# search & discovery

## German heavy-ion accelerator approaches full energy

What will probably be the most completely equipped laboratory in the world for heavy-ion research is now operating 20 km from Frankfurt. The laboratory, GSI (Gesellschaft für Schwerionenforschung), houses UNILAC, a linear accelerator that is expected to be capable eventually of accelerating heavy nuclei, such as uranium to 10 MeV/nucleon and lighter nuclei, such as argon to 14 MeV/nucleon. When it is operating at full energy, for heavy nuclei, it will have the highest energy available in the world, at least for the immediate future. The accelerator is the first to accelerate heavy ions over the full periodic table.

Although UNILAC has been doing experiments for many months now, it is still not operating with all the resonators of the third stage of its linear accelerator. This spring a uranium beam of $3 \times 10^8$ ions/sec produced with a Penning source was accelerated up to 6.6 MeV/nucleon.

The lab was founded in December 1969. Construction began at the end of 1971; the first stage of the accelerator was put into operation in April 1975. GSI now employs 400 persons, including 120 scientists. Total cost has been 158 million DM, and operating expenses are about 50 million DM per year.

Research will be done by joint groups

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**Scattering-chamber area at GSI, the heavy-ion facility** near Frankfurt. In left foreground is kinematic coincidence spectrometer with two position-sensitive particle-detector telescopes. In center foreground is multi-purpose scattering chamber with 1.5-m diameter. In right foreground is scattering chamber for particle spectroscopy with time-of-flight and $\Delta E - E$ spectrometers.

## Quasar puts limit on variation of fundamental constants

Theorists who seek to show that the universal constants of Nature actually vary over cosmic times are now faced with a harder row to hoe. By comparing radio and optical spectra from a quasar, Arthur Wolfe of the University of Pittsburgh, and Robert Brown and Morton Roberts of the National Radio Astronomy Observatory (Green Bank, West Virginia) have placed narrow limits on the possible variation of three constants.[1] The time span of the observations—granted the widely accepted interpretation of the redshift as reflecting the expansion of the Universe—is over one-third the age of the Universe. The constants are:

- $\alpha^2 g_p m/M$, with an upper variability limit of $2 \times 10^{-14}$ per year;
- $g_p m/M$, with a limit of $8 \times 10^{-12}$ per year, and
- $\alpha$, with a limit of $4 \times 10^{-12}$ per year.

Earlier ceilings on the variability of the fine-structure constant $\alpha (= e^2/\hbar c \approx 1/137)$ were derived by John Bahcall (Institute for Advanced Study) and his coworkers from astronomical data (and essentially unchanged by these new findings) and by others from radioactive-decay data. The proton $g$-factor $g_p$ is proportional to the magnetic moment of the proton; $m/M$ is the electron–proton mass ratio.

A constraint on the variability of a related constant was also obtained in a terrestrial experiment, which was reported in June, 1975 at the Fifth International Conference on Atomic Masses and Fundamental Constants. At Stanford, John Turneaure and Samuel Stein (now at the National Bureau of Standard's Boulder Laboratory) compared the frequency of a cesium clock with that of a superconducting cavity over a period of twelve days to obtain a maximum of $1.2 \times 10^{-11}$ per year on the variation of $\alpha^3 g_{Cs} m/M_{Cs}$, where $g_{Cs}$ and $M_{Cs}$ are the gyromagnetic ratio and the atomic mass of cesium.

**The concept** that fundamental constants may vary was stimulated by Paul Dirac when he noted in 1937 that the number $2.3 \times 10^{39}$ can be obtained from Nature in two ways: It is the ratio of the electric to the gravitational forces between an electron and a proton. It is also of the order of the age, now, of the Universe, expressed in either of two atomic time units, $e^2/mc^3$ (the classical time for light to traverse an electron) and $\hbar/mc^2$ (roughly interpreted as a quantum-mechanical oscillation period of the electron). This coincidence may be accidental; if it is not, it suggests a link between cosmology and fundamental physics. Dirac's suggestion that the gravitational constant $G$ might vary with time was found to conflict with the known luminosity and lifetime of the Sun. (However, the fact that neutrinos from the Sun have not been detected has left solar-evolution theory in a turmoil.) The 1967 suggestion by George Gamow that the electron charge $e$ could be varying was also dismissed, both by an argument by Denys Wilkinson (then at Oxford University) and Freeman Dyson (Institute for Advanced Study) on isotopic abundances and by the earlier astronomical limits on the variability of $\alpha$.

