

two cases can be distinguished in two ways: by the existence or nonexistence of a transient region of  $M_z(t) \sim t^{\frac{1}{2}}$  and by the magnetic field dependence of  $M_z(t)$  for large  $t$ . In either case, it is possible to compute  $C$  and thus determine  $\tau$  for the paramagnetic ion independent of a paramagnetic resonance experiment. In the case of diffusion-limited relaxation, it is also possible

to calculate the coefficient of spin diffusion from the asymptotic behavior of  $M_z(t)$  for large  $t$ .

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## Gyromagnetic Ratios of Fe and Ni

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It has been shown that the previously observed decrease in the values of  $g'$  for weakly magnetized specimens of Fe and Ni was caused by a systematic error in the measurement of magnetic moment. Recent experiments on these two metals indicate  $g'$  values of  $1.919 \pm 0.002$  for Fe and  $1.835 \pm 0.002$  for Ni.

### INTRODUCTION

A NEW laboratory has recently been built for the purpose of making measurements of the mechanical inertia effects associated with magnetism.<sup>1</sup> This laboratory was designed with the objective of obtaining a working space in which magnetic fields could be reduced to the order of  $10^{-5}$  to  $10^{-6}$  oersted. All ferromagnetic materials were eliminated from the building construction.

Much of the equipment used is similar in design to that previously reported,<sup>2-4</sup> however, many refinements have been made. The variometers for following changes in the earth's magnetic field are considerably altered and the changes are now followed by photoelectric servo systems.

Refinements have also been made in the previously used procedures<sup>3,4</sup> for measuring angular momentum and magnetic moment changes. Electronic timers are now used to supply current reversals automatically to the torsional pendulum system at the proper intervals to obtain resonance. Also as a precautionary measure the magnetic moment changes of the sample are monitored throughout the experiment. This is accomplished by a pair of pickup coils surrounding the instrument in which the ferromagnetic sample is resonating. Reversal of the magnetic moment induces a current pulse in these pickup coils. This pulse is led through the secondary of a mutual inductance to a ballistic galvanometer. Current in the primary of the mutual inductance is reversed simultaneously with that flowing in the magnetizing winding of the sample. After adjusting for a null the

primary current is determined by measuring its drop across a standard resistor. This monitoring system is calibrated by the torsional comparator previously used.<sup>3,4</sup>

### RESULTS

It was found that the previously observed change in the values of the gyromagnetic ratios for weakly magnetized specimens of Fe, Ni, and the FeNi alloys,<sup>4-6</sup> was caused by a systematic error in the determination of magnetic moments.

In the nonlinear initial region of the  $B$ - $H$  curve the induced magnetization is a function of the rate at which  $H$  is applied. In our old equipment a conducting ring surrounded the specimen in the torsional comparator. The additional circuit damping introduced by this ring slowed the rate at which  $H$  changed. This resulted in a decrease in the magnetic moment change when weakly magnetized specimens of these metals were reversed. Since this ring was not used when the corresponding angular momentum changes were measured, an error resulted. This effect became insignificant for the larger values of current used in the older work. Hence all of the high intensity values in references 4-6 are reliable.

A new series of experiments on a different sample of

TABLE I. Analysis of ellipsoidal Fe sample.

Iron	99.89%
Nickel	0.05%
Silicon	0.01%
Oxygen	0.008%
Cobalt	0.005%

<sup>1</sup> Constructed by the Charles F. Kettering Foundation.

<sup>2</sup> G. G. Scott, Rev. Sci. Instr. **28**, 270 (1957).

<sup>3</sup> G. G. Scott, Phys. Rev. **82**, 542 (1951).

<sup>4</sup> G. G. Scott, Phys. Rev. **99**, 1241 (1955).

<sup>5</sup> G. G. Scott, Phys. Rev. **99**, 1824 (1955).

<sup>6</sup> G. G. Scott, Phys. Rev. **103**, 561 (1956).

TABLE II. Values of  $g'$  for ellipsoidal sample of Fe obtained for various different runs.

Magnetizing current milliamps	$g'$
4.00	1.916
10.00	1.918
5.00	1.913
10.00	1.920
5.00	1.920
10.00	1.918
10.00	1.924
5.00	1.921
Average	1.919

pure iron was conducted at this new laboratory. In order to obtain uniform magnetization of the material, this sample was made in the form of a prolate spheroid. It had an eccentricity of 14.2 and was symmetrically placed in a hollow cylindrical winding which formed part of the torsional pendulum. Table I gives a list of the principal impurities in the sample. Table II shows a summary of this series of experiments which resulted in a  $g'$  value for Fe of 1.919.

Readings were also taken on the cylindrical Fe specimen used in our earlier experiments.<sup>4</sup> These new readings resulted in a  $g'$  value of 1.917.

TABLE III. Results of various  $g'$  experiments on same sample of Ni.

Reference	$g'$
a	1.837
b	1.831
b	1.834
Present work	1.837
Average	1.835

<sup>a</sup> S. Brown, A. J.-P. Myer, and G. G. Scott, *Compt. rend.* **238**, 2504 (1954).

<sup>b</sup> See reference 5.

New experiments were also conducted on our old cylindrical specimen of Ni. Table III summarizes all of the values of  $g'$  which have been measured for this sample of Ni excluding those obtained at low magnetization earlier.<sup>5</sup>

It is concluded from this work that  $g'$  values should be  $1.919 \pm 0.002$  for Fe and  $1.835 \pm 0.002$  for Ni.

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## Activation Energy for the Surface Migration of Tungsten in the Presence of a High-Electric Field\*†

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An activation energy for the surface migration of tungsten atoms on the tungsten crystal lattice structure and under the influence of a high electric field has been measured using field emission techniques. The initially hemispherical field emitter tip surface deforms into a polyhedral shape in a process known as build-up, when the emitter is heated in the presence of large electrostatic forces. Build-up proceeds in a regular and reproducible manner; certain stages of build-up can be identified by characteristic changes in both the field emission patterns and the current vs time characteristics of the emitter. An activation energy of  $2.44 \pm 0.05$  eV/atom was determined, from the measured values of the time required to achieve a given degree of build-up at various operating temperatures. This value may be compared with

the value of 3.14 eV/atom determined from the rate at which the tip of a heated tungsten emitter recedes in the absence of an electric field. Explanations for the difference are presented, involving two distinct factors: (1) a reduction in activation energy, through the effect of polarization of the surface atoms by the electrostatic field, by an amount which was determined in a special experiment; and (2) an inherent difference which remains after allowance has been made for the field effect. The latter is ascribed to the difference in the paths of migration in the two cases whereby, for the conditions existing in this experiment, the activation energy measured is that corresponding to migration primarily over the low index (100), (110), and (211) planes. A value of  $2.79 \pm 0.08$  eV/atom is obtained after correction for the field effect.

### I. INTRODUCTION

FIELD emission microscope techniques have yielded important advances in the understanding and measurement of surface migration. Two basic methods have been applied to quantitative migration studies:

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(1) In the first method, the surface migration constants of selected adsorbates on a fixed substrate have been obtained from measurements of the surface rate of flow of such adsorbates whose presence alters the work function of the emitting surface and thus contributes changes in the emission which can be followed on the field emission pattern.<sup>1,2</sup>

<sup>1</sup> J. A. Becker, *Advances in Catalysis* **7**, 135 (1955).

<sup>2</sup> Robert Gomer, *Advances in Catalysis* **7**, 93 (1955).