might be expected to increase somewhat with J, and thus the band head could be considerably lower in excitation.

The energy of the resonance is ~1 MeV lower in ^{29}Si than in ^{28}Si. Such a downward shift might be expected if the anomaly is regarded as a size resonance between two pieces of nuclear matter; increasing the radius of the potential would lower the energy of a given resonance. How a rotational band would be changed by the addition of a neutron is less clear.

Stokstad *et al.* remarked that the 19.7-MeV anomaly seemed more prominent at backward angles. They inferred that this indicated backward peaking in the resonant amplitude, and thus was evidence for a dominant exchange amplitude, namely, α-particle exchange between two ^{12}C cores. The forward peaking indicated by the present data seems to contradict this picture. A very sharp backward peak may still be present at very large angles, but the bulk of the angular distribution is in the forward hemisphere.

The present results seem to have improved our understanding of these resonant effects, but they point up the need for more data—especially data on other resonances belonging to this same family. The present technique of studying the resonance in quasielastic reactions rather than elactic scattering may have more general applications.

The authors would like to acknowledge useful discussions and correspondence with Dr. R. H. Siemssen.

†Work performed under the auspices of the U.S. Atomic Energy Commission.

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[1] R. H. Siemssen, in *Proceedings of the Symposium on Heavy-Ion Scattering, Argonne National Laboratory, 1971,* (Argonne National Laboratory, Argonne, Ill., 1971), p. 145.

[2] R. E. Malmin, R. H. Siemssen, D. A. Sink, and P. P. Singh, Phys. Rev. Lett. 28, 1590 (1972).

[3] R. Stokstad, D. Shapira, P. Parker, M. W. Sachs, R. Wieland, and D. A. Bromley, Phys. Rev. Lett. 28, 1523 (1972).

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Absence of Gravity-Wave Signals in a Bar at 1695 Hz

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(Received 14 May 1973)

A 118-kg bar shows vector amplitude changes ("impulses") in successive 24-msec intervals which correspond to bar energies E distributed with a probability $N=N_0\exp(-E/kT_e)$, with $T_e \sim 30$ K. Not more than one impulse larger than 537 K was observed in 9 days. Calibration impulses giving the bar 600 K of energy were detected with 60% efficiency above a 537-K threshold. In the following Letter, these results are contrasted with the gravity-wave detections of Weber.

Very large energy fluxes observed for several years by Weber in gravitational radiation have not yet been confirmed by others.[1,2] To verify that such intense gravity waves do not exist, it would suffice to have a *single* detector at f_{Weber} which does not show excitations of the magnitude which would be induced by the gravity-wave events described by Weber.

We report here results for such an experiment, which are contrasted in the following Letter with the expected results if gravity waves of the nature, intensity, and numbers reported by Weber in 1970 existed in March and April 1973.

The antenna proper is a bar of aluminum alloy, type 2024-T4, 150 cm long by 19 cm diam. The lowest longitudinal compressional mode has $f_B = 1695$ Hz. The bar is operating in a vacuum ≤ 0.3 Torr in a normal laboratory. It is supported, axis horizontal and oriented east-west, by a steel cable from a three-stage mechanical filter of 50-kg cast-iron masses separated by rubber vibration isolators (Barry type 670-7ST). The vacuum chamber and its contents is further isolated at low frequencies by suspension from a pneumatic servo isolation frame.

The amplitude of vibration of the resonant bar is measured by a transducer coupled to the end of the bar. A piezoelectric ceramic cube a few millimeters on a side (lead zirconate titanate —PZT-4) provides a signal proportional to the displacement between the end of the aluminum bar and a seismic mass (5 kg), which is supported by steel wires from pins set into the aluminum bar. The resonant frequency of the seismic mass with the stiffness of the ceramic is $f_x = 640$ Hz, so that the mass is a nearly stationary anvil from which to measure the vibration of the bar at f_B.

