3.6281	41.9324	8.1955	111.1385
3.7366	43.0376	8.4182	115.5123
3.8521	44.4798	8.5464	117.0130
3.9674	45.7505	8.7377	121.8610
4.0785	47.2203	8.8862	125.5286
4.1910	48.5838	9.0802	129.5355
4.2688	49.4693	9.2472	134.6228
4.2962	49.9345	9.4342	136.1828
4.4038	51.1094	9.6231	142.1918
4.4493	51.6738	9.7882	145.1646

Heat Capacity Results for Sc-Fe alloys-As Cast
85 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
10.0305	151.5242	13.5880	260.3528
10.0676	152.2757	14.1090	278.3330
10.4587	163.0445	14.4106	294.1306
10.4699	161.9835	14.8409	311.1116
10.8120	172.2145	15.2322	328.7129
10.9782	175.6799	15.5086	340.1631
11.3348	187.2955	16.1633	376.0449
11.4464	189.5222	16.4301	388.1265
11.8643	202.1843	17.2367	434.1106
11.9651	206.1807	17.3874	448.9617
12.2973	214.8875	18.3618	514.1682
12.6976	230.3538	18.4685	520.3481
12.8589	232.8155	19.4219	586.5383
13.4292	255.2784	19.7902	593.3545

Heat Capacity Results for Sc-Fe alloys-As Cast
111 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.2350	15.6446	1.7040	20.9132
1.2445	15.8334	1.7780	21.6588
1.2625	15.9596	1.7887	21.6788
1.2797	16.1491	1.8416	22.1111
1.2907	16.3249	1.8762	22.6932
1.3304	16.7575	1.9177	23.1598
1.3743	17.2311	1.9651	23.5113
1.3988	17.5648	1.9842	23.8102
1.3997	17.4712	2.0383	24.4902
1.4142	17.6553	2.0946	25.0710
1.4304	17.8158	2.0875	24.8983
1.4309	17.7714	2.1670	25.9009
1.4820	18.3939	2.2897	27.1140
1.4820	18.4960	2.3443	27.7624
1.5234	18.8069	2.5034	29.5498
1.5435	19.0586	2.6225	30.8997
1.5825	19.5003	2.8268	33.2533
1.6161	19.8198	2.9939	35.1051
1.6432	20.1691	3.1683	37.1381
1.6934	20.6731	3.2044	37.5580

Heat Capacity Results for Sc-Fe alloys-As Cast
 111 ppm atomic Fe
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
3.3434	39.2297	8.1925	110.9999
3.5616	41.8378	8.4275	114.3143
3.7245	43.9884	8.5057	119.5748
3.8364	45.2699	8.8227	123.5425
4.1646	49.4096	9.1730	135.0378
4.2847	51.0233	9.5573	141.2501
4.5513	54.0877	9.8511	153.4454
4.7028	56.5133	10.2220	158.1541
5.1143	61.3780	10.6173	171.0838
5.2104	63.5106	10.9970	184.2029
5.2950	63.7724	11.1194	183.9092
5.5188	67.4228	11.4852	195.6316
5.8386	72.1814	11.8519	210.7239
6.0496	74.5169	12.2062	216.1490
6.2744	77.8204	12.4333	223.6637
6.3380	78.7328	12.7930	246.3924
6.3623	78.6845	13.1682	243.4927
6.5031	80.4712	13.5001	250.8907
6.5684	82.7324	13.6332	272.0273
6.5980	82.2010	14.2097	288.0122
6.7406	85.5797	14.7418	312.1555
6.7413	86.3660	15.3289	324.1782
6.8483	86.4899	15.8551	361.7141
6.9052	88.8223	16.4677	387.6355
6.9772	89.4156	17.0968	422.1482
7.1582	91.8329	17.9229	478.6213
7.2065	94.7204	18.6306	499.3433
7.3864	96.7836	19.1931	541.5918
7.4604	100.1980	19.7434	590.2725
7.7499	103.9090	20.2811	658.7930

