letters to nature

Direct test of the constancy of fundamental nuclear constants

THE possibility that fundamental nuclear constants may vary slowly while the Universe expands has been discussed by several authors[1-5]. I try here to show that the well known resonance properties of the 'heavy nucleus plus slow neutron' system make it a sensitive 'receiver', sharply tuned to the current values of nuclear constants.

What are the restrictions, imposed by experiment that during the time interval ΔT the resonance energy shift had not exceeded ΔE_{exp}? Simple estimates of residual interaction matrix elements suggest that for the overwhelming majority of compound nucleus resonances one should expect their shifts to be not less than the single-particle resonance shift ΔE_0. The latter is connected with the relative change in strong coupling constant g_s

$$\frac{\Delta E_0}{V_0} \simeq \frac{\Delta g_s}{g_s} \qquad (1)$$

where V_0 denotes the depth of the nuclear potential well. Assuming $dg_s/dt =$ constant, we get a restriction

$$\frac{1}{g_s}\left|\frac{dg_s}{dt}\right| \lesssim \frac{1}{\Delta T}\,\frac{\Delta E_{exp}}{V_0} \qquad (2)$$

The positions of many low lying resonances have been known to an accuracy of 10^{-3} eV for quite a time[6]. Assuming $V_0 \simeq 50$ Mev (ref. 7) and $\Delta T \simeq 10$ yr we derive

$$\frac{1}{g_s}\left|\frac{dg_s}{dt}\right| \lesssim 2\times 10^{-12}\ \mathrm{yr}^{-1} \qquad (3)$$

which is the same result as that established by Davies on the basis of Dyson's cosmological argument[5].

The Coulomb force increases the average internucleon distance by $\sim 2.5\%$ for $A \simeq 150$ (ref. 7). Thus we obtain an estimate for the Coulomb coupling constant α 20 times higher than from equation (2). The weak interaction contribution to the total energy of the nucleus is $\sim 10^{-5}(\mu/m)^2$, where μ and m are the pion and nucleon mass, respectively[8]. The upper bound on the time variation of the weak coupling constant g_w is therefore 5×10^6 times higher than for g_s.

Table 1 Comparison of upper bounds of the variation of nuclear constants

	Dyson, Davies	Present work
$1/g_s\|dg_s/dt\|$ (yr^{-1})	2×10^{-12}	5×10^{-19}
$1/\alpha\|d\alpha/dt\|$ (yr^{-1})	2×10^{-14}	10^{-17}
$1/g_w\|dg_w/dt\|$ (yr^{-1})	10^{-10}	2×10^{-12}

The low lying resonance parameters determine the capture cross section for slow neutrons. So data on thermal cross section values in the remote past are of great interest. The recently discovered traces of ancient (1.8×10^9 yr old) natural nuclear reactors in the uranium deposits of Oklo (Gabon, West Africa)[9,10] have proved to be important in this respect.

The isotopic composition of Sm and Eu has been measured[11] for samples in the reactor core, irradiated by an independently determined[12] integrated flux of thermal neutrons $\varphi t \simeq 10^{21}$ neutrons cm^{-2}. Given φt and fission yields one can determine the capture cross-section values $\simeq 1.8\times10^9$ yr ago. Three standard deviations give the possible range of the cross-section variation, which is connected with the resonance energy shift through the Breit–Wigner formula. One is thus led to the restriction $|\Delta E_{exp}| \lesssim 0.05$ eV, and to the estimates of the upper bounds on the variation of fundamental nuclear constants shown in Table 1 along with the earlier limits of Dyson and Davies.

These estimates seem to exclude all variants of nuclear constants change based on Dirac's 'Large Numbers Hypothesis'[1]. It is, however, desirable to obtain as strict bounds on ΔE_{exp} as possible. Precise measurements of the isotopic shifts for all rare-earth fission products in the reactor core are desirable in this respect.

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Why measure astrophysical X-ray spectra?

MANY of the interesting results of X-ray astronomy such as the presence of compact sources in close binary systems, have been derived from light curve studies[1], obtained with quite simple detectors. On the other hand, a high resolution spectrometer, one of the most sophisticated pieces of instrumentation, is almost invariably included in solar X-ray satellites, and is used increasingly in cosmic studies[2]. Here we wish to stress that even spectra of the highest resolution are of limited applicability in many important astrophysical problems and also perhaps to indicate the value of cost-effective planning of expensive instrumentation in general.

In addition to providing useful data through measurements of Doppler shifts and line profiles, a prime aim of high resolution spectrometry is the inference of source structure in terms of