MEASUREMENT OF THE RED SHIFT IN AN ACCELERATED SYSTEM USING THE MÖSSBAUER EFFECT IN Fe^{57}

H. J. Hay, J. P. Schiffer,* T. E. Cranshaw, and P. A. Egelstaff
Atomic Energy Research Establishment, Harwell, England
(Received January 27, 1960)

In an adjoining paper[1] an experiment is described in which the change of frequency in a photon passing between two points of different gravitational potential has been measured. Einstein's principle of equivalence states that a gravitational field is locally indistinguishable from an accelerated system. It therefore seemed desirable to measure the shift in the energy of 14-kev gamma rays from Fe^{57} in an accelerated system. In order to do this we have plated a Co^{57} source on to the surface of a 0.8-cm diameter iron cylinder. This cylinder was rigidly mounted between two Dural plates which also held a cylindrical shell of Lucite, 13.28 cm in diameter and 0.31 cm thick, concentric with the iron cylinder. An iron foil 3.5 mg/cm^2 thick and enriched in Fe^{57} to 50% was glued to the inside surface of the Lucite. This assembly was mounted in a neutron chopper drive unit[2] and rotated at angular velocities up to 500 cycles per second. The gamma rays passing through the absorber were detected in a xenon-filled proportional counter. A schematic diagram of the apparatus is shown in Fig. 1.

The expected shift can be calculated in two ways. One can treat the acceleration as an effective gravitational field and calculate the difference in potential between the source and absorber, or one can obtain the same answer using the time dilatation of special relativity. The expected fractional shift in the energy of the gamma ray is $(R_1^2 - R_2^2)\omega^2/2c^2 = 2.44\times10^{-20}\omega^2$.

The number of gamma rays as a function of angular velocity is shown in Fig. 2. In a separate measurement the counting rate as a function of radial velocity was determined for this same source and absorber. It was found that with the source moving rapidly the counting rate was 1.29 times what it was with the source stationary. The measured full width of the resonance was 0.38 mm/sec. The curve calculated from these parameters is also shown in Fig. 2. The sensitivity of the equipment to vibrations was tested by vibrating the shaft of the rotor with frequencies corresponding to the rotational frequencies involved, and negligible effect was observed. Changes in counting rate due to forces on the absorber were also found to be negligible.

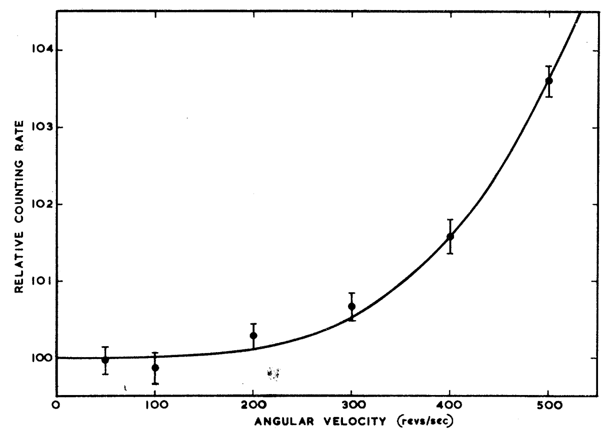

FIG. 2. Comparison of the calculated curve with experimental points. The statistical errors of each point are indicated. The curve was calculated from the parameters given in the text.

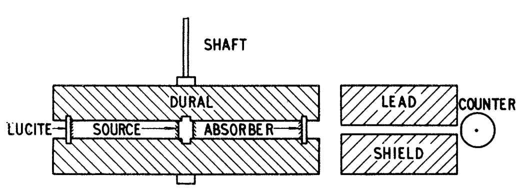

FIG. 1. Schematic diagram of the experimental equipment.

It appears that the observed effect is in reasonable agreement with expectations. The size of the shift of the gamma-ray energy in the effective gravitational field of a rotating system is in agreement with that due to the terrestrial gravitational field, within the accuracy of the measurements. The present experiment is expected to be improved when a more pure source is available for reasons stated in the previous paper. It will also be necessary to study further the factors which could influence the absorption process, including changes in the magnetic hyperfine fields due to the high velocities.