Heat Capacity Results for Sc-Fe alloys-Annealed
19 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1223	13.3237	2.9929	33.3777
1.1586	14.0435	3.0863	34.5308
1.1926	14.3463	3.1451	35.1456
1.1964	14.4772	3.2600	36.3667
1.2384	14.9174	3.3208	36.9416
1.2678	15.0165	3.4081	38.3357
1.2905	15.5025	3.4399	38.7145
1.3242	15.8223	3.5605	39.7035
1.3312	15.9051	3.6466	40.6940
1.3719	16.3796	3.7573	42.0780
1.3849	16.5327	3.8461	42.9482
1.4077	16.7246	3.9507	44.3100
1.4430	17.0556	4.0569	45.3860
1.4651	17.4970	4.0735	45.5552
1.4835	17.7234	4.2173	46.8916
1.5273	18.0117	4.2474	47.8158
1.5435	18.0583	4.2583	47.6364
1.6223	19.0561	4.2724	48.5604
1.6419	19.0879	4.3815	49.4948
1.7048	19.8891	4.3999	49.6498
1.7359	20.1825	4.5184	51.2455
1.7960	20.7115	4.5400	51.6577
1.8153	20.9765	4.6462	52.9019
1.9056	21.9482	4.6907	53.6727
1.9539	22.4262	4.7742	54.5121
2.0339	23.2958	4.8473	55.5614
2.0524	23.3889	4.8991	56.3326
2.0946	23.9565	4.9849	57.7661
2.1538	24.4492	5.1008	59.4389
2.2248	25.2487	5.1674	59.6977
2.2677	25.7447	5.2909	61.4863
2.3126	26.1773	5.3657	62.1260
2.3169	26.2280	5.4589	62.9215
2.4271	27.1981	5.5649	64.8914
2.4288	27.1519	5.6200	65.6858
2.5516	28.8126	5.6960	66.5688
2.5625	28.5861	5.7400	67.3553
2.6661	30.0599	5.7987	68.8132
2.7093	30.3623	5.8519	69.3029
2.7342	30.5594	5.9635	70.6087
2.7580	31.2003	6.0276	71.3299
2.7717	31.1367	6.1507	73.3611
2.8522	31.7231	6.2287	74.3644
2.8964	32.5816	6.4393	77.6277

Heat Capacity Results for Sc-Fe alloys-Annealed
19 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
6.5745	79.5517	10.5538	155.0183
6.5950	80.7165	10.6784	155.4005
6.7395	80.8842	10.8047	157.3966
6.8356	83.2983	10.9825	163.1946
6.9775	83.9613	11.2388	169.1773
7.0823	85.8205	11.4228	177.4529
7.2326	88.5210	11.7394	187.1746
7.3561	91.1894	12.1595	200.5404
7.4806	93.2252	12.3046	205.8260
7.6206	96.0134	12.8613	218.4483
7.7154	96.7564	13.1466	230.3929
7.7720	96.5941	13.2895	235.9284
7.8681	98.6053	13.9017	251.6070
8.0211	100.4391	13.9084	255.1269
8.1540	103.7770	14.1779	268.0686
8.3143	107.1835	14.5593	286.6829
8.4700	109.6648	14.7941	293.2942
8.6074	112.8176	15.2911	318.0103
8.7624	114.6907	15.5057	325.7212
8.9058	116.9859	16.1277	353.7771
9.0617	120.1723	16.2287	366.9229
9.1122	121.6908	16.8327	393.6606
9.2778	125.2135	16.9919	400.5366
9.4825	130.3607	17.5991	432.4917
9.6054	132.6319	17.9668	457.4939
9.8717	136.4023	18.3751	479.4268
9.9880	139.1524	18.7799	553.4387
10.2408	145.1878	19.2368	528.1030
10.3615	150.4706	20.1801	579.8545

Heat Capacity Results for Sc-Fe alloys-Annealed
30 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1844	15.3086	1.3228	16.6888
1.2324	15.8094	1.3558	17.0201
1.2691	16.1329	1.3709	17.1626
1.2812	16.2782	1.3720	17.1425
1.3206	16.6653	1.4071	17.5424

