to define a critical developmental stage, during which enrichment must be present if the brain changes are to occur, is particularly intriguing to those concerned with child development, and may offer hope to those children who were severely deprived in early life. While some workers in the area of child development have found that culturally impoverished children develop more slowly than more enriched children, others have pointed to cases where some of the detrimental effects of early impoverishment have been reversible after subsequent enrichment. Nevertheless, James Prescott, of the National Institute of Child Health and Human Development, believes that in light of the rapidly accumulating evidence on the effects of rearing environments on brain development in animals the possibility of such effects in children must be seriously considered. He believes that the studies in which brain differences are found between rats reared in social groups and those reared in social groups with frequently changed toys are particularly striking, and unnerving to anyone currently assuming that only very severe impoverishment might affect brain development in children.

Whatever effects an enriched environment may have on an individual, these effects clearly interact with other factors, such as the individual's sex, genetic makeup, and nutrition. For example, those working with rats assign some members of each litter to each of the rearing conditions in order to control at least partially for the effects of genetic variation on brain development, which always interact with the effects of rearing conditions. In addition, evidence exists that an enriched environment is able to overcome in part the detrimental effects on behavior produced by brain lesions, malnutrition, or hypothyroidism in rats. Sackett points out that some monkeys raised in impoverished conditions do not show very much abnormal behavior, which suggests that some unknown factor is interacting with the animal's rearing conditions and somehow providing him with a degree of insulation. The investigation of these unknown factors should provide clues about how impoverishment effects can be minimized and how enrichment effects can be potentiated.

While it is clear that enrichment has a definite effect on the brain, the significance of these effects remains obscure. Do these "super-rats" have superior capabilities by virtue of having more neural connections and a generally more complex brain? Most investigators tacitly agree that the changes in brain after enrichment must somehow be beneficial to the organism, but the research on behavioral differences has been slow and contradictory, and it is still not even certain that the brain changes are responsible for the behavioral differences which have been noted. A number of scientists favor putting off the question of the significance of the brain changes, in order to concentrate on specifying what the changes are, what features of the environment produced them, and in what developmental periods the brain is most susceptible to environmental modification. A great deal more about how the brain functions will have to be discovered before anyone can say just why enrichment has effects on the brain, and what these effects may mean to the animal, but that there is a connection between brain development and the richness of the environment in which an animal lives now seems inescapable.

—PATRICIA WALLACE

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Metrology: A More Accurate Value for Avogadro's Number

Scientists at the National Bureau of Standards (NBS), Gaithersburg, Maryland, have measured a value for Avogadro's number with an uncertainty that is reduced by a factor of 30 as compared with previous direct determinations. A variety of new metrological techniques and high quality silicon single crystals have been used to obtain this value. Since the new value of Avogadro's number ($6.022\ 094\ 3 \times 10^{23}$ per mole $\pm\ 6.3 \times 10^{17}$) is not greatly different from that previously known for the constant, the immediate impact of the NBS work is likely to be felt in the application of the separate methods developed for measurements of the abundance of the isotopes of silicon, the density of the silicon, and the lattice spacing of the crystalline silicon in various standards procedures.

In the future, however, with further refinements of these techniques, it may be possible to redefine the kilogram in terms of the product of the Avogadro constant and 1/12 the mass of a carbon-12 atom. This definition would remove the last remaining artifact standard (the kilogram is still the mass of a cylinder made from platinum and iridium which is kept at the International Bureau for Weights and Measures in Sevres, France).

Avogadro's number is the ratio of the mass of 1 mole of an element (the atomic weight) to the mass of one atom of the element. For a crystalline material with cubic symmetry, the mass of one atom can be found as $\rho a_0^3/n$, where ρ is the density of the material, a_0 is the lattice spacing of the cubic unit cell from which the crystal lattice is built up, and n is the number of atoms in the unit cell. The problem is to accurately measure the atomic weight, the density, and the lattice spacing. Each of these measurements constituted a separate project for the NBS team, whose efforts were coordinated by R. D. Deslattes.

