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Magnetic Identification of Headlight Glass

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ABSTRACT: Magnetic susceptibility measurements over the temperature range 4 to 300K have been used to identify and distinguish among various samples of headlight glass. With a few exceptions, it is found that the technique can be useful in such applications and that improvements in accuracy, which are possible, would even eliminate these exceptions. The method is also applicable to the identification of other types of samples of forensic science interest such as soils, window glass, and metals.

KEYWORDS: criminalistics, magnetic permeability, glass

The most common physical properties that are used to identify or match glass samples are the refractive index, density, and trace element analyses. All of these depend upon the total chemical composition of the glass which causes variations in the refractive index. Ojena and DeForest [*1*] studied the variation in refractive index of sealed beam headlights using the Mettler Hot Stage with a phase contrast microscope. More recently, Brown [*2*] has studied the refractive index distribution of window glass. Reported here is another method for identifying or matching glass samples which is more specific than those above because it depends only on the magnetic impurities which occur in glass rather than on all of the trace elements. Magnetic susceptibility measurements over the temperature range of 4 to 300K have been made on various samples of headlight glass. With a few exceptions, it is found that the technique can be useful in forensic science applications and that improvements in accuracy, which are possible, would even eliminate these exceptions. The method is also applicable to the identification of other types of samples of forensic science interest such as soils, window glass, and metals. This is believed to be the first forensic science application of an old research technique used by chemists and physicists.

Theory

Magnetic susceptibility measurements depend upon the existence of magnetic ions in the sample. In glass, the most commonly occurring magnetic ions are Mn^{2+} and Fe^{3+}. Both of these ions have half-filled d-shells which means that the five d-electrons have no net orbital angular momentum and the entire magnetic susceptibility as a result of these ions comes

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from the total spin of these electrons. Such a magnetic system should obey a Curie law [3] given by

$$\chi = \frac{C}{T} + \chi_{\text{dia}} \quad (1)$$

where χ is the measured susceptibility, χ_{dia} is the diamagnetic susceptibility of the entire sample, T is the temperature in Kelvin, and C is the Curie constant given by

$$C = N\mu_0^2 g^2 S(S + 1)/3k \quad (2)$$

In Eq *2*, N is the number of magnetic ions present, μ_0 is the Bohr Magneton, g is the Lande splitting factor, S is the total spin quantum number, and k is Boltzmann's constant. For any ion with a $(3d)^5$ electron configuration, $S = 5/2$. When all of the constants are substituted into Eq *2*, C becomes

$$C = 7.26 \times 10^{-24} N$$

Thus, N is the only parameter to be determined.

From Eq *1*, the measured susceptibility is just the diamagnetic susceptibility at high temperatures. χ_{dia} can also be used for matching forensic science samples, but it will be seen later to be rather insensitive. Therefore, by measuring χ as a function of temperature, one can determine the number of magnetic ions in the sample as well as χ_{dia} for the whole specimen.

Experiment

According to the Faraday method of susceptibility measurement, when a material is placed in a nonhomogeneous magnetic field, a force is exerted on the material which is given by

$$F = m\chi H_x \frac{\partial H_x}{\partial z} \quad (3)$$

where χ is the magnetic susceptibility, m is the mass of the sample, and $H_x \cdot \partial H_x/\partial z$ is the field-gradient product in the z-direction. The field-gradient product is a property of the particular magnet used and can be calibrated using a sample whose susceptibility is accurately known. Pure platinum and pure palladium metals are common standards used for this purpose.