Heat Capacity Results for Sc-Fe alloys-Annealed
30 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.4214	17.6295	3.2886	37.5053
1.4243	17.7375	3.3268	37.8884
1.4619	18.0606	3.4882	39.7335
1.4784	18.2487	3.5081	39.9732
1.5099	18.5760	3.6479	41.5615
1.5311	18.7628	3.6860	42.0719
1.5320	18.8253	3.8162	43.5287
1.5708	19.2354	3.8578	44.1288
1.5813	19.3005	3.9812	45.6255
1.5972	19.4563	4.0481	46.3807
1.6327	19.8237	4.1843	47.8488
1.6388	19.9153	4.2013	48.3333
1.6913	20.4314	4.2959	49.2900
1.6920	20.4317	4.3254	49.8507
1.7084	20.6097	4.3997	50.6118
1.7484	21.0432	4.4425	51.1388
1.7489	21.0188	4.5272	52.1825
1.7954	21.4977	4.5761	52.8047
1.8110	21.6138	4.6605	53.9366
1.8169	21.6512	4.7094	54.5314
1.8592	22.0967	4.7971	55.6708
1.9168	22.6931	4.8527	56.5233
1.9226	22.7798	4.9254	57.4597
1.9930	23.5319	4.9727	58.0894
2.0016	23.5761	5.0883	59.3834
2.0716	24.3347	5.1183	60.2318
2.0741	24.3722	5.2606	61.8732
2.1532	25.2183	5.2846	62.2887
2.1937	25.6321	5.4247	64.3823
2.2598	26.2553	5.4723	65.0520
2.2793	26.5338	5.5850	66.4037
2.3602	27.3050	5.7039	68.2635
2.3814	27.5486	5.7426	68.8442
2.4556	28.3178	5.8944	71.1228
2.5009	28.8319	5.9062	71.2772
2.5818	29.6618	6.0859	73.8848
2.6410	30.3819	6.2859	76.8570
2.7209	31.2028	6.2866	77.1544
2.7782	31.7891	6.4983	80.3557
2.8744	32.8165	6.6627	83.0023
2.9402	33.5482	6.6638	82.6434
3.0379	34.6332	6.8916	86.4898
3.1013	35.4853	6.8948	86.2256
3.1607	36.0262	7.1499	90.4353

Heat Capacity Results for Sc-Fe alloys-Annealed
30 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
7.1554	90.8144	11.1530	177.3100
7.4460	95.3202	11.6092	191.0083
7.4548	95.9391	11.6217	191.0436
7.7294	101.1894	11.9851	202.3772
7.7724	101.6458	12.1439	206.9255
7.8629	103.5032	12.5786	220.0037
8.0337	106.7261	12.7471	227.0646
8.0946	107.9600	13.2349	243.3192
8.3478	112.8275	13.4308	251.9959
8.3793	112.8147	14.0022	272.5955
8.6264	118.0827	14.2251	282.0850
8.7609	120.3333	14.7150	302.0464
8.9207	123.6428	15.0105	316.4180
9.1292	128.3307	15.5401	342.0117
9.1762	129.0478	15.8755	357.6633
9.4715	135.7048	16.4052	385.9180
9.5946	138.1603	16.7666	405.5452
9.8527	144.6275	17.3908	443.3867
9.8897	144.9183	17.7837	467.6123
10.2817	155.0603	18.3417	506.0361
10.2821	154.1558	18.7557	534.0137
10.7098	166.2592	19.1982	563.3176
10.7645	167.4744	19.6167	596.1587
11.1389	177.4662		

Heat Capacity Results for Sc-Fe alloys-Annealed
50 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0785	14.6379	1.6177	20.0986
1.1024	11.4580	1.6992	20.9444
1.1513	15.3751	1.7224	21.1857
1.2251	16.1200	1.7661	21.6240
1.2611	16.4725	1.8990	23.0463
1.3126	16.9628	1.9422	23.4931
1.3723	17.5960	1.9961	24.0415
1.4028	17.8975	2.0774	24.8731
1.4755	18.6520	2.1012	25.1017
1.5524	19.4436	2.1703	25.8071

Heat Capacity Results for Sc-Fe alloys-Annealed
50 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
2.2245	26.3099	6.9309	87.6918
2.3123	27.3477	7.1408	90.8412
2.3755	28.0116	7.3202	94.0308
2.4097	28.4095	7.3882	96.0213
2.4834	29.0735	7.5094	97.2164
2.5931	30.4029	7.6733	100.5982
2.6211	30.6480	7.7821	103.0216
2.7070	31.6362	7.8895	103.5424
2.8112	32.7863	8.0075	106.0475
2.8691	33.3882	8.1960	109.9988
2.9403	34.1752	8.2592	111.1662
3.0068	34.8869	8.3907	113.6673
3.0627	35.4677	8.4953	116.1107
3.1335	36.2967	8.5614	117.0829
3.2066	37.0261	8.6920	119.8343
3.3324	38.4676	8.7997	122.7080
3.4118	39.4927	8.9357	126.4802
3.6195	41.8979	9.0640	128.0376
3.7072	42.8881	9.1778	131.4554
3.8604	44.5856	9.2929	137.0331
3.9593	45.8884	9.4109	137.9773
4.0810	47.4356	9.5377	140.5465
4.1221	47.8832	9.6564	141.8526
4.2044	48.8885	9.8415	147.1324
4.2689	49.7022	9.9393	149.5538
4.3215	50.3277	10.1017	153.1468
4.4058	51.4186	10.2665	157.0023
4.5597	53.3681	10.4833	162.4345
4.6807	54.7686	10.6065	165.8690
4.7203	55.3290	10.7114	170.2943
4.8446	56.9926	10.9134	175.7598
4.9388	58.2867	11.0742	178.9352
4.9755	58.7432	11.1855	181.5014
5.2244	62.2828	11.4080	189.0010
5.2904	63.0803	11.6544	196.0147
5.5010	66.0371	11.8460	200.6938
5.7143	69.1154	12.0458	207.5509
5.7487	69.5711	12.2635	215.4244
5.8812	71.4295	12.4830	221.0289
6.0735	74.1875	12.7675	228.2607
6.2611	77.1170	12.9401	237.0113
6.5778	82.0798	13.0882	243.3554
6.6136	82.5508	13.1955	248.5539
6.8744	86.6182	13.5264	253.7046

