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EFFECT OF GRAVITY ON NUCLEAR RESONANCE*

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The effect of a gravitational potential difference on the apparent energy of the 14.4-keV γ ray of Fe^{57} was found by Pound and Rebka[1] to agree, within their uncertainties, with Einstein's prediction based on his principle of equivalence.[2] Cranshaw and Schiffer have interpreted their recently reported less precise result[3] as being consistent with the prediction. We wish herein to report the results of a new similar experiment confirming the prediction to greater precision. Our overall result is 0.9970 times the value predicted with a standard deviation of statistical origin of 0.0076. We estimate the linear sum of the limits of all systematic errors to be ±0.008.

The resonance of the 14.4-keV Fe^{57} γ ray between iron foils has again been employed. The site of the earlier experiment in the Jefferson Physical Laboratory, having about 22.5 meters of working height, was used. The beam was sent through a helium-filled plastic bag 40 cm in diameter to avoid absorption by air. A source containing 1.25 curies of 270-day Co^{57} diffused into an iron foil 10 cm in diameter, 5 mg/cm^2 thick, enriched in Fe^{56}, was obtained in March, 1963, about 12 months before the beginning of the experiment reported here. The main resonant absorber consisted of a mosaic of iron foils of 1.5 mg/cm^2 thickness enriched to 43.5% Fe^{57}. These foils covered a circle 37.5 cm in diameter on a Mylar sheet which was supported on an aluminum honeycomb structure (Hexcel) to gain rigidity and thermal conductivity. This structure was mounted in an evacuated space between Mylar windows to reduce response to airborne sound. The γ rays transmitted through the absorber were detected by an argon-methane-filled proportional counter having a side window 40 cm in diameter.

The source was cemented to a copper disk, made more rigid by ribs on its back, which was vibrated sinusoidally at 73 cps by a tubular ferroelectric transducer. Electronic gates synchronous with the modulation sine wave allowed differentiation of the absorption line with respect to source velocity. The source and transducer were also moved smoothly for periods each containing 22 001 modulation cycles alternately upward and downward by a slave hydraulic piston at a speed of about 7×10^{-4} cm/sec, with appropriate switching to separate these data. In this way a continuous effective calibration of sensitivity was maintained.

Crucial to the reliable determination of an effect so small compared to the line breadth is the employment of a separate electronic monitor channel. By recording data from absorbers positioned close to the source, effects caused by variations of the transducer waveform with time, or, particularly, with respect to necessary inversions of the whole system, can be eliminated from the result. In the final form of the monitor two absorbers of material like that of the main absorber, each 2 cm square, were mounted on beryllium plates, one offset on each of opposite sides just outside the cone defined by the source and main absorber. These monitor absorbers were contained inside a common rigid unit with the source transducer and its calibrating hydraulic cylinder. The monitor absorbers were about 40 cm along the beam from the source disk itself. A matched pair of krypton-nitrogen–filled Reuter-Stokes proportional counters detected the transmitted γ rays. Mixing of the pulses from the two counters rendered the monitor channel insensitive to small transverse source velocities. Thus the monitor channel was sensitive only to the axial motions, as was the main absorber. One test of the performance of the monitor system was the demonstration that large intentional distortion of the waveform supplied to the transducer resulted in identical shifts in the monitor and the main channels.

Regulated ovens kept the source, the monitor absorbers, and the main absorber temperatures each at about 43.5°C. In addition, precision thermistors were used to record continuously the temperatures of the source, the monitor absorbers, and the main absorber. Ceramic permanent magnets were fixed in the units to provide a saturating polarizing field at both the main and monitor absorbers and at the source directed transverse to the beam and everywhere parallel. These were intended mainly to reduce effects of the geomagnetic field, especially remanent effects resulting from the necessary system inversion. An additional benefit from this magnetic field was the enhancement of the strength of the resonance.

The experiment allows, by linear interpolation between the effects of the slow calibrating velocities, determination of a source velocity that would make the difference between the shifts of the main absorber and the monitor absorber found with an upward beam identical to that difference found with a downward beam. According to the principle of equivalence this should be the velocity gp/c that results from an acceleration g acting upward for the total time of flight p/c where p is the sum of the upward and the downward paths. For our full path this was 4.905×10^{-15} times the velocity of light. Our experiment operated over the full path for about four months with a result $4.902\times10^{-15}c$ or 0.9994 times the predicted value. Statistical fluctuations in day-to-day data were fully consistent with counting statistics. Over all, the standard deviation determined from the total number of counts was ±0.0084. About one month was devoted to a run over a part of the path with a result 0.986 times the $2.226\times10^{-15}c$ predicted, with a statistical standard deviation of ±0.018.

An uncertainty of ±1% in the coefficient of -2.12×10^{-15} fractional frequency change per degree C, measured with this apparatus itself, contributes little uncertainty to the result because the mean correction for recorded temperature differences was less than 3% of the result. We allow ±0.001 of the expected effect as a limit to the combined systematic error contributed by this and uncertainties in g, p, and c. The temperature sensed by the thermistor used to record variation in the main absorber temperature differed slightly from the mean absorber temperature as estimated from several observations, under varying conditions, of thermistors mounted at six points on the foil. We estimate the limit to the error from this cause to be ±0.005 of the predicted effect. From many measurements, over the period of the experiment, of the speed of the hydraulic calibrating piston, we believe the error from this cause to be less than ±0.002 of the predicted effect.

In summary, we believe the present experiment establishes the validity of the predicted "gravitational red shift" at the 1% level. Full details will be published elsewhere.

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