In this work, the sample was suspended in the magnetic field on the end of a quartz spring which was inside of an evacuated hang-down tube. In the end of the tube was an electrical resistance heater which was used for increasing the temperature in small increments. Helium gas at a pressure of a few millimetres of Hg was injected into the tube for the purpose of exchanging heat between the heater and the sample. The hang-down tube was then inserted into a liquid He dewar which was surrounded by a liquid N_2 dewar. A schematic diagram is shown in Fig. 1. The Magnet F in Fig. 1 could be moved up and down past the sample until a maximum deflection of the Spring K is observed through the Telescope M. The force on the sample is then given by Hooke's Law as

$$F = kd \quad (4)$$

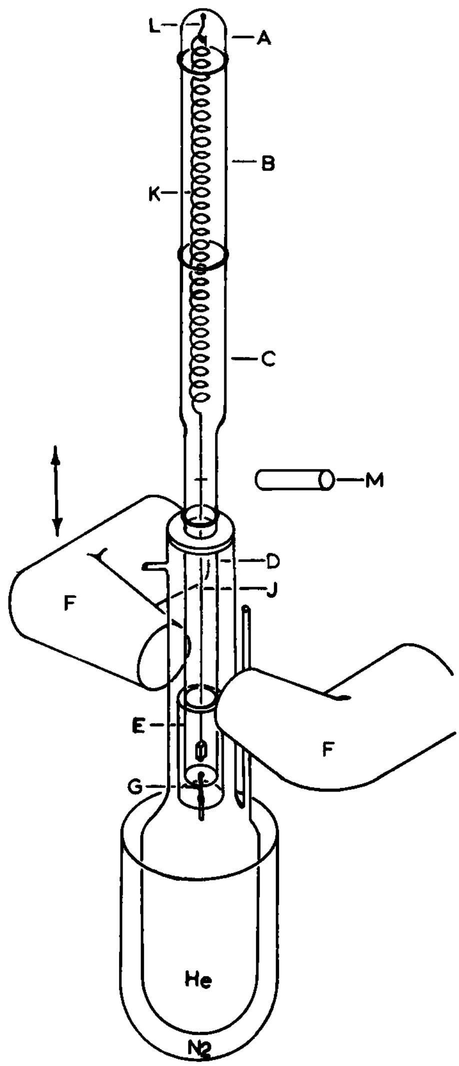

FIG. 1—*Schematic diagram of the Faraday apparatus.*

where k is the spring constant and d is the maximum deflection of the spring. The spring used in this work was calibrated and the spring constant k was found to be 4.906 ± 0.026 dynes/cm (0.4906 ± 0.0026 MN/m). Force measurements were made in this manner over the temperature range of 4 to 300K. The susceptibility was then obtained as a function of temperature using Eq 3.

Samples

Seven different sealed-beam headlights from four different manufacturers were obtained from a local wrecking yard. Only the front lense portion of each bulb was used for making samples. Some of the bulbs were sectioned and several samples from the same bulb were used to demonstrate the homogeniety of the magnetic impurity distribution. This was necessary if several pieces of glass from the same bulb were to be matched. The various samples and their masses are given in Table 1. Altogether, 13 samples were used.

Results

Figure 2 shows the measured magnetic susceptibility as a function of temperature for all three samples taken from Bulb 2. This is a typical result for all of the samples. Above about 80K, χ is negative which means that the diamagnetic contribution of the entire sample is greater than the paramagnetic contribution from the impurity ions. Near room temperature, χ is almost constant. This constant value is the diamagnetic susceptibility of the entire sample. Thus, χ_{dia} was determined for each sample and is shown in Fig. 3. Clearly, χ_{dia} is the same within experimental error for all samples and would not be useful for distinguishing different samples. This is the same problem that arises in refractive index measurements.

Equations 1 and 2 were then used to determine *N*, the number of magnetic ions in each sample. The results are shown in Fig. 4. Clearly, *N* is essentially the same for each of the samples from the same bulb. Thus, *N* could be used for matching pieces of glass from the same bulb with a high degree of confidence. Also, *N* is considerably different for the different bulbs, with the exception of perhaps Bulbs 5, 6, and 7. These exceptions will be discussed later. Thus, *N* can be used to distinguish among bulbs.