Heat Capacity Results for Sc-Fe alloys-Annealed
50 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
13.7965	265.8944	16.8807	418.5334
14.1033	280.4529	17.2030	443.6567
14.3630	291.2558	17.7987	481.6128
14.6504	305.8758	18.2082	510.6987
14.9256	318.2295	18.9132	556.7809
15.1719	330.3281	19.2240	581.6645
15.5134	346.6337	19.6341	614.6718
15.8040	364.3573	20.0339	647.0056
16.2889	390.5769		

Heat Capacity Results for Sc-Fe alloys-Annealed
85 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0866	14.7833	2.4775	29.4730
1.1023	14.9427	2.5493	30.2523
1.1518	15.4655	2.5896	30.6808
1.2114	16.0879	2.6990	31.8676
1.2557	16.5585	2.7502	32.3790
1.2649	16.6966	2.8184	33.1334
1.3715	17.7395	2.9077	34.1022
1.4482	18.5914	2.9713	34.8055
1.5191	19.3364	3.1009	36.2529
1.5942	20.1365	3.1987	37.3017
1.6427	20.6264	3.2655	38.0853
1.7143	21.4073	3.3502	39.0951
1.7804	22.0891	3.4291	40.0099
1.8095	22.3782	3.5713	41.5864
1.8909	23.2571	3.6388	42.3810
1.9226	23.5534	3.7910	44.1957
1.9710	24.0535	3.8179	44.4812
2.0464	24.8765	3.9604	46.2133
2.0699	25.0990	4.0551	47.3379
2.1454	25.9172	4.1655	48.6809
2.2163	26.6734	4.2523	49.8251
2.2508	27.0151	4.3610	51.1516
2.2944	27.4883	4.4409	52.0979
2.3312	27.8878	4.5547	53.5731
2.4099	28.7304	4.6202	54.4359

Heat Capacity Results for Sc-Fe alloys-Annealed
85 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
4.6885	55.3038	10.6623	167.4751
4.7914	56.6449	10.8593	173.0093
4.9056	58.1360	11.1329	181.1336
5.1134	60.9756	11.3040	185.2985
5.2253	62.5706	11.4405	192.0126
5.3408	64.1045	11.7941	199.0437
5.4477	65.5837	11.9902	207.0239
5.5912	67.6597	12.2054	211.9187
5.7508	69.9555	12.5051	221.2464
5.9647	73.1815	12.8123	231.9853
6.1455	75.9688	13.0298	238.7829
6.2911	78.1584	13.2364	247.3968
6.4476	80.4924	13.5113	257.5562
6.7503	85.3587	13.7764	267.6087
6.9699	88.9225	14.1047	281.6545
7.2116	93.0081	14.3506	288.6478
7.4997	98.1120	14.4278	294.5762
7.6014	99.7514	14.7613	309.8067
7.9516	106.2705	15.1444	327.7923
8.2568	112.2068	15.4457	341.5249
8.3017	112.5955	15.7977	360.1024
8.4504	115.5160	16.1892	382.4891
8.5824	117.0436	16.5053	398.5104
8.7153	118.8487	16.9411	424.4326
8.9802	126.8912	17.3158	446.9383
9.0915	129.1442	17.6210	467.2369
9.3053	133.8626	17.9956	493.5681
9.4827	135.8738	18.2647	510.1382
9.6715	142.3804	18.7046	542.0025
9.8509	146.6303	19.0049	563.6949
10.0352	151.2167	19.4652	597.9665
10.2899	157.6884	19.9424	668.2350
10.4613	162.3357		