A preamplifier (Fig. 1) consisting of a field-effect transistor followed by two integrated-circuit amplifiers is mounted on the seismic mass, and the output (proportional to the displacement of the bar) is led via cables along the bar and its support. The signal is then fed in parallel to two phase-sensitive detectors (synchronous reversing switches) operated respectively by direct and quadrature signals from a stable oscillator of frequency f_0 ($f_0 = f_B + \Delta f$; $-1 < \Delta f < 1$ Hz). The detector outputs feed resettable integrators. At the end of each interval τ (40 cycles of f_0 or ~ 24 msec), the outputs of the integrators are digitized (± 10 V full scale) by 8-bit analog-to-digital converters yielding two 8-bit (1-byte) amplitudes which are written (plus parity bits) onto an incrementing magnetic tape. The integrators are then reset.

The data are usually grouped in blocks of 16 384 bytes (3 min of elapsed time), which include 4 bytes of time information from a quartz-crystal counter. About 40 h of data can be accumulated on a single 1200-ft magnetic tape. Each data block is then processed by a computer which first computes the autocorrelation function and from it the decrement δ of the bar ($\delta = \pi \tau f_0 / Q$) and its offset $f_0 - f_B$. These data are then used to predict from each pair of amplitudes [a vector $v(t_n)$ in the phase plane] the amplitudes of the next point τ seconds later,

$$v^*(t_n + \tau) \equiv v(t_n) \exp(-\delta), \tag{1}$$

after obvious corrections for frequency offset. Predicted amplitudes are then subtracted from the measured amplitudes, with result

$$d(t_n) \equiv v(t_n + \tau) - v^*(t_n + \tau). \tag{2}$$

The $d(t_n)$ represent estimates (corrupted by amplifier noise) of the successive amplitude changes during the interval τ by virtue of the coupling of the bar to the reservoir at room temperature (damping) and through the absorption of any gravity waves. To each of the $d(t_n)$ corresponds an energy E_n which would be given to a bar *at rest* by its impulsive excitation to an amplitude $d(t_n)$. If a large calibration pulse can be calculated *a priori* to give the bar at rest an energy E_c, and if the normal computer processing as outlined above yields for the interval containing the calibration pulse an amplitude change d_c, then the $d(t_n)$ may be taken to represent energies

$$E_n = E_c [d(t_n)/d_c]^2. \tag{3}$$

The sensitivity of this system to an impulse is independent of the pre-existing state of oscillation of the bar, unlike systems which require threshold crossings.

Figure 2 shows a typical autocorrelation function $AC(m\tau)$ for the bar in thermal equilibrium at 295 K calculated from 8000 successive data points with an interval $\tau = 24$ msec. The autocorrelation function may be used to compute the mean bar energy. If AC^* is the extrapolation to

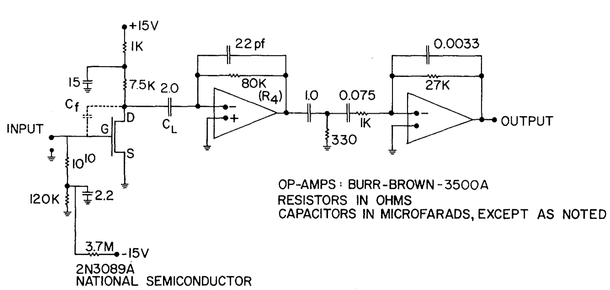

FIG. 1. Schematic of preamplifier mounted on seismic mass. Piezoelectric ceramic transducer of 28-pF capacitance is connected at input.

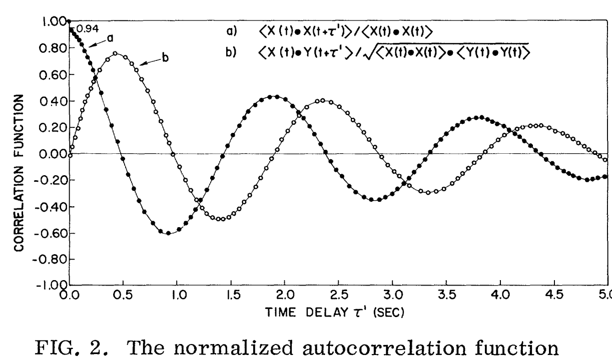

FIG. 2. The normalized autocorrelation function $AC(m\tau)$ for x (curve a) and the cross-correlation function for x and y (curve b) computed from the digital data of 14 March 1972. Then $AC(0) \equiv 1$, and the measure of amplifier noise is the deviation from 1 of the extrapolated value AC^* of $AC(m\tau)$ as $m \to 0$. Here $AC^* = 0.94$. The correlation functions oscillate with frequency $f_B - f_0$.