We would like to acknowledge helpful and illuminating discussions with Dr. J. S. Bell, Dr. W. Marshall, and Dr. T. Skyrme. We would also like to thank Dr. E. Bretscher for his support and encouragement.

*John Simon Guggenheim fellow, on leave from

Argonne National Laboratory, Lemont, Illinois.
[1]T. E. Cranshaw, J. P. Schiffer, and A. B. Whitehead, preceding Letter [Phys. Rev. Letters 4, 163 (1960)].
[2]Egelstaff, Hay, Holt, Raffle, and Pickles, J. Inst. Elec. Engrs. (London) (to be published).

STABLE CONFINEMENT OF A HIGH-TEMPERATURE PLASMA*

R. F. Post, R. E. Ellis, and F. C. Ford
Lawrence Radiation Laboratory, University of California, Livermore, California

and

M. N. Rosenbluth
General Atomic, San Diego, California
(Received January 18, 1960)

Stable, long-time confinement of hot plasma in a "magnetic bottle" is the ultimate objective of high-temperature plasma research. Theoretically,[1-4] there are relatively few plasma-magnetic field configurations which should permit stable confinement. Even these, when experimentally tested, have until now been found to be unstable, forcing re-examination and extension of the theory. We wish in this Letter to report experiments which represent a contrary example, providing evidence for the existence of a stably confined plasma, observed under circumstances where the simplest hydromagnetic theory predicts instability.

Our two criteria for defining stable confinement are: (1) The observed confinement time shall be very much longer than the theoretically predicted exponentiation time of instabilities. (2) The rate of escape of the plasma out of the magnetic bottle shall agree reasonably with that expected from collisional diffusion (which ultimately limits the attainable time scale for any mode of plasma confinement).

To satisfy both criteria, the plasma must be hot and its particle density must not be too high. This is because rates of diffusion, being proportional to interparticle collision frequencies, become slower in a plasma the lower is its density and the higher is its temperature, whereas hydromagnetic instabilities are predicted to grow faster the higher the plasma temperature, at a rate which is essentially independent of plasma density.

In our experiments the hot plasma was confined in a Mirror Machine[5] and was produced by the adiabatic (i. e., slow) magnetic compression of a low-density burst of hydrogen plasma injected into the evacuated confinement chamber. Magnetic compression ratios ($B_{\text{final}}/B_{\text{initial}}$) of 1000 or more are used, resulting in a spindle of heated plasma typically 3 or 4 cm in diameter and about 20 cm in length. The most striking feature of this plasma is its very high electron temperature.

Following the 500-μsec compression period the magnetic field coils are short-circuited, so that the confining field decays slowly from its peak value, with a time constant of several milliseconds.

Preliminary evidence of plasma heating and long-time confinement in our experiments, first observed in 1953, was obtained by microwave methods. Subsequently the spatial and energy distribution of the confined plasma were measured and reported.[6] Typical values are:

1. Plasma particle density: initial, 10^{11} to 10^{12} cm^{-3}; compressed, 10^{13} to 10^{14} cm^{-3}.
2. Plasma electron temperature: initial, 10 ev; compressed, 10 to 25 kev.
3. Magnetic field: initial, 0 to 100 gauss; final, 10 000 to 40 000 gauss.
4. Calculated plasma β [pressure$\div(B^2/8\pi)$]: up to 0.08.
5. Observed total plasma confinement times: up to 30 milliseconds (typical half-life at peak compression, 2 milliseconds).

Confinement times and densities have been deduced by detection of x rays, by microwave radiometry and interferometry, by calorimetry, and by calculation from the initial densities, and most fruitfully by observing the time dependence of the flux of escaping fast electrons detected by scintillator plus photomultiplier placed near the magnetic axis outside one of the mirrors. (See trace of Fig. 1.) Electron temperatures were determined by absorber foils in front of