Silicon was the material chosen to be measured mainly because of the large effort on the part of the electronics industry over the last 15 years to make very pure and very uniform single crystals with well-defined properties. Silicon also has a resistant oxide coating that protects it from the environment; it contains a single principal isotope (silicon-28); and it is transparent to the x-rays used in the lattice spacing measurement. Three high quality silicon single crystals with different histories were selected for the experiments.

Although silicon consists primarily of the isotope silicon-28 (about 92 percent), it also contains lesser amounts of silicon-29 (about 5 percent) and silicon-30 (about 3 percent). Thus, in order to ascertain the average atomic weight of a silicon sample accurately, it is necessary to know the absolute abundance of each of these isotopes in the sample. This task was accomplished by a group headed by I. L. Barnes through the use of quantitative chemistry techniques that were accurate to 1 part in 10,000 and a mass spectrometer

that was optimized for concentration measurements (in contrast to mass measurements).

According to Barnes, isotopically pure compounds of silicon were obtained from Oak Ridge National Laboratory, Oak Ridge, Tennessee, which were then chemically purified in order to obtain specimens that were both chemically and isotopically pure. Finally, a series of mixtures, each with different but precisely known amounts of the silicon isotopes, were prepared from the purified material. In order to determine the abundance of the three silicon isotopes in the crystalline silicon samples, a two-step comparison process was carried out.

First, a standard reference material (SRM 990) was made from a large silicon single crystal (not one of the samples). The isotopic abundance of the SRM 990 was determined by measuring the concentration ratios of the silicon isotopes in the standard with the help of the mass spectrometer and then applying correction factors that were determined from similar measurements on the mixtures with known compositions. Finally, the pure silicon samples were compared to the SRM 990 to obtain the isotopic abundances needed for the atomic weight determination. And, by use of tabulated nuclidic masses, the atomic weight of a silicon sample was given by the average mass of the isotopes weighted by their respective abundances.

The time-honored method for determining the density of an object is based on hydrostatic weighing (Archimedes' principle): the loss of weight of the object when it is immersed in a liquid is a measure of the volume of the object. Thus weighing the object in air and in the liquid leads to its density, but only if the density of the liquid is known very accurately. The usual liquid is water, which must be purified by multiple distillation; but when it is pure, it is very corrosive to many objects that one might wish to measure (that is, they dissolve slightly in the water). And gas molecules from the air are constantly being absorbed by the water as well. The result is a continuously changing and poorly defined medium, rather than one with a precisely known density.

At NBS, a group led by H. A. Bowman solved the water problem by using highly spherical steel balls as temporary density standards. The mass of each steel ball (about a kilogram) could be very accurately measured by standard procedures with an air balance, according to Bowman; others had previously shown that the volume of a spherical object can be found as accurately as desired simply by measuring enough values of its diameter. To determine the volume of a ball, the NBS scientists used a laser interferometer capable of measuring its diameter to within 1 part in 10^7.

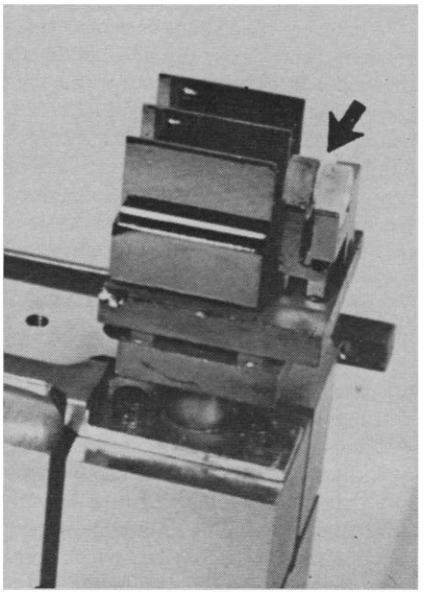

Fig. 1. Combined x-ray and optical interferometer. X-rays pass from back to front through the three upright planar pieces of silicon that are formed from a common single crystal. The silicon is cut in two so that the front piece is movable in a direction parallel to the other. The arrow points toward the optical interferometer formed by two mirrors, one of which is fixed and the other of which is movable, in such a way that the optical cavity length changes as the silicon moves. [Source: R. D. Deslattes, National Bureau of Standards]