It was the long-sought-for opportunity to measure both the hydrogen 1420-MHz hyperfine line and an optical line for the same high-redshift object that made the new tests possible. This object is the BL-Lac-type quasar AO 0235 + 164, which flared five optical magnitudes. Spectral lines for an alkali-like atom, $Mg^+$, were measured[2] at Kitt Peak National Observatory by E. Margaret Burbidge and her colleagues from the La Jolla and Berkeley campuses of the University of California. They found a redshift ($\Delta\lambda/\lambda_0$) of $z_{Mg}$ = 0.52392 ± 0.00010 in a doublet with laboratory wavelengths 2795.53 Å and 2802.70 Å. The redshift found[3] by Roberts and his collaborators for the 21-cm hydrogen line was $z_H$ = 0.52385 ± 0.00001.

To obtain the three independent limits, Wolfe, Brown and Roberts made three different tests, as follows:

▸ A comparison of the hydrogen hyperfine splitting frequency with the frequency of either member of the MgII doublet. The ratio of these two frequencies, when terms above first order in $m/M$ and $\alpha$ are neglected, is a constant times $\alpha^2 g_p m/M$. This quantity at the time of photon absorption (thousands of millions of years ago), divided by the corresponding quantity at the present time, is equal to

$$\frac{1 + z_{Mg}}{1 + z_H} = 1.00005 \pm 0.0001$$

This result requires no assumption as to the origin of the redshift. (Some theorists feel that mechanisms other than expansion may contribute to the redshifts, as high as two or three, of quasars.) Assuming now that the absorption redshift is completely cosmological, and using the Friedmann cosmology with a deceleration parameter $q_0$ of zero, Wolfe, Brown and Roberts obtained[1] a look-back time of at least $0.7 \times 10^{10}$ $(50/H_0)$ years and the maximum rate of change already mentioned for this constant, $2 \times 10^{-14}$ per year. ($H_0$ is the Hubble constant in km $sec^{-1}$ $Mpc^{-1}$.)

▸ A comparison of the hydrogen hyperfine frequency with the $Mg^+$ fine-structure separation at the two epochs. Because the expressions for both of these contain $\alpha^2$, Wolfe and his coauthors were able to eliminate $\alpha$ and obtain the quoted ceiling of $8 \times 10^{-12}$ per year on the variability of $g_p m/M$.

▸ An analysis of the observed separation of the $Mg^+$ fine-structure doublet, which leads to the quoted constraint on $\alpha$.

**The implications to astronomy** of measuring at the same high redshift, a 21-cm absorption line and identified optical absorption lines go beyond the question of whether fundamental constants vary. They also include:[3]

▸ A check on the expression for the Doppler shift over a much larger redshift interval than before;

▸ a verification that the optical lines were identified correctly;

