Experimental Test of the Freundlich Red-Shift Hypothesis*

GERALD D. BLUM AND RAINER WEISS
Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received 30 September 1966)

An experiment to test the Freundlich photon-scattering hypothesis, which was designed to explain the Hubble cosmological red shift, is described. Laser light is passed through an rf cavity placed in one arm of an interferometer sensitive to 10^{-8} fringe shift. The experiment sets a limit of $\Delta\nu/\nu<10^{-18}$ on the frequency shift of 6328-Å photons passing through 2 m of X-band radiation field with an energy density of 2 erg/cm^3.

IT has been proposed that Hubble's cosmological red shift—usually attributed to a recessional Doppler shift—might be due to an energy loss of photons as they pass through the cosmic radiation fields between the earth and the emitting galaxy. In particular, Freundlich[1] has hypothesized

$$\Delta\nu/\nu=-k_u uL\,, \tag{1}$$

where $\Delta\nu/\nu$ is the relative frequency shift of a photon from a source at distance L from the earth after the photon has traversed a radiation field of energy density u. An alternative hypothesis is to let the relative frequency shift be proportional to the photon density of the radiation field:

$$\Delta\nu/\nu=-k_n nL\,, \tag{2}$$

where n is the number of photons per cubic centimeter. These effects are not predicted by quantum electrodynamics; nevertheless, they need not violate the conservation principles of energy and momentum.

An experiment to test both of these hypotheses has been reported previously.[2] In that experiment, a search was made for a frequency shift of 14-keV Mössbauer photons as they traversed a 1300°K thermal radiation field and the rf field in an X-band cavity. The experiment gave a null result. Several factors have prompted us to repeat the experiment. The optical maser has made it possible to test the Freundlich hypothesis with visible light and thereby remove an objection that might be raised against the first experiment. This objection was that since the cosmological red shift has only been observed in the visible range, the extrapolation to 14 keV of a mechanism to explain it might not be justified. Recent radiometer experiments have yielded excess antenna temperatures which could be attributed to a cosmic black-body temperature of 3°K.[3–5] These obser-

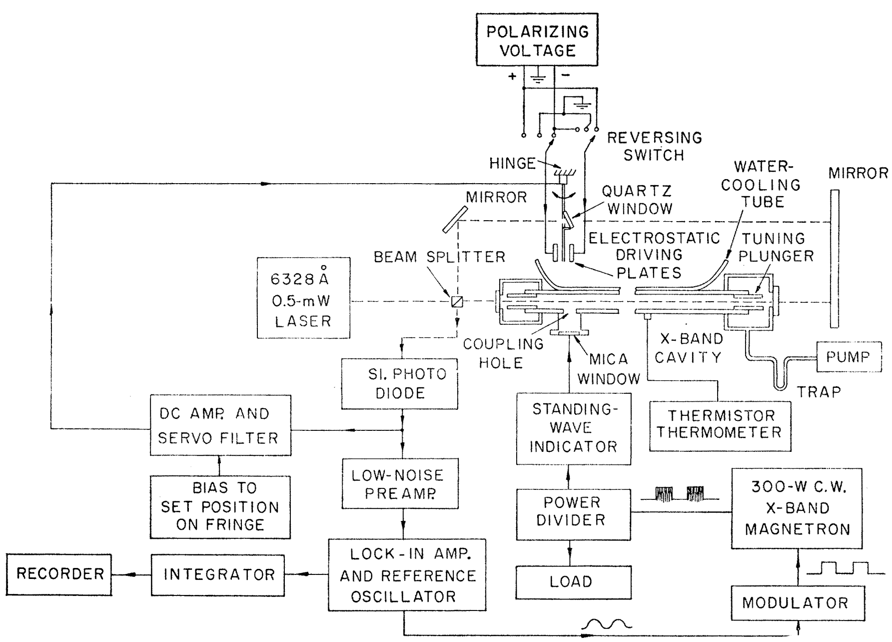

FIG. 1. Block diagram of the apparatus.

* This work was supported by the Joint Services Electronics Program under Contract No. DA36-039-AMC-03200(E).
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[3] A. A. Penzias and R. W. Wilson, Astrophys. J. **142**, 419 (1965).
[4] R. Dicke, J. Peebles, P. Roll, and D. Wilkinson, Astrophys. J. **142**, 421 (1965).
[5] P. Roll and D. Wilkinson, Phys. Rev. Letters **16**, 405 (1966).