zero delay, the average bar energy is

$$\langle E_B \rangle = \langle v^2(t_n)\rangle (E_c/d_c^2) AC^*. \tag{4}$$

This measured $\langle E_B\rangle$ is used to define a bar temperature T_B, $kT_B \equiv E_B$. Thermal excitation of the bar, and noise from the amplifier, should result in E_n being Boltzmann distributed with frequency of occurrence $N = N_0 \exp(-E_n/kT_e)$. The value expected for T_e as a result of bar temperature and amplifier noise may now be calculated as

$$T_e^* = 2T_B[\delta + (1 - AC^*)/AC^*]. \tag{5}$$

Large τ allows a larger influence of bar temperature [the first term in Eq. (5)], and short τ a wider-band contribution of noise from the amplifier [the second term in Eq. (5)].

To provide sensitivity independent of impulse arrival time within the interval τ, we use an algorithm similar to Eq. (2), but involving

$$V(t_n + m\tau) \quad (m = -2, -1, 1, 2),$$

for which the expected effective value of T_e is

$$T_e^* = 2T_B\left(\delta\frac{(K+1)(2K+1)}{3K} + \frac{(1-AC^*)}{KAC^*}\right). \tag{6}$$

With $\tau = 24$ msec (40 cycles), $(1-AC^*)/AC^* = 0.06$; $\delta = 0.010$. $T_e^* = 33$ K, as compared with the observed 1-day averages of $T_B = 300.1$ K and $T_e = 28.9$ K. Thus, for our bar $Q/\pi = 4200$.

To provide a known oscillation energy to the bar, we use N periods of a calibrating voltage, the value of which in successive half-cycles of the bar reference oscillator f_0 is $+V, 0, -V, 0$. The energy given to a long thin bar by this signal applied to a plate of area A spaced s cm from the end of the bar is (cgs-esu)

$$E_c = A^2N^2V^4/4\pi^2 M_B \omega_0^2 S^4. \tag{7}$$

We have $A = 25\pi$ cm^2; $s = 0.17$ cm; $N = 5$. In deriving Eq. (7), we made use of the fact that the oscillation energy of a long bar is related to the peak amplitude a as $E = \frac{1}{2}M_e\omega^2 a^2$, with the effective mass of the bar $M_e = \frac{1}{2}M_B$. With $V = 10$ V $= \frac{10}{300}$ esu, $E_c = 4.31 \times 10^{-13}$ erg or 3130 K. The mean energy of the bar is thus determined from Eq. (4) to be 300.1 K, in reasonable agreement with the room temperature of 295 K.

The significant data from the experiment are contained in the pair of numbers $d(t_n)$ computed each τ seconds which represents the vector change in amplitude of oscillation of the bar. A typical distribution of the energies E_n corresponding to the observed amplitude changes is shown

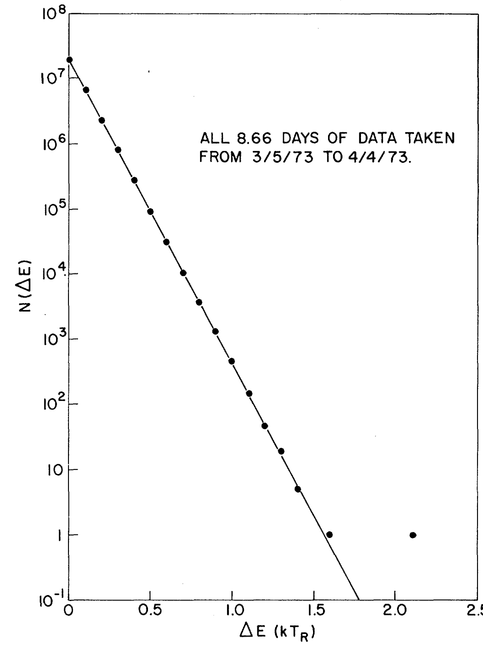

FIG. 3. Typical distribution of observed amplitude changes, plotted as the differential distribution of energies communicated to a bar with zero oscillation energy, as a function of energy increment ($T_R = 300$ K). The straight line is the expected result of the contributions of bar damping and amplifier noise, with no gravity waves incident.