Discussion

The feasibility of using magnetic susceptibility measurements to match and distinguish headlight glass has been demonstrated. The use of the diamagnetic susceptibility is shown to be ineffective for this purpose, but the paramagnetic susceptibility appears to be a very specific probe that could be used in forensic science analyses. The exceptions mentioned above can easily be removed by using a more sensitive spring or by using a null electrobalance for measuring the force. The latter has been used in other work [*4*] and considerably reduces the size of the error bars shown in Figs. 3 and 4.

The major disadvantage of the method for a forensic science laboratory would be the time element. Since liquid He and liquid N_2 are used to obtain the extremely low temperatures, the system cannot be opened for changing samples until it has warmed to room temperature and then it must be cooled down again. Cooling down, taking measurements, and warming

TABLE 1—*Sealed-beam headlight samples used in this work.*

Samples	
Bulb	Mass, mg
1a	138.15
1b	130.26
1c	123.11
1d	144.05
2a	148.50
2b	129.35
2c	136.99
3a	138.96
3b	148.47
4	116.44
5	111.98
6	129.14
7	120.20

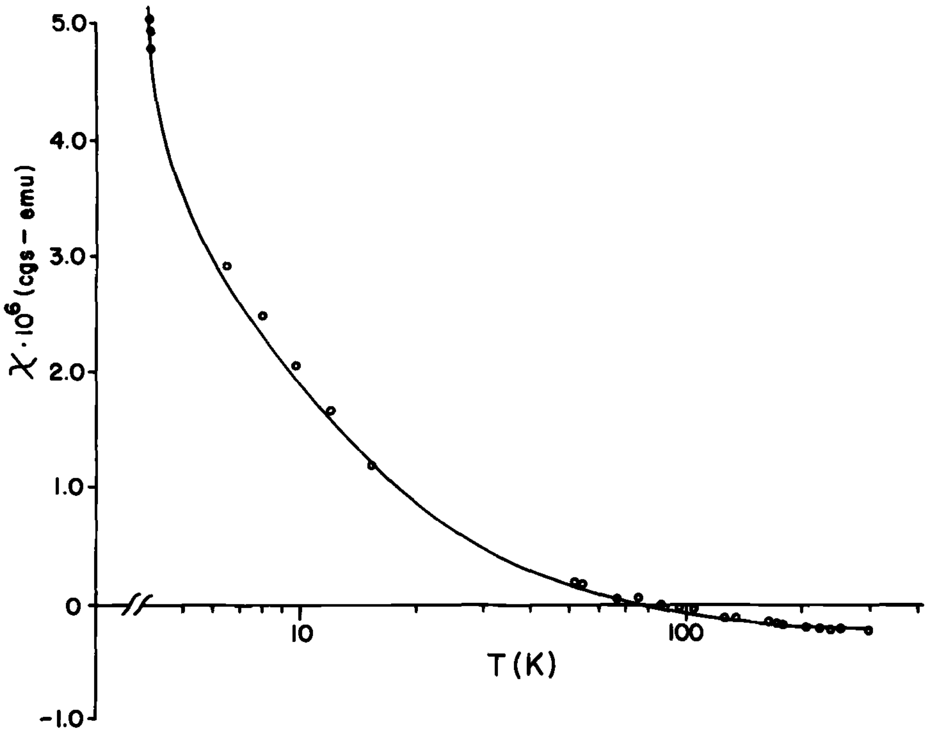

FIG. 2—*Magnetic susceptibility as a function of temperature for all three samples from Bulb 2.*