Heat Capacity Results for Sc-Fe alloys-Annealed
111 ppm atomic Fe

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.0743	14.2889	1.0854	14.4378

Heat Capacity Results for Sc-Fe alloys-Annealed
 111 ppm atomic Fe
 (continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
1.1101	14.7332	2.7057	32.6871
1.1247	14.9060	2.7857	33.4427
1.1450	15.1371	2.8317	33.9907
1.1615	15.3278	2.8768	34.5732
1.1791	15.4934	2.9221	34.9962
1.2026	15.7965	3.0407	36.3999
1.2199	15.9486	3.0928	36.9065
1.2463	16.2989	3.2124	38.4650
1.2676	16.5334	3.2641	38.8671
1.2917	16.7952	3.3816	40.1831
1.3238	17.0853	3.4431	41.0160
1.3513	17.4271	3.5397	42.0746
1.3782	17.7167	3.5574	42.1618
1.4117	18.1091	3.6145	43.0099
1.4379	18.4179	3.6883	43.5633
1.4754	18.8550	3.6930	43.8963
1.5019	19.1263	3.8214	45.2392
1.5486	19.5943	3.8504	45.5769
1.5509	19.7213	3.9693	47.2345
1.6031	20.3278	4.0180	47.6059
1.6228	20.5536	4.1087	48.8184
1.6800	21.1564	4.1878	49.7794
1.6921	21.3660	4.2026	49.8346
1.7608	22.0677	4.2575	50.4120
1.7614	22.0901	4.3036	51.0671
1.8308	22.9452	4.3816	52.0076
1.8354	22.9480	4.4579	52.9135
1.9174	23.8048	4.5164	53.6689
1.9297	23.8969	4.5769	54.2588
1.9720	24.3832	4.6481	55.1578
1.9999	24.7485	4.7047	56.1404
2.0650	25.4513	4.7800	56.8248
2.0912	25.7069	4.8613	58.1014
2.1441	26.2337	4.8904	58.1780
2.2088	26.9989	5.0047	60.0711
2.2266	27.1998	5.0266	59.9823
2.2366	27.3849	5.1733	62.1282
2.3243	28.3267	5.1829	62.6451
2.3430	28.6285	5.3134	64.5009
2.3667	28.8690	5.3702	64.9943
2.4779	30.0422	5.4535	66.3585
2.4791	30.0235	5.5589	67.3373
2.5965	31.3270	5.5717	67.7874
2.6266	31.8557	5.7175	69.7994

Heat Capacity Results for Sc-Fe alloys-Annealed
111 ppm atomic Fe
(continued)

T (K)	C (mJ/g-atom K)	T (K)	C (mJ/g-atom K)
5.7745	70.7412	9.1369	129.3528
5.8936	72.3736	9.2366	131.8493
5.9090	72.8011	9.4597	135.5219
6.0788	75.4110	9.5894	138.6549
6.0857	75.3471	9.8214	144.1649
6.2805	78.4858	9.8524	144.9823
6.2811	78.2629	10.1413	151.9717
6.4293	80.4207	10.2789	154.5173
6.4948	81.6704	10.4988	160.1582
6.6426	83.7388	10.7618	166.7093
6.7250	85.4524	10.9059	172.0949
6.8480	87.0206	11.1445	177.5044
6.8801	87.4109	11.3597	183.5120
7.0301	89.8072	11.5997	189.6261
7.0911	91.2669	11.8127	196.3756
7.2134	93.3436	12.1294	206.8070
7.2977	94.1334	12.4211	214.8013
7.3052	94.4034	12.7303	226.7320
7.4749	97.0677	13.0732	238.3684
7.5012	97.2418	13.3977	251.2847
7.6650	99.8706	13.8167	243.7960
7.7080	100.8811	14.0772	276.8899
7.8425	102.8414	14.6675	300.1599
7.9092	104.6300	15.0593	319.0593
8.0748	108.2528	15.5473	340.5515
8.1565	109.1092	16.2193	375.7832
8.3286	112.7204	16.6147	395.6040
8.3364	112.5336	17.5353	452.0405
8.6084	118.3093	17.7371	462.5706
8.6083	118.4571	18.8948	542.3032
8.9119	124.3603	18.9122	543.4939
8.9135	124.9025	20.0990	664.9658