of e^2 would make Cm^{238} the stablest nuclide with $A = 238$, etc.

It is perhaps conceivable that our present U^{238} previously existed as Cm^{238}, which subsequently underwent four β^+ decays (or K captures). However the problem of Pb^{208} is more difficult: A billion years or so ago it would have existed as Rn^{208}, which is a gas. Our present lead ores would then be uniformly distributed throughout the world (they are not).

More generally, different isotopes of the same element would have a different chemical history (i.e., would have had different chemical elements as parents some time in the past). There would then be wide fluctuations in the isotopic compositions of elements coming from different sources in the world. It is well known that such variations are extremely small.

We can therefore conclude that the fundamental electric charge has varied very little (if at all) since the formation of the earth's crust.

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[1]G. Gamow, Phys. Rev. Letters 19, 759 (1967).

[2]This effect cannot be offset by an over-all decrease of nuclear forces (except for isolated values of A).

DOES THE FINE-STRUCTURE CONSTANT VARY WITH COSMIC TIME?*

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The fine structure constant at red shifts $\Delta\lambda/\lambda \approx 0.2$, corresponding to an epoch around two billion years ago, has been determined using the wavelengths of a pair of O III emission lines measured in the spectra of five radio galaxies. We find $\alpha(z=0.2)/\alpha(\text{lab}) = 1.001 \pm 0.002$ probable error.

Gamow[1] has suggested that part of the red shift of quasistellar sources may be due to the change of e^2, or the fine-structure constant α, with cosmic time. This suggestion was earlier shown to be unacceptable on experimental grounds by Bahcall and Salpeter,[2] who made use of the observed fine-structure splitting of the O III and Ne III emission lines in the spectra of the quasistellar radio sources 3C 47 and 3C 147. A more stringent test of the constancy of α was recently described by Bahcall, Sargent, and Schmidt.[3] For the quasistellar radio source 3C 191, with a red shift $\Delta\lambda/\lambda_0 = z = 1.95$, we found $\alpha(z=1.95)/\alpha(\text{lab}) = 0.97 \pm 0.05$ from measurements of the observed fine structure of Si II and Si IV absorption lines. More recently Gamow[4] has suggested that the observed absorption lines are not associated with the quasistellar sources in whose spectra they are detected but instead are produced in intervening galaxies.[5,6] This latter suggestion is inconsistent with observations of the spectrum of 3C 191. The excited fine-structure states of Si II ions are seen to be populated in the absorption spectrum of this object[2] and the densities or photon fluxes required to populate these excited states are orders of magnitude too high to be obtainable in intervening galaxies.[7]

The main purpose of the present Letter is to show how a particularly strong check on the constancy of α can be inferred from the spectra of radio galaxies with red shifts about 0.2. It is generally agreed that the light-travel time for such galaxies is around 20% of the Hubble expansion age or about 2×10^9 y. We use unpublished measurements of the wavelengths of the O III multiplet lines, 5007 and 4959 Å, in the emission spectra[8] of five radio galaxies. Because of the high accuracy with which the wavelength measurements can be made for the radio galaxies, the present data furnish a more critical test of the hypothesis that α changes with cosmic time than has been possible so far with quasistellar sources.

Table I contains a list of the observed wave-

Table I. Observed wavelengths and computed values of $\alpha(z)/\alpha(\text{lab})$ for some radio galaxies.