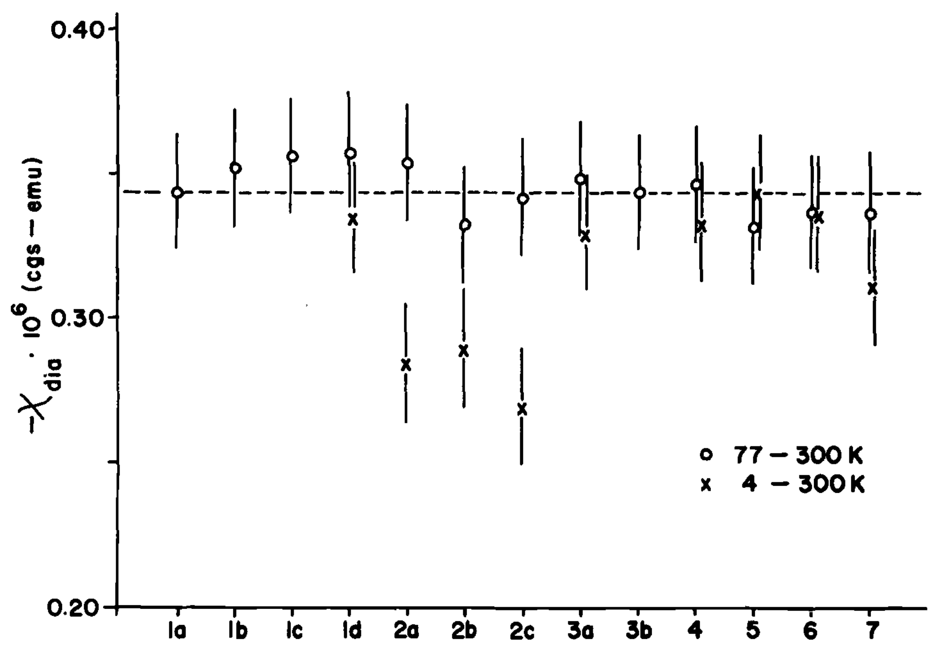

FIG. 3—χ_{dia} *for each sample.*

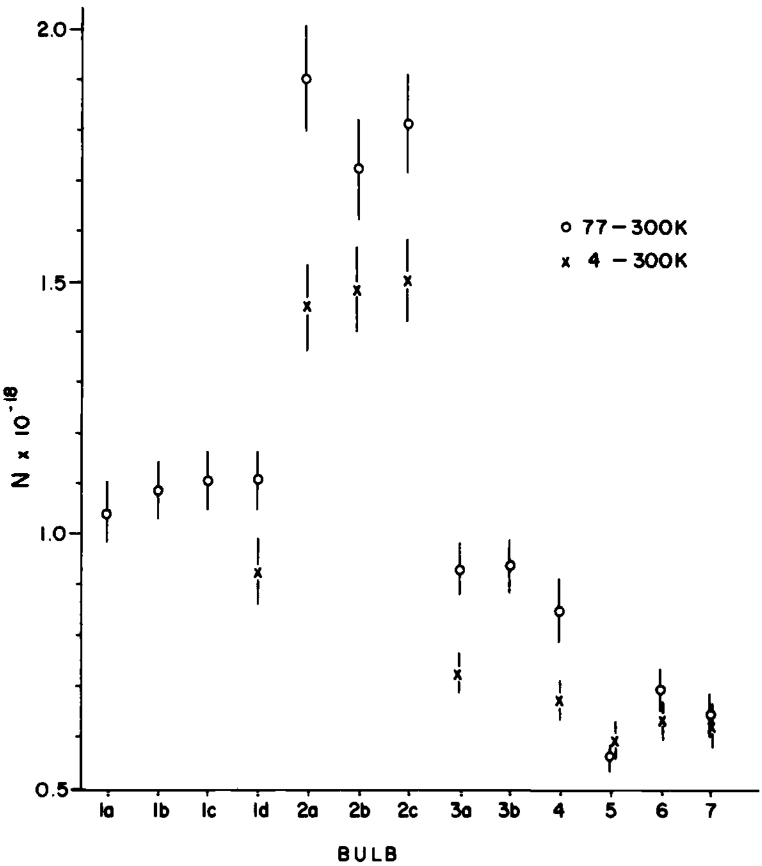

FIG. 4—*The number of magnetic ions,* N, *for each sample.*

to room temperature requires about four to five days. Another disadvantage compared to refractive index measurements is the sample size. Rather large samples are necessary because the paramagnetic force is extremely small. However, the specificity of the method might justify the time delay and large samples are available in many cases such as hit-and-run accidents. Also, the method can be used on other samples of forensic science interest.

Acknowledgment

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