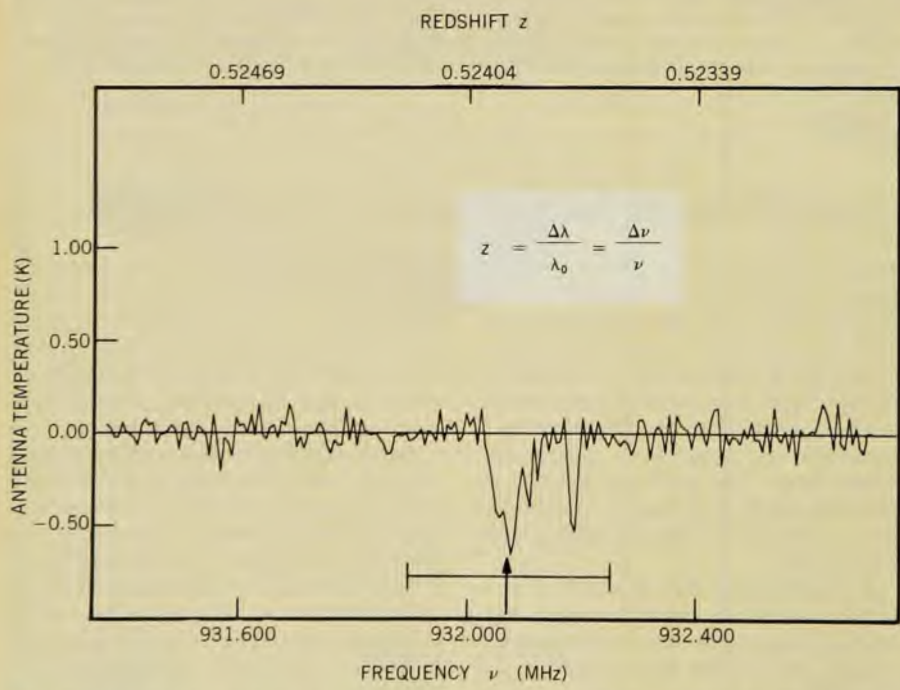
▸ a new means of estimating abundances of heavy elements relative to that of hydrogen, and

▸ clues to the location of the absorbing gas with respect to the continuous emitter behind it.

—HRL


**References**

1. A. M. Wolfe, R. L. Brown, M. S. Roberts, Phys. Rev. Lett. 37, 179 (1976).
2. E. M. Burbidge, R. D. Caldwell, H. E. Smith, L. Liebert, H. Spinrad, Astrophys. J. Lett. 205, L117 (1976).
3. M. S. Roberts, R. L. Brown, W. D. Brundage, A. H. Rots, M. P. Haynes, A. M. Wolfe, Astron. J. 81, 293 (1976).


**The absorption-line profile of hydrogen** in the direction of the radio source AO 0235 + 164. The comparison with the optically measured redshift (arrow) and its associated error (reference 2) results in a new, more restrictive limit on the possible variation of some fundamental constants.

## Japanese synchrotron yields 10-GeV protons

The first accelerator for high-energy physics in the Far East was recently dedicated at the KEK laboratory in Tsukuba science city, 60 km northeast of Tokyo. The proton synchrotron, whose construction began in 1971, has exceeded its initial design energy of 8 GeV on 19 March, when it reached over 10 GeV. After the main ring power supply and cooling capacity are modified, the machine is expected to reach a peak energy of 12 GeV.

In July KEK expected to have a 4-GeV negative pion beam from an internal target; in addition, KEK will have a fast external beam for the already operational 1-meter hydrogen bubble chamber. A slow extracted beam is being planned, and counter experiments using internal targets are expected to begin next May.

The machine consists of a 750-keV Cockcroft–Walton preinjector, a 20-MeV linac, a 500-MeV booster synchrotron and the 12-GeV main ring. Extraction from the booster and injection into the main ring are accomplished with fast kicker and septum magnet systems in a single turn. The main ring, with a mean radius of 54 meters, has a circumference nine times the booster circumference so that it can accommodate nine booster pulses. The separated-function lattice has four superperiods and seven cells per period.

Normalized beam emittance from the 12-GeV beam is expected to be $200\,\pi \times 40\,\pi$ $(\text{cm-mrad})^2$.

Each target station of the slow extracted beam will initially support one secondary kaon or antiproton beam, one in the momentum range less than 1 GeV/$c$ and the other 1–2 GeV/$c$.

Special precautions have been taken to maintain the alignment of the KEK linac in the presence of the frequent but minor earthquakes in the Tsukuba region. The linac tanks are supported on steel plates