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ORIGIN OF COSMIC X RAYS*

F. Hoyle
University of Cambridge, Cambridge, England, and California Institute of Technology, Pasadena, California

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Penzias and Wilson[1] have recently obtained evidence for a background radiation temperature of 3.5± 1.0°K at 4080 Mc/sec. If the measured radiation comes from a universal thermodynamic radiation field at this temperature, the corresponding energy density is $\sim 10^{-12}$ erg cm^{-3}, about a hundred times the intergalactic energy density of starlight. Such a high radiation density must have an important application to the problem of the inverse Compton effect, suggested by Felten and Morrison[2] as the source of cosmic x rays and γ rays.

The energy-loss rate from relativistic electrons due to the inverse Compton effect is related in a simple way to the synchrotron energy-loss rate, by

$$\frac{\text{inverse Compton loss rate}}{\text{synchrotron loss rate}} \approx \frac{\text{energy density of radiation field}}{H^2/4\pi},$$

where H is the magnetic intensity. Since a considerable amount of information is already available concerning synchrotron emission in the galaxy and in radio sources, this relation can be used to estimate the importance of the inverse Compton effect. The latter is equivalent to synchrotron radiation (so far as energy emission rates are concerned) in an "effective magnetic field" of intensity $2\pi^{1/2}$(energy density of radiation field)$^{1/2}$. With $\sim 10^{-12}$ erg cm^{-3} for the energy density, the equivalant field has intensity $\sim 3\times 10^{-6}$ G. This is probably comparable with the magnetic field in the galaxy and in many extragalactic radio sources. It follows that the inverse Compton radiation arising from the background discovered by Penzias and Wilson should probably be as strong in many cases as the synchrotron radiation.

Consider next the frequency that the inverse Compton radiation is likely to have. For a temperature of 3.5°K the maximum of the Planck distribution is at $\sim 10^7$ Å, and the average quantum energy $\sim 10^{-3}$ eV. After scattering by a relativistic electron of energy γmc^2 such a quantum acquires energy $\sim 10^{-3}\gamma^2$ eV. Since the electrons in radio sources are believed to have typical energies of ~1 BeV, i.e., $\gamma \approx 2000$, the resulting quantum energies fall in the region of the observations of Giacconi, Gursky, Paolini, and Rossi,[3] and of Bowyer, Byram, Chubb, and Friedmann,[4] i.e., at ~3 Å.

Emission of x rays by a typical radio galaxy should be of order 10^{43} to 10^{44} erg sec^{-1}. A system such as Cygnus A, lying at a distance of $\sim 5\times 10^{26}$ cm, would give an x-ray flux at the Earth of order 10^{-10} erg cm^{-2} sec^{-1}, showing that strong extragalactic radio sources could also be x-ray sources near the present-day limit of detectability. Emission of x rays by the galaxy should be comparable with the radio emission, $\sim 10^{38}$ erg sec^{-1}, giving a flux of $\sim 10^{38}(4\pi d^2)^{-1}$, where $d \approx 3\times 10^{22}$ cm is the distance of the solar system from the galactic center. The flux should be $\sim 10^{-8}$ erg cm^{-2} sec^{-1}, comparable to the measured x-ray background.

The degradation time for an electron of initial energy γmc^2 due to synchrotron radiation is $\sim 10^9\,\gamma^{-1}H^{-2}$ sec. The degradation time due to the inverse Compton effect is obtained from this by setting $H = 3\times10^{-6}$ G, viz., $10^{20}\,\gamma^{-1}$ sec, so that an electron with initial $\gamma \approx 2000$ is appreciably degraded in 5×10^{16} sec, less than the cosmological time scale of 3×10^{17} sec. Such electrons cannot survive in intergalactic space for more than about 10% of the ages of the galaxies. Since the universal energy density of x rays cannot exceed $\sim 10^{-17}$ erg cm^{-3}, it follows that the electron energy density in intergalactic space cannot have been maintained as high as 10^{-17} erg cm^{-3} over the past 10^{10} years, and the likely inference is that the present energy density of electrons in intergalactic space is less than this.

Protons are degraded by the inverse Compton effect in a time scale $\sim 10^{20}\,\gamma^{-1}\,(m_p/m_e)^3$ sec, the initial proton energy being $\gamma m_p c^2$. This is $\sim 3\times10^{17}$ sec for $\gamma \approx 3\times10^{12}$, i.e., for protons of initial energy $>10^{21}$ eV. Intergalactic protons are not degraded, therefore, up to the present limit of the observed energy spectrum.

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OBSERVATION OF THE ISOTOPE SHIFT OF $K_{\alpha1}$ X RAYS OF URANIUM*

R. T. Brockmeier and F. Boehm
California Institute of Technology, Pasadena, California

and

E. N. Hatch
Institute for Atomic Research and Department of Physics, Iowa State University, Ames, Iowa

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The purpose of this Letter is to report the first experimental evidence of the volume-dependent isotope shift of electronic K x rays.

It is well known that the addition of neutrons to a nucleus reduces the nuclear charge distribution experienced by an electron whose wave function penetrates into the nucleus. The result is a decrease of the electron binding energy, giving rise to a volume-dependent isotope shift. Only $s_{1/2}$ and $p_{1/2}$ electrons overlap with the nucleus to an appreciable extent; thus, only these electronic levels are expected to exhibit an isotope shift.

From the large number of observations[1] of the optical isotope shift and the theoretical interpretations[2] which have been advanced to explain these data, several general features of the shift have emerged, some of which are rather poorly understood. Three such features are (1) the anomaly of the even-odd staggering, (2) the theoretical overestimate of the magnitude of the shift (in most cases by about 40%), and (3) the discrepancies in the shift for isotopes with $N \approx 90$.[3] Part of the difficulty resides in the problem of being able to separate the roles that atomic and nuclear effects play in the shift. Optical transitions involve outer electrons. Hence, shielding corrections for optical isotope shifts are large. If it were possible to detect a shift in energy of one of the inner electrons, a more reliable comparison with theory could be gained because of the availability of better electron wave functions. Thus, experimental observations of x-ray isotope shifts would contribute to the understanding of the deficiencies of the present isotope-shift theory. Furthermore, these observations would provide a new tool for the study of nuclear-structure effects.

An earlier attempt[4] to observe the isotope shift of the $K_{\alpha1}$ x rays of Mo and of some L x rays of U was unsuccessful due to inadequate