in Fig. 3. The straight line is $N = N_0\exp(-E/kT_e)$, with an effective temperature $T_e = 29.2$ K. Except possibly for one pulse, the totality of data reduced thus far is indistinguishable from the thermal distribution which would be obtained in the absence of gravity waves. The isolation against mechanical and electrical disturbances is evidently good enough to make such extraneous influences negligible contributors to the oscillation energy of the bar.

A few percent of the data blocks are unreadable by the computer as a result of tape-recorder errors. Furthermore, almost one event per day has been edited from the data as uniquely identifiable as the result of a known defect in the electronic interface. The single event of Fig. 3 at $\Delta E = 2.2kT$ could well be such an error, but could not be uniquely identified as such. It occurred at 11:02:30 GMT on 21 March 1973. The most direct demonstration of the sensitivity of the system is contained in Table I, which shows the results of applying sets of 30 impulses of mechanical energy to the bar (via the electrostatic calibrator plate), and allowing the standard computer program to process the data blocks containing

TABLE I. Pulse detection efficiencies and background. Thirty pulses of each energy (300 K $\leq E \leq$ 700 K) were introduced at random times. The number (of 30) detected above various thresholds (442 K $\leq H \leq$ 758 K) by the computer processing is shown in the body of the table. The number of pulses detected above the thresholds in 9 days of operation are shown in the last line (cumulative distribution). If the pulse in bin 22 is indeed due to tape-recorder error, the cumulative distribution is entirely interpretable as the thermal tail of the 29.2-K Boltzmann distribution. Each bin has width 31.6 K. The threshold of bin 1 is 0 K.

Bin	Threshold (K)	Pulse energy (K) 300	400	500	600	700	9-day background
15	442	5	16	22	24	28	7
16	474	5	16	19	21	25	2
17	506	3	10	19	21	24	2
18	537	2	7	15	19	23	1
19	569	0	5	14	16	22	1
20	600	0	4	11	15	20	1
21	632	0	2	7	11	20	1
22	663	0	2	4	10	19	1
23	695	0	2	4	9	14	0
24	727	0	2	2	6	10	0
25	758	0	2	1	5	10	0

these impulses, exactly as if they were bar excitations caused by gravity waves. As an example, with a 442-K threshold, the detection efficiency for 600-K pulses is $\frac{24}{30} \sim 80\%$; and the detection background is seven pulses in 9 days, when eight pulses would be expected above that threshold from thermal background.

The significance of these results is the subject of the following letter.[3]

We wish to acknowledge useful visits to J. A. Tyson and J. Weber, and the counsel of G. J. Lasher.

[1]J. Weber, Nature (London) 240, 28 (1972).
[2]J. L. Logan, Phys. Today 26, No. 3, 44 (1973).
[3]Note added 14 June 1973: After modifying the tape recorder, we have taken 6 more days of data with no points deviating significantly from a Boltzmann distribution like that of Fig. 3 (absent the outlying point at $\Delta E = 2.2$).

Single Gravity-Wave Detector Results Contrasted with Previous Coincidence Detections

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Coincidence detectors of Weber have given a 10:1 ratio (R^*) of prompt to delayed coincidences. Simplified analysis indicates that such an R^* would require daily gravity-wave incidence rate and energy depositions that would have been seen in the single-bar detector of the preceding Letter (and were not), suggesting that Weber's 1969-1970 events were not produced by gravity waves or that such waves do not exist in similar numbers and intensity in 1973.

The preceding Letter[1] presents data from a single gravitational wave (GW) antenna at 1695 Hz, which shows that the number of events depositing 410 K or more of oscillation energy in this antenna is much less than 1 per day.

A GW event which gave to one of Weber's antennas of mass M_W an energy E_W in a time less than about 25 msec would give to our antenna of simi-