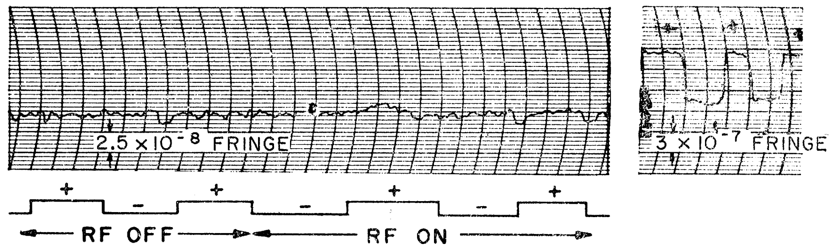

FIG. 2. Sample data. The trace on the left shows the lock-in amplifier output signal with pulsed cavity power on and off. The + and − signs refer to the servo polarizing voltage. The trace on the right is the Kerr effect in air when the cavity is brought to atmospheric pressure.

vations make the Freundlich hypothesis somewhat more attractive; apparently not attractive enough, however, as the present experiment gives a null result.

The experimental arrangement is shown in Fig. 1. 6328-Å light from a 0.5-mW He-Ne optical maser is passed through a modified Michelson interferometer which develops Twyman-Green interference fringes on a silicon photodiode with 30% quantum efficiency. Light in one arm of the interferometer passes through an evacuated (1×10^{-3} mm Hg) cylindrical X-band cavity, 1 m long, operating in the $TE_{1,1,31}$ mode at 10.1 kMHz with a loaded Q of 6000. The cavity dissipates 240 W from a magnetron that is pulse modulated at 10 kHz with a duty cycle of $\frac{1}{2}$. Light in the other arm travels in air and passes through a thin quartz plate. The plate serves as a continuously adjustable optical path-length modulator which is incorporated into a servo system. This system holds the interference pattern fixed, for low-frequency fluctuations, at either the positive- or negative-slope inflection point of an arbitrary fringe. The interference pattern is investigated for a 10-kHz component by synchronous detection with a lock-in amplifier. The sensitivity of the apparatus was found to be limited by the shot noise in the light beam, which is equivalent to approximately 10^{-8} fringe at 10 kHz in a bandwidth of approximately $\frac{1}{3}$ Hz. The data were taken with the interference pattern locked alternately at the plus- and minus-slope inflection points, in order to discriminate rf pickup from an actual phase shift in the interference pattern.

A typical recording of the output signal is shown in Fig. 2, along with noise recorded when there was no rf power in the cavity and the Kerr effect in air at 1 atm in the cavity. The data give an upper limit of 10^{-8} fringe for the shift in the light beam passing through the cavity radiation field.

The interpretation of the experiment and its relation to the Freundlich hypothesis is not completely unambiguous.

A possible model to describe the light wave while in the rf cavity is

$$\mathcal{E}(x,t)=\epsilon_0 \sin[(\omega_0/c)(1-K_n nx)(x-ct)]. \tag{3}$$

The wave suffers a progressive change in wavelength and frequency. At the detector, the relative phase shift between the interfering light beams would be given approximately by

$$\delta(t)=K_n n(t)2L(\omega_0/c)(2L-ct), \tag{4}$$

where L is the length of the rf cavity, and $n(t)$ is the rf pulse of duration $0.5f_{\mathrm{mod}}$. The first term of the phase shift comes from the change in wavelength and is a constant during the rf pulse. The second term, much larger than the first in this experiment, is due to the change in frequency and gives a cumulative phase shift during the time when the rf pulse is on. At the end of the pulse,

$$\delta=-K_n nL\omega_0/f_{\mathrm{mod}}. \tag{5}$$

If $\delta\ll\pi/2$, the signal would appear as a periodic sawtooth pulse in the detector output. The experiment was performed over a range of rf power to preclude the possibility that $\delta>\pi/2$ and consequently might have averaged out over a modulation cycle. Furthermore, one run was made with the cavity fed continuously, while the servo error signal was frequency analyzed for a steady-beat note in the interference pattern. Although this technique is limited by low-frequency noise, we were able to set a limit of $f_{\mathrm{beat}}<10^{-1}$ Hz.

With the use of the experimental parameters $u=2$ erg/cm^3 on the axis of the cavity, or $n=3\times10^{16}$/cm^3, $L=100$ cm, $\omega_0=3\times10^{15}$ rad/sec, $f_m=10^4$ Hz, the experiments set the following limits on k_n and k_u.

$$k_n<3\times10^{-39}\ \mathrm{cm}^2,\quad k_u<3\times10^{-23}\ \mathrm{cm}^2/\mathrm{erg}. \tag{6}$$

These values are to be compared with

$$k_n=1.5\times10^{-31}\ \mathrm{cm}^2,\quad k_u=2\times10^{-16}\ \mathrm{cm}^2/\mathrm{erg}, \tag{7}$$

which must hold if the Freundlich hypothesis is to account for the observed relation

$$\Delta\nu/\nu=k_H L,\quad k_H=8.3\times10^{-29}\ \mathrm{cm}^{-1} \tag{8}$$

for the cosmological red shift in a universe at 3°K.

One of us (R.W.) would like to thank Professor L. Grodzins for discussions concerning this experiment.