The NBS researchers then turned to an inert fluorocarbon liquid, whose density did not need to be known as long as it remained constant, for use as the immersion medium in their hydrostatic weighing apparatus. By comparing the results of a series of measurements involving combinations of objects with unknown densities and the steel balls with known densities, the density of the liquid could be eliminated as a variable. Thus, the density of the unknown was determined, in effect, by comparing it with that of the steel balls. As in the isotopic abundance experiments, silicon objects (in this case, 200-gram blocks) were used as an intermediate standard. The densities of these blocks were measured by comparing them with the steel ball standards in the weighing apparatus. Finally, the densities of the pure silicon crystals were obtained by comparing the crystals with the intermediate silicon standards.

The final phase of the project was to measure the lattice spacing of the silicon crystals. The traditional means of measuring lattice spacings, x-ray diffraction, was limited by the fact that x-ray wavelengths could not be accurately related to any existing optical wavelength standard. Thus, metrologists quote x-ray wavelengths in units called kxu, where 1 kxu is about equal to 1.002 angstroms; but determining the precise relationship between kxu's and angstroms has been a problem. Deslattes and A. Henins, who were responsible for the lattice spacing measurements, overcame this difficulty by combining x-ray and optical interferometry in a way that the x-rays served only as a kind of marker and their wavelength did not need to be known.

The x-ray interferometer was constructed from the silicon crystal itself and mounted on a steel block (Fig. 1). The entire assembly was carefully isolated from mechanical vibrations and electromagnetic interference. The silicon and the block were cut in a manner such that one part of the silicon could be moved with respect to the other. X-rays passed through the pieces of silicon in such a way that when the lattice planes in the fixed and in the movable pieces of silicon were lined up correctly, a condition of constructive interference for the x-rays occurred and the transmitted beam of x-rays had a maximum intensity. As one piece of silicon was moved, the x-ray intensity varied with a periodicity equal to one lattice spacing of the silicon.

The distance traveled by the silicon crystal between x-ray peaks was measured with an optical interferometer. The optical cavity of the interferometer was made up of two mirrors, one fixed to each of the two pieces of silicon. A visible laser (whose wavelength could be measured against a krypton-86 wavelength standard) was the source of optical radiation. Since a peak in the transmission of the laser light through the interferometer occurred when the length of the optical cavity was an integral number of half wavelengths, the lattice spacing was measured simply by counting the number of x-ray peaks per optical peak (when a small correction associated with a nonplanar optical wavefront was taken into account).

In determining the accepted values for the various fundamental constants,

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such as the speed of light, the electronic charge, Avogadro's number, and others, metrologists do not rely only on direct measurements. Rather the "best" value of each of the constants is tied to measurements of other fundamental constants via a statistical procedure called a least squares adjustment. To see the effect that a more accurate value of Avogadro's number might have on the values assigned to the other constants was a major motivation for undertaking the project at NBS. However, each of the phases of the project has also yielded important results apart from the improvement in the knowledge of fundamental constants.

For example, the SRM 990 will be the publically available (for about $50 a wafer, according to Barnes) silicon standard with a known atomic weight. In addition, techniques akin to those used in the silicon studies are being used both for the determination of the atomic weights of other elements with several naturally occurring isotopes, and in isotopic dilution methods for the quantitative determination of trace impurities in various substances. Similarly, an immediate outcome of the density studies is that the intermediate silicon blocks are now serving as "working" standards for density measurements throughout the United States. And, in a separate experiment, Deslattes and Henins were able to accurately determine the correction factor for converting kxu units to angstroms, by (in effect) reversing the usual x-ray diffraction procedure. Thus, by using silicon crystals of known lattice spacing as the diffraction medium, they measured x-ray wavelengths.

As for the possibility of redefining the kilogram, Deslattes pointed to several possible improvements (such as the use of isotopically pure silicon crystals) in the procedures necessary for finding Avogadro's number, which together hold the possibility of reducing the overall uncertainty by another factor of 100. However, because of the magnitude of the effort that would be required, such an "esthetic problem" likely would have a lower priority than other more pressing and practical problems.—ARTHUR L. ROBINSON

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