Object	z	λ_{ob}	λ_{ob}	$\alpha(z)/\alpha(\text{lab})$
Laboratory	0.0	4958.9	5006.8	...
3C 219	0.17	5823.1	5880.4	1.009
3C 234	0.18	5875.2	5932.3	1.003
3C 26	0.21	6003.2	6060.1	0.990
3C 171	0.24	6140.6	6200.5	1.005
3C 79	0.26	6230.0	6289.7	0.996

lengths of the O III lines in five radio galaxies with appreciable red shifts. Given the observed wavelenths, the ratio $\alpha(z)/\alpha(\text{lab})$ can be computed from the relation $[\alpha(z)/\alpha(\text{lab})]^2 = (\delta\lambda/\lambda)_{\text{ob}} \times (\delta\lambda/\lambda)_{\text{lab}}^{-1}$. Here $\delta\lambda$ is the fine-structure splitting and λ is the weighted mean wavelength, weighted according to $(2J+1)$. We find from Table I that

$$\alpha(z\approx 0.2)/\alpha(\text{lab}) = 1.001 \pm 0.002 \text{ probable error}$$

considering only statistical errors. The hypothesis[1] that α is proportional to cosmic time requires $\alpha(z\cong 0.2)/\alpha(\text{lab}) \approx 0.8$ and hence is ruled out by the above results.

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†Alfred P. Sloan Fellow.

[1]G. Gamow, Phys. Rev. Letters 19, 759 (1967). Gamow's suggestion was based on the ideas of P. A. M. Dirac, Nature 139, 323 (1937); Proc. Roy. Soc. (London) A165, 198 (1938).

[2]J. N. Bahcall and E. E. Salpeter, Astrophys. J. 142, 1677 (1965).

[3]J. N. Bahcall, W. L. W. Sargent, and M. Schmidt, Astrophys. J. 149, L11 (1967).

[4]G. Gamow, Phys. Rev. Letters 19, 193 (1967), and to be published.

[5]The idea that absorption lines in the spectra of quasistellar sources might be produced by clusters of galaxies was proposed by J. N. Bahcall and E. E. Salpeter (Ref. 2), and Astrophys. J. 144, 847 (1966), before the discovery of quasistellar sources with rich absorption spectra.

[6]See R. V. Wagoner, Astrophys. J. 149, 465 (1967), for a detailed discussion of the effects of an intervening galaxy on the radiation from distant sources.

[7]J. N. Bahcall, Astrophys. J. 149, L7 (1967).

[8]M. Schmidt, Astrophys. J. 141, 1 (1965).

CROSSOVER AND POLARIZATION PHENOMENA IN HIGH-ENERGY SCATTERING. CUTS, CONSPIRACIES, AND SECONDARY REGGE POLES

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The usual interpretation, in Regge-pole models, of the change in signs of the cross section differences $d\sigma(\bar{A}B)/dt - d\sigma(AB)/dt$ at $t \sim -0.15$ (GeV/c)^2 observed in elastic πN, KN, and NN scattering is inconsistent with recent data on the reaction $\gamma p \to \pi^0 p$. It is pointed out that this contradiction is direct evidence for the existence of contributions to the high-energy scattering amplitudes in addition to those of the leading Regge poles. Alternative explanations of the crossover phenomena which avoid the foregoing difficulty are proposed, and their implications are discussed.

A common experimental feature of high-energy $\pi^\pm p$, $K^\pm p$, $\bar{p}p$, and pp elastic scattering is the change in the sign of the cross section differences[1]

$$D(AB) = d\sigma(\bar{A}B)/dt - d\sigma(AB)/dt \quad (1)$$

at momentum transfers $t = t_c \sim -0.15$ (GeV/c)^2. This "crossover" phenomenon is usually explained in Regge-pole models for these reactions by supposing that the signs of the helicity-nonflip residue functions for the ρ- and ω-exchange amplitudes change sign at this point.[2,3] This explanation is inconsistent with recent data[4] on the reaction $\gamma p \to \pi^0 p$, thought to be dominated by ω exchange,[5] as will be discussed below.

In the Regge exchange model, $D(AB)$ can be expressed as

$$D(AB) = 2\,\text{Re}\sum_{[\lambda]} T_{[\lambda]}^{*} V_{[\lambda]}, \quad (2)$$

where $[\lambda]$ labels the particle helicities in the t channel. The amplitude $T_{[\lambda]}$ is a sum of amplitudes for exchanges even under charge con-